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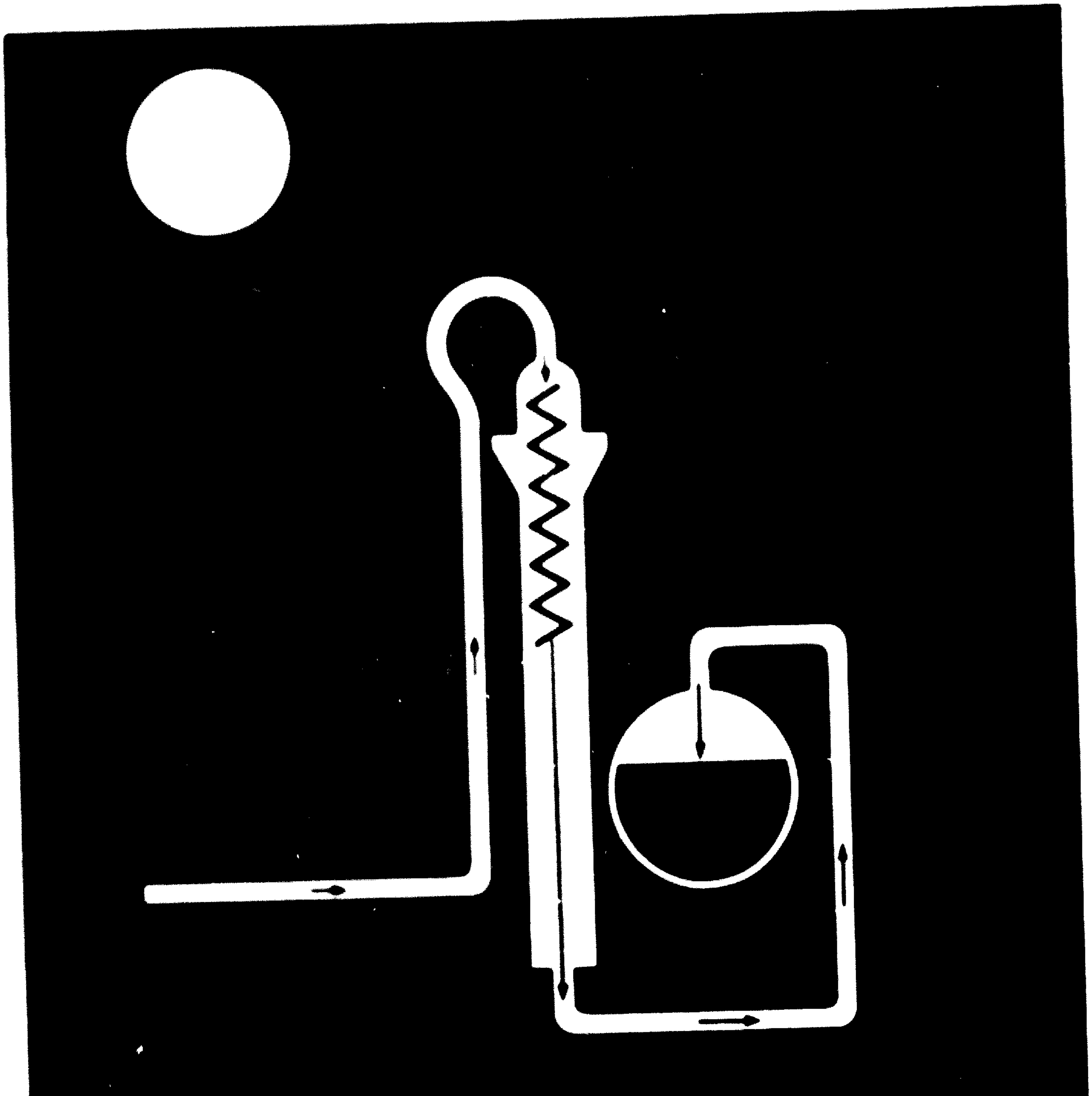
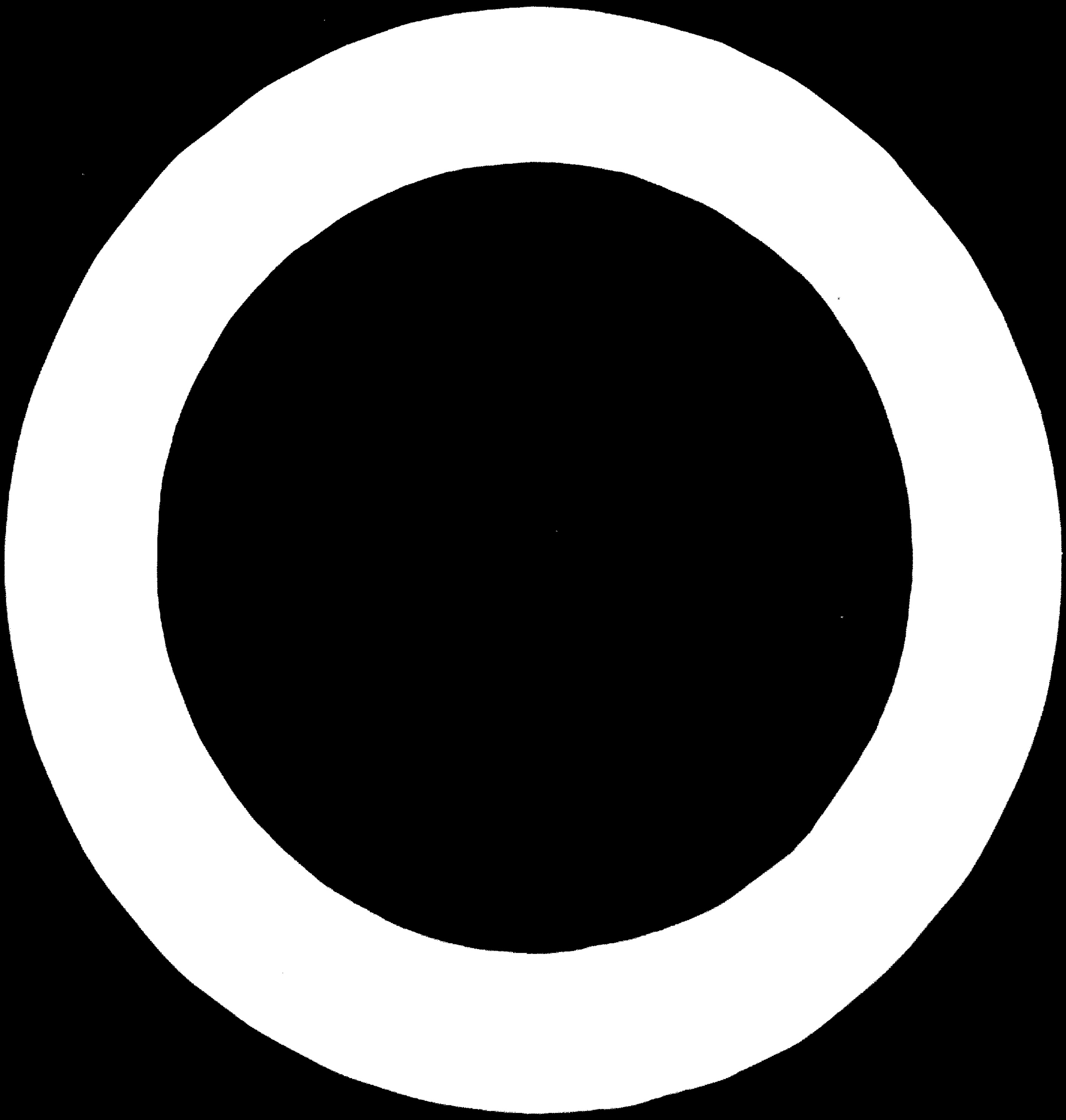
Fertilizer Manual





United Nations Industrial Development Organization

FERTILIZER MANUAL

UNITED NATIONS
New York, 1967

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PREFACE

One of the most pressing problems in the world today is to find means to accelerate the economic growth of developing countries. In many cases, this growth is in danger of being frustrated through the failure of food production to keep pace with the increased growth of population. Preliminary estimates for 1965/1966 indicate that the *per capita* food production in the developing regions has dropped back to the 1957/1958 level, which is the same as the inadequate pre-war level.

It has been estimated that even without the use of other inputs to raise agricultural production, the application of fertilizers can increase output by at least 50 per cent under the conditions prevailing in many developing countries.

The United Nations Centre for Industrial Development has been taking active measures to develop the fertilizer industry in developing countries. In accordance with the decisions of the Committee for Industrial Development of the Economic and Social Council, a manual on fertilizer production dealing particularly with modern technological developments of interest to developing countries has been prepared. A draft of the Manual was circulated to the Economic and Social Council Committee for Industrial Development at its fifth session in 1965. The various chapters of the Manual were discussed during the Inter-Regional Seminar on the Production of Fertilizers held at Kiev in August-September 1965. The text has been used extensively in seminars, training courses and as a reference document.

The combined world output of fertilizers in the form of nitrogen (N), processed phosphoric acid (P_2O_5) and potash (K_2O) in 1964/1965 is estimated at 42.2 million tons. In the case of nitrogen, the developing countries produced only about 15 per cent of the world output of 16.6 million tons in 1964/1965. Many developing countries are taking active steps to increase their fertilizer production and the Manual is designed to assist them in their planning.

The United Nations Industrial Development Organization (UNIDO), the successor to the Centre for Industrial Development (CID), will continue to expand the activities in the field of development of the fertilizer industry. It is hoped that the *Fertilizer Manual* will also be of assistance in this task.

I. H. **ABDEL-RAHMAN**
Executive Director
United Nations Industrial Development Organization

EXPLANATORY NOTES

The following symbols have been used throughout the manual

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions

A slash (/) indicates a crop year or financial year, e.g., 1963/1964.

Use of a hyphen (-) between dates representing years, e.g., 1953-1961, signifies the full period involved, including the beginning and end years

References to "tons" indicate metric tons unless otherwise stated

References to "dollars" indicate United States dollars

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers

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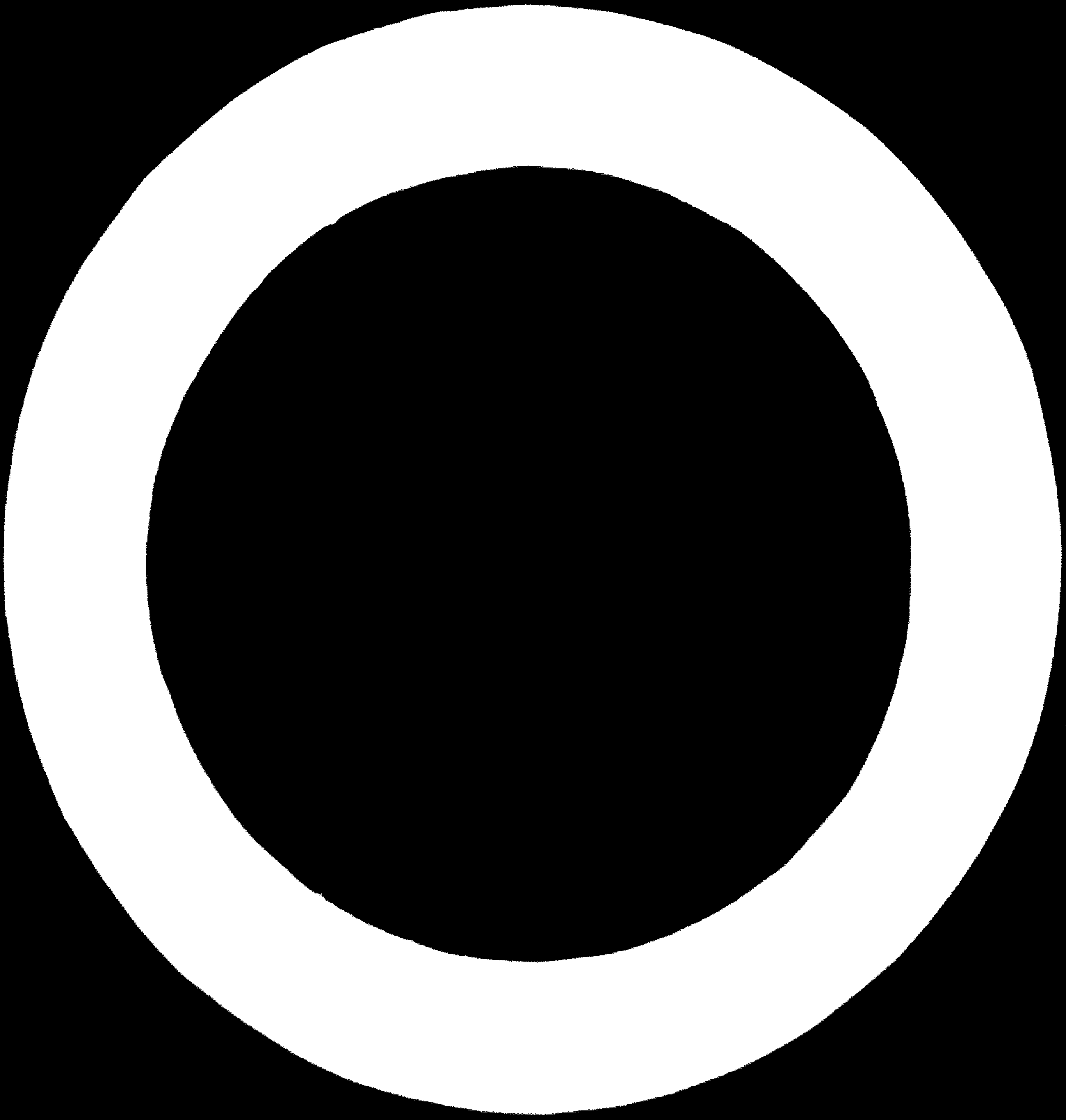


INTRODUCTION

The United Nations Committee for Industrial Development has endorsed the preparation of manuals in selected branches of industry as part of the work programme of the Centre for Industrial Development. The present manual is one outcome of this programme.

The fertilizer industry provides a unique link between agricultural development and industrial development. In a country with a rapidly growing population which is unable to increase the land available for agriculture, greater use of fertilizers offers the best prospect for more intensive agriculture and for higher yields. Even without other measures to raise agricultural productivity, it has been estimated that fertilizers can increase agricultural output by 50 per cent under conditions prevailing in many developing countries. Moreover, the fertilizer industry often presents a nucleus for a broadly based development of a heavy chemical industry. Thus, in many developing countries, the prospects for a new fertilizer industry are being studied with vital interest.

The aim of this manual is to adapt and transfer modern fertilizer technology for use in developing countries, with particular emphasis on the problems and special conditions common to those countries. It discusses not only key aspects of fertilizer production, but also problems of fertilizer use in agriculture. It analyses pre-investment data and economies of scale. It covers end products and intermediate products associated with the fertilizer industry.

The manual is designed to be of value to planning bodies, departments of industries, industrial development corporations and other similar bodies. Its main objective is to meet the need felt in many developing countries for a single reference source containing both technical and economic information. It is intended to help planners in a developing country make a general evaluation of problems and prospects in the establishment of a fertilizer industry. While much information on the industry is available in various sources, this work is designed specifically to cover the conditions encountered in developing countries. It is also intended to serve as teaching material for engineers and technical personnel in the fertilizer industry.

In preparing the chapters presented here, the Centre benefited from consultations with, and advice from, a number of experts and organizations. The Food and Agriculture Organization of the United Nations has given valuable guidance over a period of time. Dr. Raymond Ewell, Vice-President for Research, University of New York at Buffalo, Dr Frank W. Parker, Deputy Director, Rural and Community Development Service, Agency for International Development (AID), United States Department of State; and Dr. Lewis B. Nelson, Manager of Agricultural and Chemical Development, Tennessee Valley Authority (TVA), have given substantial assistance to this project. AID arranged with the United States Department of Agriculture and TVA in preparing several chapters.

Chapter I was prepared by D. D. Steward of the United States Department of Agriculture; chapter II was prepared jointly by D. D. Steward and F. A. Coffey, chapter III by D. D. Steward and chapter IV by F. A. Coffey. TVA reviewed chapters I, II and IV. The following persons associated with TVA prepared or reviewed the chapters indicated: E. C. Houston reviewed chapter VI and prepared chapter XI; J. A. Burnett, Jr. reviewed and added to chapter VII; G. M. Blouin reviewed chapter X; M. M. Striplin, Jr. prepared chapter XII; E. L. Newman prepared chapter XIV. Chapter XVI was originally prepared by The Sulphur Institute, Washington, D.C.; it was reviewed and supplemented by J. M. Stinson of TVA.

Chapters V, VI, VII, VIII, X, XIII, XV and XX were provided by the United Nations. C. J. Pratt of Mobil Chemical International Ltd. prepared chapters IX, XVII and XIX. Chapter XVIII was prepared by the International Minerals and Chemical Corporation and reviewed by TVA; chapter XXI was prepared by D. W. Bixby, The Sulphur Institute.

The Centre for Industrial Development is grateful for the assistance received from the above-mentioned sources and from numerous others.

The manual is organized in three parts. Part One contains five chapters, giving a world review of fertilizer production, assessing the role of fertilizers in agricultural expansion, establishing criteria for production vis-à-vis imports into developing countries, considering forecasts of demand and setting up principles for the distribution and pricing of fertilizers.

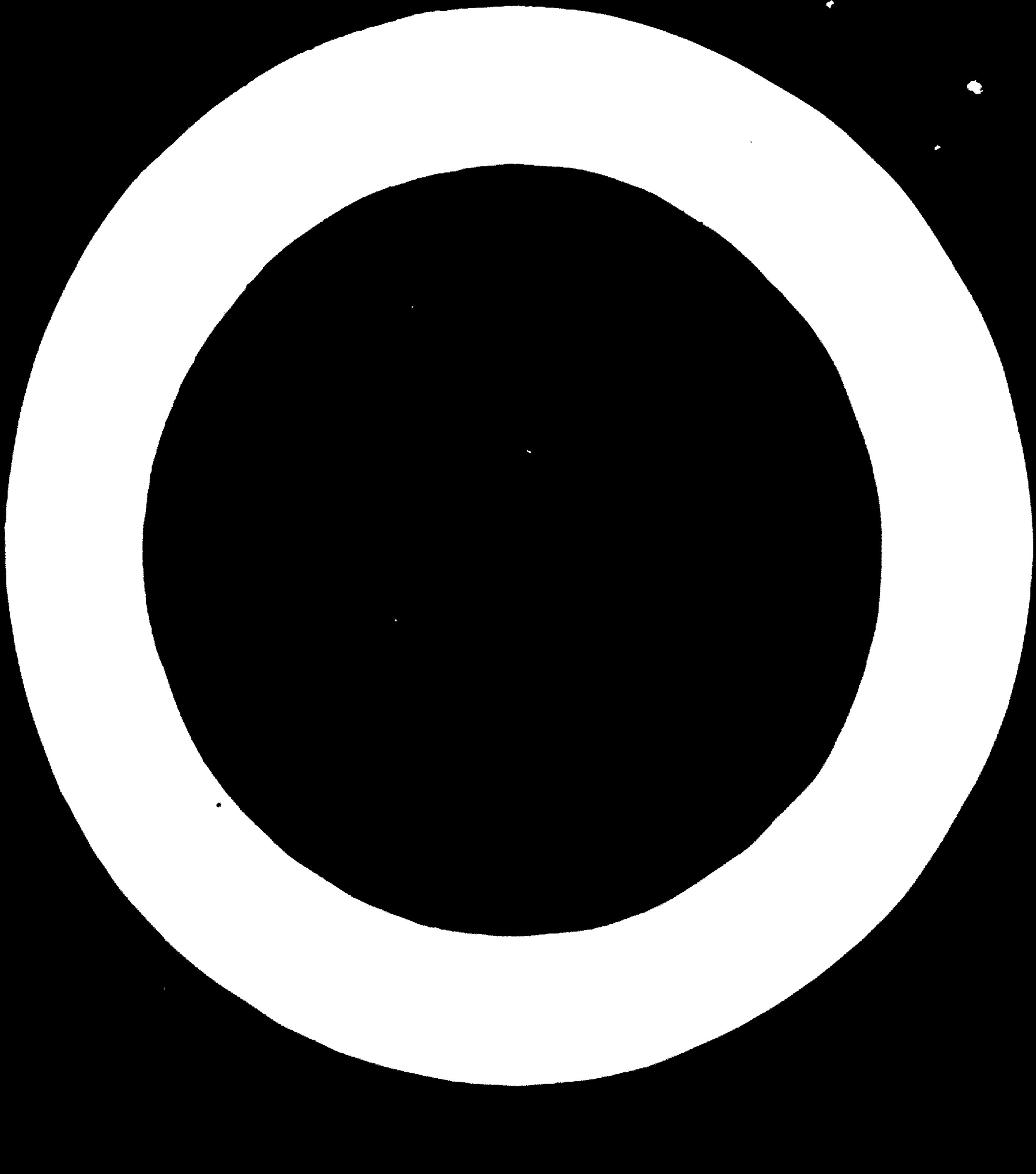
Part Two, in eleven chapters, begins with basic technical data and definitions. The technology of production of the three principal fertilizer groups, namely nitrogen, phosphate and potash, are discussed in subsequent chapters. Separate chapters include data on nitrogen, the production of ammonia, the production of various ammonium salts (e.g., ammonium sulphate, nitrate and chloride) and the production of urea and nitrogen solutions. The production of phosphates and potash is then discussed, followed by chapters on multinutrient and mixed fertilizer production and auxiliary raw materials.

Part Three in five chapters, considers problems of planning, including plant location, and general problems which have arisen in other countries and are likely to confront a new fertilizer industry in a developing country.

It contains also a case study of the establishment of a fertilizer plant in a developing country, highlighting the steps taken, the difficulties encountered and the results obtained. The last chapter consists of tables showing the economies of scale and the costs of production of fertilizers.

Draft chapters were used in the programme for the training of planning and economic officers from African countries at Cairo in the spring of 1965. Some chapters served as discussion papers at the Interregional Seminar on Fertilizer Production held in Kiev, Ukrainian Soviet Socialist Republic, in August-September 1965.

Part One



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I. WORLD SURVEY: PEOPLE, FOOD AND FERTILIZER

The world population is growing more rapidly than at any other time in recorded history, and with this population growth, man is faced with the problem of expanding the world food-supply at a fast enough pace to meet his growing needs.

How great an increase in the world food-supply is needed? How can this increase most easily be met? The purpose of this chapter is to provide partial answers to these important questions. Attention will be devoted to: historical and future trends in world population growth; the urgent requirement of expanding the world food-supply; the means by which rapid increases in food production might most readily be achieved; the importance of fertilizer in contributing to increased agricultural production; and the world fertilizer situation — production, consumption, international trade and prices.

A. THE WORLD FOOD-POPULATION PROBLEM

1. *Growing population*

From the origin of man, the world's population slowly grew to a total of 200-300 million people at the beginning of the present era. Over sixteen centuries passed before this number was doubled.

By contrast, the population in 1960 was almost double that of 1900, having grown from 1,551 million in 1900 to almost 3,000 million in 1960. Indications are that this figure will again double in less than forty years, reaching at least 6,000 million by the end of this century.

In other words, the rate of population growth has increased from 2.5 to 5.0 per cent per century in the first sixteen centuries of the present era to nearly 1 per cent per annum by 1900 and to about 2 per cent per annum by 1960. The rate of growth is expected to be even higher during the remainder of this century.

The high rate of population growth currently being experienced is so recent a phenomenon that man has only begun to recognize the magnitude of the problems associated with it and to attempt to cope with these problems. Foremost among these is that of expanding the world food-supply to meet the growing needs.

The population increase in the brief span of time from 1960 to 2000 will be as great as the total growth throughout all previous history of man. During this short period world food production must be doubled if even the current level of consumption is to be maintained. In addition, if the problems of hunger and malnutrition are to be resolved, even larger increases in the world food-supply will be necessary.

Numerous factors can be offered in explanation of the recent increases in the population growth rates. Major among these is man's continuing effort to improve his general health and well-being. The expansion of health education and medical facilities, combined with increased knowledge of life-saving techniques, is rapidly increasing the life expectancy in many countries throughout the world. Rapid progress has been made in the control and eradication of such diseases as tuberculosis and smallpox, which earlier were devastating, and in the prevention of wide-scale epidemics. Infant and child mortality is declining. In addition, improved nutrition and its general effect on health have no doubt played a part in enhancing the procreation of man.

At the same time that life expectancy is being extended and death-rates are declining, there has not been an offsetting decline in birth-rates. Many countries have become increasingly alarmed about the resulting population explosion, and programmes have been initiated to check the high and increasing rates of population growth. It appears, however, that current actions directed at population control will not, in the immediate future, retard the birth-rate sufficiently to reduce the growth rate of the world population below its current level. Consequently, the world must face up to the problem of rapidly expanding its food-supply in light of the expected population growth and the need to overcome hunger and malnutrition.

2. *Geographical considerations*

Vast geographical differences exist in the current distribution and growth rate of the world's population. In 1960, over 55 per cent of the world's people were located in Asia (see tables 1 and 2). India alone contained 450 million people. By contrast, the entire western hemisphere accounted for 403 million people, less than that of India, although the total land area was nearly eleven times greater than that of India.

Population growth rates are generally higher in the developing areas of the world than in the developed areas. Asian countries, which already have a relatively high population density, are experiencing rates of population growth of approximately 2 per cent annually. Latin American countries with lower population densities face more rapid rates of population expansion — frequently as high as 3 per cent per annum. By contrast, in some of the industrially developed countries of the world, notably Japan and those of western Europe, population growth has declined to only 1 per cent per annum.

There are available far more detailed studies of the current and future world population situation than that presented in this chapter. The brief comments included here, however, are sufficient to demonstrate the differences existing between regions and countries throughout the world both of current population and of expected future growth.

[illegible]

Region	[illegible]	[illegible]	[illegible]	[illegible]
North America	[illegible]	[illegible]	[illegible]	[illegible]
Latin America	[illegible]	[illegible]	[illegible]	[illegible]
Europe [a]	[illegible]	[illegible]	[illegible]	[illegible]
Africa	[illegible]	[illegible]	[illegible]	[illegible]
Asia	[illegible]	[illegible]	[illegible]	[illegible]
Oceania	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]

Source: United Nations [illegible]

[a] Including the Union of Soviet Socialist Republics.

Table 2. [illegible]

Region	Land area [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
North America	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Latin America	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Europe [a]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Africa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Asia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oceania	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
World [b]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Source: Food and Agriculture Organization of the United Nations, Production Yearbook [illegible]

[a] Including the Union of Soviet Socialist Republics.

[b] Excluding [illegible] and [illegible]

While the world, in general, is faced with an acute problem of providing adequate food-supplies to the current and projected population, the problem is more acute within the developing countries. [illegible]

3. Future world food needs

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]

The provision of these [illegible] may depend on expanding the demand for agricultural products, the establishment of appropriate price and subsidy policies by Governments, the development of suitable market and transportation facilities, making some changes in land tenure systems and modernizing the scale and organization of production.

[illegible] Importance of fertilizers

Increased fertilizer use has been a major factor in increasing crop yields in many of the technologically more advanced countries. For example, nearly one half of the yield increase in the United States of America between 1940 and 1957 is credited to the increased use of more fertilizers. Obviously large yield increases from the use of more fertilizers can only be attained where other necessary conditions are met. In other words, crop response from the application of fertilizers necessarily is dependent on the yield-producing potential of the crop variety being used, the adequacy of soil moisture, control of insects and diseases, and other improved practices. Some of the many experts are of the opinion that the increased use of fertilizers is the major single factor by which rapid increases in crop yields can be achieved. Charles E. Kellogg, for example, stated: "Recently great emphasis has been given to the critical role of chemical fertilizers in food production in the newly developing countries. [illegible]" he added "fertilizers are economically effective only if (a) the correct kinds and amounts are used for each local kind of soil and (b) the needed practices to meet the other requirements for good harvests are adopted at the same time." Dr. Lester Brown wrote: "The extended use of fertilizers is strategically important, for in areas of adequate moisture it is the primary means of achieving yield increases and greater over-all food production."[26]

A more detailed discussion of the importance of fertilizer and its role in increasing agricultural production is contained in chapter II. For present purposes, therefore, it is sufficient to conclude that in efforts to expand food production by increasing yields on land already under cultivation or by bringing additional land into production, larger amounts of fertilizers are essential to improve soil fertility and crop output.

[illegible]

[illegible] Consumption

Rapid expansion in the production and consumption of fertilizers has been a major phenomenon of recent years. In the decade ending in 1962/1963, total fertilizer [illegible] throughout the world increased [illegible] million tons (see table 1)[illegible] an annual compound rate of [illegible] per cent over the decade. The increase has not been shared equally throughout the countries of the world. Of the total increase in fertilizer consumption of [illegible] million tons, [illegible] per cent occurred within the more developed countries — Canada, those of Europe and Oceania, the United States of America and other developed countries. By contrast, increased consumption in the developing areas of the world — Latin America, Africa (excluding South Africa and the United Arab Republic), and Asia (excluding Japan) — amounted to 2.5 million tons or only [illegible] per cent of the total world increase.

Europe (western and eastern regions) alone accounted for [illegible] per cent of the fertilizer nutrients consumed in 1962/1963 and for [illegible] per cent of the increase in world consumption over the preceding decade. This occurred even though Europe contains less than 11 per cent of the world's arable land.

While most of the additional fertilizer was consumed in the more developed areas of the world, the annual rate of increase in fertilizer consumption has been higher in the developing than in the developed areas (see table 3). In spite of this, current levels of fertilizer consumption continue to be low in the developing countries. This fact is demonstrated by the data in table 4. Although some limitations exist as to the accuracy and comparability of the data,[a] they show the levels of fertilizer consumption to differ greatly among the areas and countries of the world. For example, nutrients consumed per 1,000 hectares of arable land in 1962/1963 ranged from [illegible] tons in Europe to 1.15 tons in Africa. Among individual countries consumption per 1,000 hectares of arable land ranged from as high as 518.82 tons in the Netherlands to 2.84 tons in India and less than 1 ton in Ghana. While conditions exist within individual countries that [illegible] account for the current levels of fertilizer use, the differences suggest that there is a vast potential in many countries for using larger amounts of fertilizers in efforts to increase agricultural production and food supplies. A comparison of the intensity of fertilizer consumption in 1957-1958 with that in 1962/1963 illustrates the increases in consumption levels that have been achieved. During the five-year period, the Republic of Korea, for example, increased consumption per 1,000 hectares by 66.21 tons.

In addition to the differences in levels of fertilizer consumption, considerable variation exists in the nutrient ratio of fertilizers used in different parts of the world (see table 5). Such variations may be largely justified by

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For purposes of contrast, fertilizer consumption increased at least three times as rapidly as population and more than twice as fast as agricultural production.

[a] Total fertilizer nutrients consumed are divided by area of arable land and [illegible]. Adjustments are not made here for differences among countries in the definition of what constitutes arable land or for differences in soils, farming systems, crops, use of such natural fertilizers as compost and use of fertilizers on permanent pastures and meadows. In view of the magnitude of differences, however, the data permit broad comparisons among countries.

TABLE 3. WORLD CONSUMPTION OF FERTILIZER NUTRIENTS AND COMPOUND RATE OF INCREASE, 1953/1954-1963/1964

(Thousands of tons)

Area	Fiscal year											Compound rate of increase (percentage)	
	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1954-1964	1959-1964
Developed regions													
Western Europe	7,095	7,552	7,991	8,503	8,926	9,236	9,912	10,004	10,542	11,347	12,149	5.5	5.6
Eastern Europe	3,067	3,526	3,668	4,018	4,423	4,801	5,067	5,264	5,497	6,180	6,960	8.5	7.7
North America	5,807	5,887	5,845	6,101	6,251	7,101	7,146	7,564	8,158	9,173	10,011	5.5	7.1
Oceania	616	722	762	709	790	760	836	924	969	944	1,229	7.1	10.0
Other [a]	1,141	1,442	1,599	1,703	1,613	1,899	1,881	2,282	2,099	2,178	2,335	7.4	4.2
TOTAL	16,585	19,129	19,865	21,034	22,003	23,797	24,842	26,038	27,265	29,822	32,684	7.0	6.5
Developing regions													
Africa	114	172	170	172	214	217	235	273	274	297	388	13.0	12.3
Asia	490	646	700	851	893	936	1,144	1,361	1,578	1,695	2,024	15.2	16.6
Latin America	458	481	570	690	690	719	739	959	965	1,103	1,284	10.8	12.2
TOTAL	1,223	1,299	1,440	1,613	1,797	1,872	2,118	2,593	2,817	3,095	3,696	11.6	14.5
WORLD TOTAL [b]	17,808	20,428	21,305	22,747	23,800	25,669	26,960	28,631	30,082	32,917	36,380	7.4	7.2

SOURCE: Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review of World Production, Consumption and Trade*, 1954-1964 (Rome, 1955-1965).

[a] Developed countries within developing regions: Japan, South Africa and United Arab Republic.

[b] Excluding mainland China.

TABLE 4. INTENSITY OF FERTILIZER CONSUMPTION IN RELATION TO ARABLE LAND, BY AREA AND SELECTED COUNTRIES

Area and country	*Plant nutrients per thousand hectares of arable land (tons)* 1957/1958	1962/1963
Area		
Europe [a]	72.76	96.59
North and Central America	25.30	37.94
Oceania	33.12	27.77
Asia [b]	6.70	9.96
South America	4.92	7.68
Africa	2.53	3.15
Country		
Netherlands	446.63	518.82
Belgium	335.65	487.75
Federal Republic of Germany	245.64	305.32
Japan	245.72	276.53
Taiwan	197.36	197.01
United Kingdom	144.36	191.56
Republic of Korea	109.02	153.23
France	90.67	122.41
United Arab Republic	71.38	93.05
Italy	45.78	56.99
Greece	33.53	53.49
United States of America	31.31	47.00
Malaysia	—	17.61
Chile	—	16.16
USSR	—	11.95
Brazil	8.64	10.21
Mexico	—	11.37
Pakistan	—	4.19
Turkey	.83	2.92
Sudan	—	2.87
India	1.39	2.85
Iran	—	1.07
Ghana	—	.36

SOURCE: Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review of World Production, Consumption and Trade*, 1958 and 1963 (Rome, 1959, 1964).

[a] Excluding the Union of Soviet Socialist Republics.

[b] Excluding mainland China and North Korea.

TABLE 5. NUTRIENT RATIO OF FERTILIZERS CONSUMED, MAJOR REGIONS OF THE WORLD, 1962/1963

Region	*N*	*P_2O_5*	*K_2O*
Europe [a]	1.0	1.0	1.0
North and Central America	1.6	1.3	1.0
Oceania	.5	8.8	1.0
Asia [b]	2.4	1.1	1.0
South America	1.9	1.8	1.0
Africa	3.4	2.6	1.0
WORLD	1.3	1.2	1.0

SOURCE: Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review of World Production, Consumption and Trade, 1963* (Rome, 1964).

[a] Excluding the Union of Soviet Socialist Republics.

[b] Excluding mainland China and North Korea.

differences in the soil and climatic conditions, the crops being grown, the fertilizers available and the price-cost relationships that prevail. In Asia, for example, nitrogen consumption is twice that of P_2O_5 or K_2O: the nutrient ratio in 1962/1963 was 2.4 kilogrammes of nitrogen (N) and 1.1 kilogramme of phosphorus (P_2O_5) for every kilogramme of potash (K_2O) consumed. As a whole, the developing areas use larger amounts of nitrogen in relation to P_2O_5 or K_2O, while nutrients used in the more developed areas approximate a 1-1-1 ratio. However, there is an indication that in the more developed countries, the consumption of nitrogen is increasing more rapidly than that of either phosphorus or potash.

2. *Pattern of world production*

The bulk of the fertilizer production in the past and at the current time has been centred among the more industrialized countries of the world. In 1963-1964, about nine-tenths of the world fertilizer supply was produced in Europe, the Union of Soviet Socialist Republics, the United States of America and other developed areas.

Several factors have contributed to the heavy concentration of fertilizer production. Included are: (*a*) the availability of raw materials, either from resources within the country or by importation from other areas; (*b*) the relatively advanced state of technical knowledge and skills of the people; (*c*) the stage of industrial development and the capacity to produce fertilizers; and, of major importance (*d*) the level of demand for fertilizers within the country.

Beyond the absolute physical limitations of obtaining or producing the required raw materials and within the restriction imposed by government policies, production is largely influenced by the ability of the industry in one country or area to compete with that in other countries or areas in producing comparable fertilizers at lowest costs to potential purchasers. Import and export policies of individual countries, plus political allegiances and animosities, no doubt have frequently affected international trade and have exerted considerable influence on the pattern of development of the fertilizer industry throughout the world.

Production of nitrogen fertilizers is more widely dispersed throughout the world than is the case of either phosphorus or potash. With the discovery of methods of fixating the nitrogen of the atmosphere, and of producing nitrogen as a by-product of coke-ovens and gas plants, the production of nitrogen fertilizer is no longer dependent on mineral deposits of nitrates. Consequently, as countries make progress in industrial development, the production of nitrogen fertilizers generally can be initiated more rapidly than that of either phosphorus or potash, unless local mineral deposits of phosphorus or potash are readily accessible or the raw materials are imported. At the current time, however, there is a continuing trend towards local production of phosphate fertilizers, even though many countries must import the phosphate rock from which the fertilizer is made.

In 1963/1964, the Federal Republic of Germany, France, Italy, Japan, the United Kingdom and the United States of America were the leading producers of nitrogen fertilizers, contributing over 70 per cent of total world output. However, many of the developing countries are constructing plants as their demand for nitrogen fertilizers increases. The Republic of Korea, Taiwan and the United Arab Republic are examples of countries which are expanding their production of nitrogen fertilizers. In the five-year period from 1958/1959 to 1963/1964 production of nitrogen fertilizer in Taiwan increased from 30,266 to 92,460 tons and in the United Arab Republic production expanded from 34,302 to 120,362 tons in 1962/1963. Nitrogen production in the Republic of Korea began in 1960/1961, when 19,754 tons of nitrogen were produced. In 1963/1964, production had risen to 38,023 tons. As yet, however, even these countries must rely upon imports in meeting their fertilizer needs, as their demand has been expanding more rapidly than their domestic capacity to produce nitrogen.

The United States of America continues to be the largest producer of phosphatic fertilizers. In 1963/1964 it supplied 3,480,000 tons of phosphorus (P_2O_5), amounting to over 27 per cent of total world output. Other leading producers are the Federal Republic of Germany, France, Italy, the USSR and the United Kingdom.

Production of potash is largely concentrated in a small number of countries. In 1963/1964, over 90 per cent of the total world supply was produced in five countries — Eastern Germany, the Federal Republic of Germany, France, the USSR and the United States of America. The recent rapid development of large deposits in Saskatchewan, Canada, should soon make Canada a leading potash producer and exporter. In the absence of known domestic deposits of mineral sources from which potash could be economically produced, many countries currently must rely upon imports in order to meet their potash fertilizer needs. The mere fact that potash is not as readily available as either nitrogen or phosphorus no doubt helps to explain the relatively limited use of this material compared with the use of both nitrogen and phosphorus in large parts of the world.

3. *International trade*

Of the 36,300,000 tons of fertilizer nutrients consumed in 1963/1964, approximately one-fourth was imported by the consuming country.

Among the three major nutrients, large differences exist in the amount that entered into international trade. Slightly less than one-fourth of all nitrogen produced was exported by the producing countries. Phosphorus exports were only 13 per cent of total production. By contrast, 64 per cent of all potash produced entered into world trade, reflecting the high concentration of potash production in relatively few countries.

In general, the major fertilizer producing countries also are the largest users of fertilizers. As a result, some of the leading producers consume most, if not all, of the fertilizer they produce, leaving relatively little for export. The major exporting countries of nitrogen are the Federal Republic of Germany, Italy, Japan, the Netherlands, Norway and the United States of America. These six countries supplied nearly [illegible] per cent of the total nitrogen fertilizers that entered into world trade in [illegible]. The leading exporters [illegible] Federal Republic of Germany [illegible] lands and the United [illegible] of the phosphate [illegible]. The principal potash [illegible] Germany, the Federal Republic [illegible] USSR and the United States [illegible] produced 92 per cent [illegible] countries exporting [illegible] and Spain.

Many of the developing countries of Asia, Africa and Latin America rely largely [illegible] meeting fertilizer requirements. Although [illegible] are making considerable progress [illegible] tic fertilizer industry, they [illegible] increasingly larger imports as the demand for fertilizers increases.

At the current time, for example, [illegible] fertilizers consumed in Asia (excluding Japan) [illegible]. Throughout Latin America, Africa, Oceania and the Far East virtually all potash fertilizers are [illegible] imports.

In view of the rapid increases in world fertilizer requirements and the importance of fertilizer in increasing food production, shifts in the pattern of international trade are expected. The most rapid growth in demand for fertilizers is almost certain to occur in the developing countries. Many of these countries even now are primarily dependent on the world market for fertilizers, and as increased imports would mean a further drain on foreign exchange, the need to develop a domestic fertilizer industry so as to become largely self-sufficient merits increasingly greater consideration in plans for development.

During recent years, the rising demand for fertilizers and strong pressures for industrialization in the developing countries have led to increased pressures for the development of domestic supplies of fertilizers. As such development occurs, as new sources of raw materials are discovered and as new techniques are developed in the fertilizer industry, the world pattern of production and trade in fertilizers is certain to change. The effect may be that international trade in compound fertilizers will decline in relation to shipments of raw materials, e.g. rock phosphate and potassium chloride.

D. [illegible]

Levels and movements of fertilizer prices have influenced the geographical pattern of development of the fertilizer industry throughout the world, the flow of international trade in fertilizers and the consumption levels prevailing in different countries. In order to understand fully the international price structure and its influences, an analysis of the many price determinants would have to be made. This would include consideration of the sources of raw materials for each country, the nature and amount of transportation and production costs, the development of the domestic fertilizer industry and the degree of monopoly or competition existing in each country. In addition, detailed knowledge would be required of the governmental policies relating to [illegible]

[illegible]

[illegible]

Considerable differences exist in fertilizer prices throughout the world, both at the wholesale and at the retail level. Table 5 [illegible] the major types of fertilizers in four [illegible] countries. These data show that wide differences exist in the cost of different types of fertilizers as a source of the same nutrient, both within a given country and among countries. In 1963, for example, in the Federal Republic of Germany and the United Kingdom, ammonium nitrate was somewhat more costly than ammonium sulphate as a source of nitrogen. But in the United States of America, the price relationship was reversed, with the wholesale price of ammonium nitrate being more than twice that of ammonium sulphate.

Table 5. Wholesale prices of selected fertilizers in four countries, 1963

Dollars per hundred kilogrammes of plant nutrient

Fertilizer	Federal Republic of Germany	France	United Kingdom	United States of America
Nitrogen				
Ammonium sulphate	[illegible]		[illegible]	[illegible]
Ammonium nitrate	[illegible]	[illegible]	[illegible]	[illegible]
Phosphorus				
Basic slag	[illegible]	[illegible]	[illegible]	
Superphosphate	[illegible]	[illegible]	[illegible]	[illegible]
Potash				
Muriate	[illegible]	[illegible]		[illegible]
Sulphate	[illegible]	[illegible]		

Source: Food and Agriculture Organization of the United Nations, Fertilizers: An Annual Review of World Production, Consumption and Trade, 1964 (Rome, 1965).

Similarly, great differences exist in the wholesale prices of both phosphorus and potash fertilizers. In 1963, basic slag was generally a less expensive source of phosphorus than superphosphate. Potassium in the muriate form was lower priced than in the sulphate form. Among these four countries shown, the wholesale price of basic slag varied from [illegible] in France to [illegible] in the United Kingdom for 100 kilogrammes of P_2O_5. Superphosphate prices ranged from [illegible] in the United States of America to [illegible] in the United Kingdom for 100 kilogrammes of P_2O_5.

These limited data demonstrate the wide variations that exist in fertilizer prices at the wholesale level. When costs of transportation, distribution, additional processing and packaging are added, the fertilizer price to farmers is much higher than the wholesale prices. Many countries, however, have adopted subsidy and price-control programmes on fertilizers in order effectively to reduce the price paid by farmers as a means of encouraging them to increase their use of fertilizers.

The variations that exist in the net prices paid by farmers for different types of fertilizers (see table 7) strongly influence the farmers' preferences among alternative fertilizers as well as such government policies as subsidies and price controls.

Differences in country-to-country prices paid by farmers often can be ascribed to transportation costs. These can be very great in countries which rely on imports from distant sources. Prices of nitrogenous fertilizers, for example, are understandably higher in Asia and Africa, where large tonnages of the nitrogen consumed are imported.

Government policies, however, may be the most important factor accounting for price differences between countries. The use of subsidies and price controls is based on the assumption that as fertilizer prices decline, farmers will increase their consumption of fertilizers. Whether the higher level of consumption achieved in this manner will continue after removal of the subsidy will depend on the farmers' experiences in the use of these fertilizers in combination with other technological improvements.

While many other factors besides price influence the world pattern of both production and consumption of fertilizers, careful consideration must be given to the subject of price in the development of a country's fertilizer programme. Analysis of the world fertilizer market and comparison of import prices with costs of domestic production of fertilizers are essential in arriving at decisions on whether to produce or import the required types and amounts of fertilizers.

In addition, determination of appropriate price and subsidy policies may be of major concern in the development of a fertilizer programme. The demand for fertilizers is basically dependent on the ratio of the cost of fertilizers used by the farmer and the value of the increased production achieved by their use. If fertilizer prices are too high to induce farmers to use them, fertilizer prices must be reduced, commodity prices increased or improved production technology developed, so that the farmer can obtain greater yield response from the same investment in fertilizers.

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TABLE 7. FERTILIZER PRICES PAID BY FARMERS BEFORE SUBSIDY, SELECTED FERTILIZERS, 1963/1964

(Dollars per hundred kilogrammes of nutrients)

	Nitrogen				*P_2O_5*		*K_2O*				
	Ammonium sulphate		*Ammonium nitrate*		*Normal superphosphate*		*Potassium sulphate*		*Potassium muriate*		
Country	*Bulk*	*Bag*	*Bulk*	*Bag*	*Bulk*	*Bag*	*Bulk*	*Bag*	*Bulk*	*Bag*	*Subsidy*
Federal Republic of Germany	24.8	29.2	24.2	—	18.5	22.8	8.8	10.2	6.5	8.0	None
France	30.0	—	23.8	—	16.9	—	13.1	—	8.2	—	None
India	—	36.7	—	—	—	30.9	—	16.8	—	13.1	25 per cent of cost on phosphates in some states
Italy	—	25.6	—	22.4	—	17.1	—	14.9	—	10.4	None
Japan	—	26.4	—	23.9	—	22.9	—	13.9	—	9.7	None
Lebanon	—	27.7	—	29.2	—	13.0	—	13.9	—	10.7	None
Netherlands	—	26.9	—	25.3	—	19.3	—	—	—	8.8	None
Nicaragua	—	44.0	—	34.7	—	—	—	—	—	—	None
Peru [a]	—	28.4	—	25.6	—	—	—	23.4	—	16.5	None
Republic of Korea [b]	—	31.4	—	30.1	—	20.5	—	16.1	—	9.8	55 per cent to farms with farm land-tax under 300 won
Taiwan	—	44.0	—	—	—	23.6	—	15.0	—	12.5	None
United Arab Republic	—	31.3	—	31.5	—	—	—	11.5	—	—	None
United Kingdom	—	15.6	—	18.0	—	12.9	—	12.8	—	10.3	AS-$9.90, AN-$9.40, NSP-$7.80
United States of America [c]	27.4		26.2		22.2		—		9.9		None

SOURCE: Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review of World Production, Consumption and Trade, 1964* (Rome, 1965).

[a] Factory price.

[b] Subsidy not deducted.

Average bag and bulk price.

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II. ROLE OF FERTILIZER IN AGRICULTURAL PRODUCTION

For the present purposes, fertilizer is defined as any material put in or on the soil to improve the quality or quantity of plant growth. Therefore, in this chapter, the basic concern with fertilizer lies in its physical and economic potential to increase crop production, and the primary interest is in chemical or inorganic fertilizers, as contrasted with such organic materials as manures, compost, night-soil and green manure.

In this chapter, discussion centres on the role of fertilizer in the production process, primarily from the economic viewpoint. The economics of fertilizer use is of paramount importance in farmers' decisions concerning the kinds and amounts of fertilizers, in helping to explain the prevailing low levels of fertilizer consumption in many countries and in suggesting appropriate policies for stimulating greater fertilizer use and thus food production.

As knowledge is acquired of the potential for increasing crop production through the use of fertilizers, decisions concerning the kinds and amounts of fertilizers to use are largely dependent on economic considerations. A farmer's demand for fertilizer depends basically on the relationship between fertilizer costs and the value of the additional production expected from its use. Thus, a necessary condition for the increased consumption of fertilizers is the prospect of increased profits. The greater the prospects for profit, the greater the incentive for farmers to expand their use of fertilizers.

In the final analysis, fertilizer use by farmers in any country or area depends on (*a*) research to develop technical knowledge of crop production responses from the use of different types and amounts of fertilizers in combination with other inputs and practices, (*b*) extension of this knowledge to farmers, (*c*) availability of suitable fertilizers, (*d*) potential profits to be expected from their use, and (*e*) ability of the farmer to finance the use of fertilizer and other inputs. The objective of increased production and consumption of fertilizers, as a means of increasing food and fibre production, can hardly be achieved without taking into consideration these five broad and basic requirements.

Although this chapter is basically concerned with the economics of fertilizer use, the nature of agricultural production makes it difficult to establish the simple cause and effect relationships for any single input or action. Therefore, to understand fully the role of fertilizer in agricultural production, the interrelationships between the use of fertilizer and other farm practices, as they influence crop yields and profits, must be studied.

A. RELATIONSHIP TO OTHER FACTORS IN SCIENTIFIC AGRICULTURE

Kellogg has described four minimum and essential conditions which must be provided by nature or man in order for crop production to occur (1). These are soil fertility, adequate moisture in the rooting zone of the soil, varieties adapted to the environment and protection against diseases and pests. Yield levels are a function of the extent to which the correct quantity and proportion of these necessary conditions are met. If any factor is lacking, it may seriously limit the response that might be expected and may render ineffective any increase from the use of other factors until such time as the deficiency is corrected.

Related to and interacting with these four conditions is a wide range of improved cultural practices. These include seed-bed preparation, time, method and rate of planting, timing and placement of fertilizer and other inputs, crop rotations, soil-tillage practices, and harvesting methods. In the absence of developed localized research and education, the rapid development of improved cultural practices and their adoption by farmers can scarcely be expected. Nevertheless, considerable increases in crop yields can be obtained before optimum conditions are met, provided no single factor of production is so limited as to restrict yield increases.

Experience in much of the developed world indicates that high yields and increased agricultural output are closely related to an increased use of fertilizer. The major objective of this manual is to point out ways to achieve a rapid and efficient increase in the world food supply through an increased use of fertilizers. This chapter deals with factors likely to encourage or discourage the increased use of fertilizers in various parts of the world.

1. *Shifting cropping patterns to changed conditions*

As a new technology becomes available and is put to use, a shift in cropping patterns may be essential if optimum use of agricultural resources is to be achieved. The production response of different crops to new technologies may vary quite markedly. The most profitable crops to be grown may, in some instances, no longer be the same as those grown prior to the introduction of the new inputs and techniques.

For example, in the Southern High Plains north of Lubbock, Texas, in the United States of America, the introduction of well-pump irrigation eliminated water shortages as the major factor limiting crop production. Removal of this restriction permitted the economic application of other modern technological practices. This resulted in a prominent shift in crop production to larger acreages of cotton and sorghum, the introduction of potatoes as an important crop in the area and the reduction of acreages in small grains. Increased fertilizer use accompanied and was an essential part of this shift. Without the adoption of other practices, chiefly irriga-

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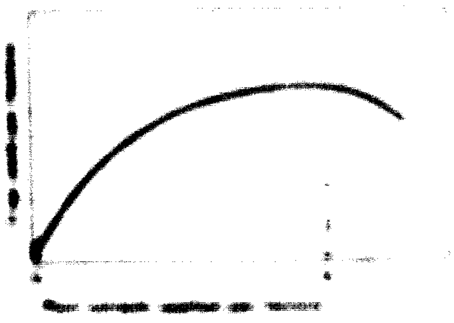

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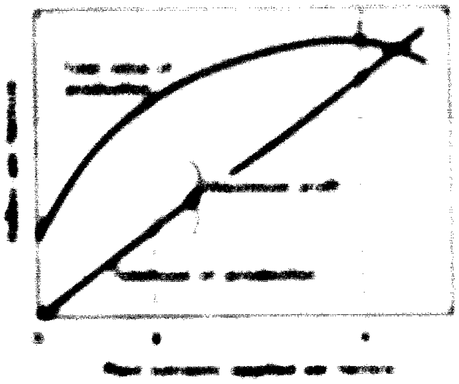

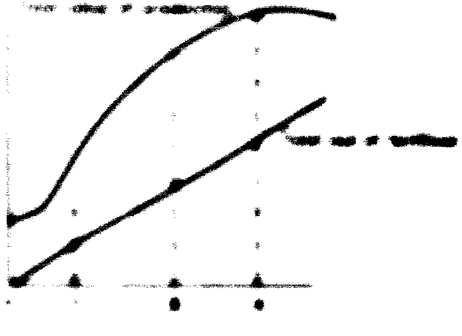

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			

[1] Value of production less cost of fertilizer applied. At very low levels of fertilizer use, per hectare costs of application may be high, reducing the net returns somewhat.

[2] Average added marginal return per $1 of increment in investment in fertilizer.

the elasticities of demand for alternative commodities, the availability of food grains for importation and the adequacy of existing market and distribution facilities. National decisions may also be influenced by the desire that a nation have self-sufficiency and be free from dependence on world markets.

9 *Restricted fertilizer for a given crop*

When the fertilizer available for a given crop is less than that amount which will return the maximum profit to every hectare of that crop being grown, the farmer and the nation will still wish to use the limited fertilizer in such a way as to maximize profit from its use. The question then arises: will it be more profitable to apply heavy dosages of fertilizer on part of the crop although some of the crop receives no fertilizer, or should all of the crop be fertilized, but at a lower rate?

Again using the example in table [illegible], it can be seen that the most profit would be received when $[illegible] was invested in fertilizer per hectare of wheat. However, one may suppose that a farmer had 2 hectares of wheat and only $12 to invest in fertilizer. If all of the fertilizer were applied on 1 hectare, the value of the increase in production from the use of that fertilizer would total $27. If, however, he were to apply half of the fertilizer to each hectare, the value of the increased production would be $19 per hectare or $38 from the 2 hectares. This is $11 more than if all the fertilizer were applied on 1 hectare of wheat. Thus, the greater total profit can be expected by putting the limited fertilizer on larger acreages, rather than applying larger amounts on part of the crop and leaving the remainder unfertilized.[3] An obvious limitation to this statement, however, is that at very low levels of fertilizer application, the labour and the other costs of applying the fertilizers may prohibit its application.

10 *Risk and uncertainty*

In the absence of perfect knowledge, man makes decisions in an environment of risk and uncertainty. To a degree, considerable uncertainty may be associated with technological change. Until farmers have acquired personal knowledge of or experience with the use of new practices or have developed a high degree of confidence in the reliability of recommended changes in methods of production, they may be hesitant to try the use of new technologies. Because of such doubts and uncertainties, they may be willing to apply fertilizers to only a limited acreage of a crop or in smaller dosages than are recommended. As they gain confidence, they are more likely to adopt the full fertilizer recommendations and to be more receptive to other technological changes.

In a country where the agriculture is highly traditional, new technologies may initially meet with slow adoption. But with the trial and acceptance of one or more new production practices, farmers normally become more receptive to change and more readily accept other scientific practices.

Even after farmers overcome their initial skepticism about the use of fertilizer and acquire greater knowledge of crop responses from its use, their decisions regarding the amounts of fertilizers to apply are still influenced by the uncertainties of the future. Weather variations may cause crop response to fertilizers to fluctuate, either above or below expectations. With highly favourable weather during the growing season, higher yields and

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[3] See foot-note 2 for example.

range as often from the use of fertilizer can be expected. At the other extreme, adverse drought, floods or other calamities can result in partial or complete loss of the crop in which case returns may not be sufficient to cover costs. While a farmer may decide on a most likely response from the use of fertilizer for a given season of the crop [illegible] To compensate for risk [illegible] he may reduce his use of fertilizer to less than the optimum amount.

Uncertainties of crop prices may also have a depressing influence on fertilizer consumption. While investments in fertilizer are made before or at planting time, returns from it are obtained after the crop has been harvested. During this period prices can change. If crop prices are generally stable, fairly accurate decisions regarding profitable levels of fertilizer use can be made. If, however, year to year price fluctuations are large, farmers tend to restrict fertilizer use as an insurance against price risks.

For example, analysis of production responses might indicate that fertilizer applied to a particular crop at the rate of 100 kilogrammes per hectare will result in a return of $3 for every dollar invested. If, however, an individual farmer faces a high degree of uncertainty of production or prices, he may fear that the $3 return will not be realized. To compensate for the uncertainty, he may discount the possible returns from $3 to $1. Stated differently, he may decide that a return of $1 on the investment is more probable. Accordingly, he may reduce the application of fertilizer somewhat below 100 kilogrammes per hectare. If the risk of total crop failure is high, if the farmer is in a poor risk-bearing position or if alternative opportunities promise a higher return, the farmer may decide not to apply any fertilizer to that crop.

The amount of reduction in the rate of fertilizer application would also depend on the farmer's income and capital position, and on his ability to absorb risk. Farmers living at a subsistence level would normally be in a relatively poor risk-bearing position and might greatly restrict their use of fertilizers. In countries where a subsistence type of agriculture prevails and farmers face considerable risks in production, fertilizer use may be limited unless price-cost relationships and profit potentials are highly favourable. By contrast, high levels of fertilizer application might be made when there is little risk in either price or production, even though price-cost relationships are not very favourable and expected net returns from investments in fertilizer are comparatively low.

Reducing the influence of such uncertainties is essential if rapid expansion in food production is to be achieved through increased consumption of fertilizers. Uncertainties associated with change can be alleviated through educational efforts. Reducing the risks of production may require flood control and drainage programmes, the provision of adequate and reliable supplies of water for irrigation and other actions to reduce the chances of crop failure due to hazards of nature. In the absence of such programmes, the depressing influence of risks on amounts of fertilizers used might be partially offset by creating a more favourable price-cost relationship through price support or fertilizer subsidy programmes. If these can be effectively implemented, the use of [illegible] might be encouraged.

Land tenure [illegible]

[illegible] conditions of land tenure [illegible] the use of fertilizers [illegible] are easily [illegible] greatly reduced.

In some systems of share-cropping [illegible] in the developing countries, the tenant [illegible] the land and the landlord [illegible] all other inputs including fertilizer. Since the production and returns are shared, the production [illegible] 50%, 60% [illegible] the costs of all fertilizer [illegible] share of the increased output. The result is [illegible] the increased output while [illegible] the increased costs of production.

Consequently, the incentive for the tenant to use fertilizers is considerably less than that of [illegible] a tenant paying a fixed rent [illegible] only partially [illegible] the fertilizer [illegible] the total increase in output.

If landlords can be induced to share the cost of fertilizers, the incentive of the tenant to use fertilizer will be the same as that of an owner-operator. Sharing of such costs by a landlord will be to his benefit as well as to that of the tenant.

The lack of permanency of tenure may discourage the use of fertilizer particularly where a significant amount of the effect of fertilizer applied in one year is realized only in succeeding years. If tenancy is insecure or in fact if landlords or owner-operators have grave doubts regarding continuing claims to their land, their incentive to use fertilizer may be considerably reduced. Similarly, insecurity of tenure may reduce the incentive of both owners and tenants to make other improvements which might enhance the crop response from fertilizer and thus make its use more profitable.

Any country launching a fertilizer programme must be fully aware of the prevailing tenure situation as it might influence the consumption of fertilizer. While land reform action lies beyond the scope of a fertilizer programme, actions to overcome land tenure conditions unfavourable to increased fertilizer use and increased agricultural production should be included in overall plans for the development of agriculture.

12. Residual effects

Only a portion of the fertilizer applied in any year is recovered and used by the crop being grown. While nitrogen is subject to heavy loss by leaching and [illegible], particularly in hot humid climates, phosphorus and potash not used by the crops during the year of application may be partially recovered by succeeding crops. The higher the rate of fertilizer application the lower the percentage recovered by the growing crop in the year of application. In turn, the higher the rate of fertilizer application, the greater the residual remaining in the soil. The amount of the residue will vary considerably among the different nutrients, depending on the crops being grown, the rate of fertilizer being applied, the type of soil

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[illegible] is even higher before farmers will be induced to adopt the practice.

Table [illegible] shows the results of fertilizer trials and demonstrations on maize, wheat and rice in several developing countries. Fertilizer applications shown are those which reported the largest net return per hectare above that of the control plots. In all cases considerable increases in yields were obtained ranging from 22 per cent to [illegible] per cent, and the value of the increased production was more than the cost of the fertilizer used. These data show that it is generally profitable for traditional farmers in developing countries to use fertilizers. This is indicated by the return per dollar invested in fertilizers; where the returns per dollar are more than unity the use of fertilizer is economic. In nearly all the situations for which data are shown, the returns per dollar invested were more than $2 and in most cases, more than $3. However, the returns from the fertilization of wheat were generally low in most countries. With other crops and in other countries where economic relationships are more favourable, large increases in fertilizer use can be expected after farmers are educated to appreciate the high profits that fertilizers can bring them. Thus, educating farmers to appreciate the advantages of using fertilizers is, in addition to favourable cost/price relationships, an important factor.

Considerable variation exists within countries in both the physical and the economic responses from the use of fertilizer. In Ghana, for example, considerable differences are shown between the forest and savanna regions in the optimum economic level of fertilizer application and in the yield and income response of rice from the use of the respective fertilizers. Such internal differences demonstrate the need for regional research within any country where soil, climate and economic conditions vary significantly.

14. *Prices and price relationships*

Under any existing price relationship, profit maximization occurs when available inputs are applied until marginal returns from their use is greatest. The physical output response per kilogramme of fertilizer applied is usually higher for applications other than those that show the largest net profit. If the objective is to achieve the highest possible levels of agricultural output under known methods of technology, economic conditions may need to be altered so as to make the use of larger amounts of such inputs more profitable to the farmer. Such conditions may necessitate changes in prices and price relationships, as well as actions to overcome other economic restrictions to increased production. In any case, data on physical and economic responses are required for the formulation of policies directed at determining the optimum level of fertilizer use.

Adequate price information is essential to the initiation of sound plans for development in virtually all countries. In most developing countries, this type of information is quite limited.

Comparable price data on fertilizers are available for various countries (see table 11). In 1960/1961, wide variations existed in the fertilizer prices paid by farmers in

TABLE 10. RESULTS OF FERTILIZER TRIALS AND DEMONSTRATIONS ON MAIZE, WHEAT AND RICE, SELECTED COUNTRIES

Crop and country[a]	*Fertilizer treatment N-P$_2$O$_5$-K$_2$O (kg per hectare)*	*Yield (kg per hectare)*		*Yield increase*		*Net return to fertilizer*		*Output per kilogramme of nutrients*
		Control	*Fertilized*	*Kilogrammes per hectare*	*Percentage*	*Dollars per hectare*	*Per dollar of fertilizer*	
Maize								
El Salvador-central	90-90-0	2,420	4,146	1,726	71	93	3.1	9.6
Ghana								
Forest	22.4-0-22.4	1,419	2,287	868	61	47	4.6	19.3
Savanna	44.8-0-0	1,159	2,022	863	74	41	3.2	19.3
Honduras								
Hybrid-north	90-90-90	4,788	9,801	5,013	105	272	5.3	18.6
Local	45-45-45	1,674	3,110	1,436	86	64	3.0	10.6
Morocco-north								
Irrigated	40-40-0	1,436	2,395	959	67	31	2.9	12.0
Non-irrigated	0-40-0	648	1,053	405	62	13	2.8	10.1
Morocco-south								
Non-irrigated	20-40-0	723	1,139	416	58	9	1.7	6.9
Nigeria								
Forest	0-0-22.4	1,521	1,861	340	22	11	4.2	15.2
Savanna	0-0-22.4	1,262	1,559	297	24	9	3.7	13.3
Turkey								
Marmara	40-40-0	2,246	3,194	948	42	50	3.0	11.8
Black Sea	40-40-0	2,072	3,788	1,716	83	111	5.4	21.4
Wheat								
Lebanon								
Irrigated	60-60-30	1,905	3,744	1,839	96	126	4.4	12.3
Non-irrigated	60-60-0	1,430	3,267	1,837	128	131	5.1	15.3
Morocco								
South	20-40-0	391	944	553	141	28	3.4	9.2
North	40-60-40	914	1,541	627	69	19	1.7	4.5
Syria								
Irrigated	60-60-60	1,860	2,802	942	51	11	1.3	5.2
Non-irrigated	0-40-0	968	1,181	213	22	2	1.2	5.3
Turkey-Central Anatolia								
Irrigated	60-60-0	1,530	3,010	1,480	97	86	3.3	12.3
Non-irrigated	30-30-0	1,401	2,104	703	50	40	3.1	11.7
Turkey-Thrace								
Irrigated	20-40-0	1,543	2,661	1,118	72	76	5.2	18.6
Non-irrigated	60-60-0	1,308	2,318	1,010	77	47	2.2	8.4
Rice								
El Salvador-central	90-90-90	1,982	4,428	2,446	123	214	4.9	9.1
Ghana								
Forest	22.4-22.4-0	1,302	1,970	668	51	45	3.3	14.8
Savanna	26.9-26.9-0	1,797	3,218	1,421	79	113	5.8	26.4
Nigeria								
Forest	22.4-22.4-0	1,869	2,859	990	53	98	6.9	22.0
Savanna	22.4-22.4-22.4	1,289	2,051	762	59	69	4.4	11.3
Senegal								
Casamance	90-0-0	1,218	1,968	750	62	40	3.2	8.3
Fleuve	45-45-45	1,917	2,442	525	27	19	1.8	3.9
Sine Saloum	90-0-0	603	1,555	952	158	56	4.0	10.6
Turkey								
Central Anatolia	40-40-0	3,460	5,280	1,820	53	228	10.1	22.8
Thrace	60-60-0	3,545	5,288	1,743	49	204	6.4	14.5

SOURCE: Food and Agriculture Organization of the United Nations, *Review of trial and demonstration results* 1961-1962, 1962-1963 and 1963-1964 (preliminary), Freedom from Hunger Campaign Fertilizer Programme (Rome, 1963, 1964, 1965).

Note. Results shown include only that fertilizer application showing the largest additional return per hectare of the crop. In some instances, a different fertilizer application produced a larger increase in yield, a higher net return per dollar invested in fertilizer or a larger output per kilogramme of fertilizer applied.

[a] Data by area, variety and irrigated or non-irrigated land included where available.

TABLE 11. FERTILIZER PRICES PAID BY FARMERS IN SELECTED COUNTRIES, [illegible]

Country	[illegible]	N	P_2O_5	K_2O	Average
Latin America					
Venezuela	1.8	[illegible]	[illegible]	[illegible]	[illegible]
Africa					
Sudan [b]	2.7	[illegible]	[illegible]	[illegible]	
Europe					
Greece	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Yugoslavia	[illegible]		[illegible]	[illegible]	
Near East and South Asia					
India [d]	3.3	[illegible]	[illegible]	[illegible]	[illegible]
Iran	8	[illegible]	[illegible]	[illegible]	[illegible]
Israel [b]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pakistan [e]	4.2	[illegible]	[illegible]	[illegible]	[illegible]
United Arab Republic (Egypt)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Far East					
Federation of Malaya	3.2	[illegible]	[illegible]	[illegible]	[illegible]
Japan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Philippines	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Republic of Korea	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Taiwan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thailand [f]	2.3	[illegible]	[illegible]	[illegible]	[illegible]
Netherlands	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
United States of America	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SOURCE: Food and Agriculture Organization of the United Nations, Production Yearbook [illegible] (Rome, [illegible]).

[a] Prices cited are for major materials used, net of subsidy except where noted.

[b] C.i.f. port prices.

[c] Net of transportation subsidy, net of subsidy on [illegible].

[d] Subsidies of 25 per cent in some States. No allowance included here.

[e] Net of 50 per cent subsidy.

[f] Wholesale prices at company warehouse.

these countries. In Greece, Israel, Spain, the Republic of Korea and the Sudan, fertilizer prices were generally comparable to those in the Netherlands and the United States of America. By contrast, prices were at least one-third higher in the Federation of Malaya, India, Iran, the Philippines, Taiwan, Thailand, the United Arab Republic (Egypt) and Venezuela. The higher prices prevailing in many of the developing countries reflect the higher costs of domestic production of fertilizers, the added cost of transportation of imported fertilizers and fertilizer materials, and the relatively high cost of domestic distribution at the current state of development.

Some countries have established subsidy programmes to reduce the fertilizer prices paid by farmers and thus to make the use of fertilizers more profitable. The low prices in Pakistan, for example, result largely from the high government subsidy on fertilizers. As this has been a rather recent development, the impact on fertilizer consumption is as yet limited. While fertilizer prices to farmers are high in Taiwan, free distribution of at least limited amounts of fertilizer in the past and other development activities have stimulated rapid increases in the consumption of fertilizers.

While high prices tend to discourage farmers from using fertilizers, the prevailing level of consumption depends upon the fertilizer-product price relationship relating to the physical response achieved from the use of fertilizers. Tables 12 and 13 demonstrate such price relationships for selected countries.

It should first be noted that considerable variations in product prices exist among countries, as indicated by the prices for wheat and rice in [illegible]. Wheat prices varied from 6.7 cents per kilogramme in the United States of America to 11.1 cents per kilogramme in Japan. Rice prices ranged from 6.7 cents in Thailand to 11.1 cents in the United States and 13.3 cents in Japan. The low rice price in Thailand reflected a heavy export tax on rice, while the high price in Japan resulted largely from government policies aimed at encouraging domestic rice production.

The fertilizer-product price ratios given in table 12 show the increase in production that is necessary to equal the cost of a given unit of fertilizer. In the United States, for example, a physical response of at least 2.84 kilogrammes of wheat per kilogramme of fertilizer applied would be necessary if fertilizer use were to be profitable.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.27	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.82
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.47
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	4.21	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.68

Source: Food and Agriculture Organization of the United Nations, *Production Yearbook 1962*

[illegible]

Kilogrammes of increased production required to equal cost of a kilogramme of fertilizer.

[illegible]

[illegible] prices converted to paddy using coefficient of 0.66.

Under 1960-1964 prices, a somewhat higher response (1.50 kilogrammes) would be required in the United Arab Republic (Egypt), whereas fertilizer use would be profitable in Pakistan, Japan and Spain even if the respective yield responses were as low as 1.10, 1.80 and 1.89.

Price relationships of fertilizer to rice varied considerably more than those of wheat. Among the developing countries included in table 12, only Japan and Pakistan had a more favourable price relationship than the United States of America. Fertilizer used on rice in Pakistan would be profitable wherever a crop response of more than 1.27 kilogrammes of rice per kilogramme of nitrogen could be expected. By contrast, the responses required in the United Arab Republic (Egypt) and in Thailand would have to be at least 7.5 and 6.6 kilogrammes, respectively, per kilogramme of nitrogen. Thus, the response in the United Arab Republic (Egypt) would have to be six times as great as that in Pakistan and two and one-half times as great as that in the United States.

Table 13 shows the amount of increase in the yield of wheat and rice that would be necessary to cover the cost of 50 kilogrammes of the different fertilizer nutrients at 1964 prices. The required response from nitrogen ranges from 77 to 266 kilogrammes of wheat and from 64 to 374 kilogrammes of rice in the various countries for which data are available. Unless the physical response from the use of 50 kilogrammes of fertilizers is at least as great as that shown in table 13 for the respective countries, the application of 50 kilogrammes of fertilizer would not be profitable. In such a case, in order to achieve increased output through the use of more fertilizers, either improved practices must be developed that will enhance the yield response, or price relationships must be altered to make the use of larger amounts of fertilizer profitable to farmers. While higher product prices might be achieved through market development and lower fertilizer prices might accrue through increased efficiency in fertilizer production and distribution, direct price policy actions may offer a more immediate means of expediting improved favourable factor-product price relationships.

15. *Selection of fertilizers for production and consumption*

Determination of the kind and quantity of fertilizers to be produced and consumed evolves around two basic considerations of a physical nature. The type and amount of fertilizers required for crop production must be determined through controlled agronomical research and fertilizer trials under actual farm conditions. A continuing programme of research will be needed in different regions of each country to determine the suitability of different fertilizer materials in supplying the nutrients necessary for crop production and in acquiring an expanded knowledge of crop response to fertilizers at varying levels of application. The second basic consideration is the availability of raw materials from which suitable fertilizers can be produced. Assessment should be made of the domestic sources of mineral deposits of phosphorus and potash, the local availability of coal or natural gas as a source of nitrogen, the potential for fixing nitrogen from the air and the potential for importation.

TABLE [illegible]. INCREASE IN YIELD OF WHEAT AND RICE NECESSARY TO COVER COST OF 50 KILOGRAMMES OF FERTILIZER AT 1961 PRICES

Commodity and country	Amount of increase necessary in crop yield (kilogrammes)				Increase necessary over 1959/1960–1961/1962 yields (percentage)			
	N	P_2O_5	K_2O	$N-P_2O_5-K_2O$	N	P_2O_5	K_2O	$N-P_2O_5-K_2O$ [a]
Wheat								
India	197	173	67	135	24.0	21.4	8.3	16.7
Japan	125	99	41	88	4.9	3.9	1.6	3.5
Pakistan	77	60	27	55	9.5	7.4	3.3	6.8
Spain	147	109	31	–	15.8	11.7	3.3	—
United Arab Republic (Egypt)	266	150	116	178	11.0	6.2	4.8	7.3
Netherlands	152	86	57	97	3.6	2.0	1.3	2.3
United States of America	200	146	71	139	12.4	9.1	4.4	8.6
Rice (paddy) [b]								
India	353	311	120	243	23.9	21.0	8.1	16.4
Japan	91	72	30	64	1.9	1.5	.6	1.3
Pakistan	64	50	22	45	4.1	3.2	1.4	2.8
Philippines	157	128	68	118	13.4	10.9	5.8	10.1
Republic of Korea	146	87	46	93	4.9	2.9	1.5	3.1
Taiwan	230	127	67	141	7.4	4.1	2.2	4.6
Thailand	332	265	172	273	24.4	19.5	12.6	20.1
United Arab Republic (Egypt)	374	211	163	249	7.5	4.2	3.2	5.0
United States of America	119	87	42	83	3.1	2.3	1.1	2.2

SOURCES: Tables 11 and 12.

[a] N, P_2O_5, K_2O in 1-1-1 ratio.

[b] Milled-rice prices converted to paddy, using coefficient of 0.66.

Within the limitations imposed by the availability of fertilizer materials and the nutrient requirements for plant growth, the selection of the fertilizers to be produced and consumed depends upon variations in the cost of producing and distributing alternative fertilizers. These will be influenced by the costs of raw materials, the scale of plant operation and unit cost of processing, the transportation costs and the level of demand for different fertilizers. A concerted effort should be made to produce fertilizers suited to the farmers' needs at the lowest possible nutrient costs.

16. *Mixed* versus *single-nutrient fertilizers*

Arguments can be offered in favour of both mixed and single-nutrient fertilizers. If only single-nutrient fertilizers are produced, additional labour is required for application; and even though labour may be relatively abundant, the additional work may discourage farmers from using fertilizers. Mixing of fertilizers is tedious, as care must be taken to ensure uniformity throughout the mixture. If the nutrients are applied to the land separately, extra care must be taken, particularly if broadcast by hand, to ensure even distribution of each fertilizer.

By contrast, if mixed fertilizers are produced, mixing facilities will be needed and additional processing may increase costs. However, purchasing and handling can be restricted to only one fertilizer rather than three, and where a limited amount of any nutrient is required, more uniform application can be facilitated.

17. *Restricted number of fertilizers*

In the production of mixed fertilizers, the number of different mixtures should be limited. Unfortunately, as different ratios are frequently required for different crops, there is a tendency to produce a separate mixed fertilizer to meet each such need. As a result, farmers are faced with the problem of choosing from a large number of mixed fertilizers, leading to considerable confusion. In addition, preparation of limited amounts of a large number of mixed fertilizers is almost certain to result in increased costs per unit of nutrients.

If equal portions of N, P_2O_5 and K_2O were needed, a 1-1-1 ratio would be appropriate. In other circumstances or on other crops, results of agronomical studies might indicate that other nutrient ratios are required, such as a 4-2-1 ratio where the nitrogen content in the soil is deficient or 0-3-1 where legumes are grown and more phosphorus is required.

Thus, it is possible that fertilizers in many different ratios would be indicated. If possible, however, the number of these ratios should be restricted to as few as the five or six that most nearly approximate the optimum ratios for all different conditions. That is, where the use of a 6-8-7 ratio is indicated, the use of fertilizers containing a 1-1-1 ratio may be adequate. Or if nutrients are required for one crop in the ratio of 2-1-1, these might be supplied by use of 1-1-1 ratio plus a side-dressing of nitrogen.

Any required ratio can be supplied in a wide range of analyses. A 1-1-1 ratio might range from a low-analysis fertilizer, such as 5-5-5, to a high-analysis nature product, such as 15-15-15. That is, 100 kilogrammes of fertilizers could easily be made containing either 5 or 15 kilogrammes of each of the three major nutrients. Farmers could be faced with the problem of selecting from a wide range of fertilizers of different ratios and of several fertilizers containing the same ratio, but in varying degrees of concentration. Limitation of the numbers of both single-nutrient and mixed fertilizers minimizes the farmer's problem of deciding which fertilizers to buy and use.

18. *High-analysis fertilizers*

Selection of higher analysis fertilizers generally results in lower costs per kilogramme of nutrients. This is particularly true where transportation and handling are major items of cost. For example, if 30 kilogrammes per hectare of each nutrient were to be applied, only 200 kilogrammes of a 15-15-15 analysis would be needed, while 600 kilogrammes of a 5-5-5 analysis would be required. Similarly, nutrient costs of single-nutrient fertilizers are frequently lower where the analysis is higher. Consideration should also be given to such factors as the physical properties of fertilizers of different analyses and the effect of other materials present upon production. In any case, full information should be made available to farmers of the nutrient content of different fertilizers and the kinds and qualities of ingredients they contain.

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III. CRITERIA FOR PRODUCTION *VERSUS* IMPORTATION OF FERTILIZERS

A. Basic factors influencing the decision

In the development of a successful fertilizer programme, each developing country faces the problem of deciding how far it should go towards meeting its fertilizer requirements through domestic production. Should the country become self-sufficient in its fertilizer supplies? Or might it be most advantageous to import part or all of the required amounts of fertilizer?

To date, the bulk of the world supply of fertilizers has been both produced and consumed in the developed countries of western Europe and North America, and in Japan. Indications are, however, that the rate of increased consumption in the next twenty years will be most rapid in the developing countries of Latin America, Asia and Africa. In these areas, for example, total fertilizer-nutrient consumption is likely to increase at an average compound rate of 10 to 15 per cent *per annum*. This would mean an increase in consumption from 3 million tons in 1960 to over 28 million tons in 1980. In other words, fertilizer supplies in the developing countries will need to be increased almost tenfold within the relatively brief period of two decades. By contrast, fertilizer consumption in the developed areas of the world, already at relatively high levels, is likely to increase at a compound annual rate of about 3 per cent, expanding from 20 million to perhaps 36 million tons over the twenty-year period.

If the developing countries are to achieve so rapid an increase in consumption, concerted action must be taken to assure the provision of the essential fertilizer supplies. Quite generally, conditions favour the continued production of much of the world's fertilizers in the industrially more developed countries. At the same time, strong arguments can be made for rapid expansion of the fertilizer industry in many of the developing countries.

In the early stages of attempting to expand fertilizer consumption, developing countries will almost certainly need to rely on imported fertilizers. As fertilizer demand increases, however, the country may sooner or later wish to establish or promote the development of a domestic fertilizer industry. The initial step may be to prepare mixed fertilizers from imported materials. Alternatively, it may elect to construct a plant for processing imported materials, e.g. ammonia, into nitrogenous fertilizers while continuing to import other fertilizers. Eventually, however, the stage will be reached when actual manufacture may be the appropriate course of action.

Unfortunately, no simple rule can be offered by which any and all nations can readily determine the best course of action to follow in ensuring adequate fertilizer supplies for its farmers. Many factors must be considered in arriving at a decision as to whether to import or to produce the increasingly larger amounts of the various fertilizers required. Much will depend on the availability of the natural resources essential to fertilizer production, the cost of production *versus* importation, the country's capital and foreign exchange position and, of course, the political situation that prevails.

B. Available raw material

Decisions to produce or to import fertilizers will be influenced by the availability of local and external sources of low-cost raw materials and other inputs required in the fertilizer industry. Whereas phosphorus and potash manufacture consist largely of processing mineral raw materials, nitrogen fertilizers are usually based on the complex and costly production of ammonia. A brief discussion of the sources of fertilizer materials and their implications for development of a fertilizer industry is therefore appropriate.

In earlier years, natural nitrate deposits like those in Chile were the primary sources of nitrogenous fertilizers. More recently, following the development of methods of fixing nitrogen from the air and combining it with hydrogen to form ammonia, over nine-tenths of the world supply of nitrogenous fertilizers has come to be produced by synthetic processes. The development of these processes has led to increasingly greater technical feasibility for any and all nations to manufacture nitrogen fertilizers. Nevertheless, manufacturing of nitrogen fertilizers may be limited unless the electric-power supply or other energy sources are sufficient to meet the large requirements for producing ammonia.

Phosphatic rock provides most of the world's phosphate fertilizers. While vast deposits are known to exist, these are largely concentrated in relatively limited areas, with major deposits located in the Union of Soviet Socialist Republics, the United States of America and northern Africa. Basic slag, a by-product of the steel industry, is an important local source of phosphorus in some of those countries where the steel industry has been developed. Similarly, bone-meal becomes an important phosphorus fertilizer in those countries containing a large meat packing industry.

By far the greater part of the world's potassic fertilizers are derived from vast underground deposits of mineral ores containing varying amounts of potassium salts. Huge deposits exist in a number of countries, notably Canada, Eastern Germany, the Federal Republic of Germany, Spain, the USSR and the United States of America. Few of the developing nations have local access to large deposits of potassium ores.

Inland salt lakes provide a source of potash in some countries and extensive efforts are being made to extract potassium salts from sea water, but as yet these sources provide limited amounts of the potassic fertilizers consumed in the world.

Many of the developing countries do not have access to local raw materials as a source of potassium and phosphorus. Consequently, they have little choice but to import the prepared fertilizers or to limit the development of their chemical industry to processing imported raw materials into suitable fertilizers. In the case of nitrogen production, unless large supplies of low-cost energy are available for use in the nitrogen-fixing process, the feasibility of producing their domestic needs may be limited.

Anticipated development in other fields should be considered in planning for the development of a fertilizer industry. Expansion of electric-power and water-supply systems may provide the required energy for plant operation; rapid expansion of the steel industry may make basic slag or coke-oven gas available; the discovery of economically exploitable deposits of phosphate rock, potash ores, petroleum or natural gas may provide a domestic source of raw materials. Such factors as these may also be decisive in indicating the type of plant to be built, where it will be built and what is to be produced. Thus, again, plans for development of a fertilizer industry should be based on both short-run and long-run considerations.

C. Economics of production

Under existing conditions, cost considerations in most of the developing countries favour continued reliance on world trade as the primary source of required fertilizers. Many of the countries most urgently in need of increased food production have limited access to the capital and raw materials required in the development and operation of an efficient fertilizer industry. In addition, personnel with the special skills required in the fertilizer industry are in short supply in most of the developing nations. As a consequence, the cost of fertilizer production exceeds the price of fertilizers available on the world market. In some cases, in fact, the current cost of domestically produced fertilizers far exceeds that of imported fertilizers even when shipping costs and import taxes are included.

Where such conditions exist, cost considerations would suggest that the required fertilizer supplies should be imported from the more efficient, lower cost producing areas. From a short-run point of view, such an action would seem particularly appropriate. From a long-run viewpoint, however, the decision to develop an indigenous fertilizer industry must be based in part on the feasibility of developing that industry at a size and level of efficiency sufficient to make it competitive on the world market.

In developing countries where much of the capital equipment and required raw materials are not domestically available, the amounts needed must be obtained on the world market. Thus, costs of inputs will exceed those in the source countries at least by the cost of shipping, tending to increase the cost of fertilizer production. Production costs can be minimized, however, by selecting low-cost methods of fertilizer manufacture, by constructing large-scale plants which can benefit from the economies of scale and the development of [illegible] well trained in the knowledge and skills [illegible] the efficient operation of a fertilizer industry. As rapidly as such improvements can be effectively put into practice, costs of domestic production should decline for at least some fertilizers, making them increasingly more competitive with imported fertilizers. Similarly, success in the development of the other areas may contribute to achieving low-cost production of fertilizers. For example, with further development of electric-power facilities, water supplies and transportation systems, reductions in the costs of power, water and transportation may be effected, thus reducing the cost of production of fertilizers.

D. Use of low-cost processes

In recent decades, tremendous strides have been made in reducing unit costs of fertilizer production. This has been particularly true in the case of nitrogen, where improved processes of nitrogen fixation have been developed. The economic significance of such developments is demonstrated by the fact that in the United States of America, the cost of producing ammonia by the steam-reforming process is considerably lower than by the partial-oxidation process. For example, where naphtha is used in both processes, production costs are lowered by about $6.50 per ton when the steam-reforming process is used. By substituting natural gas for naphtha under existing price conditions, even larger reductions in unit cost of production have been obtained. This reduction has sometimes amounted to as much as $11 to $12 per ton of ammonia, meaning a saving of at least 25 per cent.[1]

The differences in the costs of production for alternative processes in other countries are almost certain to vary considerably from that indicated in the United States. That process which will result in the lowest cost production of fertilizer will depend on conditions prevailing in individual countries, relating to the availability and cost of substitute raw materials, such as coal, fuel oil, naphtha and natural gas in the case of ammonia production. Consequently, in deciding whether to produce or to import, a thorough cost analysis of the alternative processes becomes essential in order to determine the lowest cost method of fertilizer production.

E. Economies of scale

The size of the plant has a significant effect on both the capital requirements and the operating costs per ton of installed capacity. Within broad limits, as the plant size increases, the unit cost of production declines. As a general rule, doubling the size of the plant, as from 100,000 to 200,000 tons annual capacity, increases the total capital investment by approximately 40 to 50 per cent. In other words, the capital investment per ton of capacity declines about one-third as the plant size is doubled. This results in lower capital or fixed costs per ton of fertilizer produced.

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[1] O. J. W. Price, "Fertilizer nitrogen in international trade", paper presented at the Meeting of American Chemical Engineers, Houston, Texas, February 1965.

[illegible] particularly [illegible] small plants operating [illegible] variable [illegible] per ton of fertilizer also decline as the plant size increases. In the case of ammonia production in the United States of America, for example, the cost of production is reduced by approximately $6 per ton when the plant size is increased from 33,000 to 66,000 tons annual capacity. With a further increase in the plant size to a capacity of 200,000-250,000 tons, costs are reduced an additional $5 to $6 per ton.[1] By constructing a 200,000 ton plant, therefore, the cost of production per ton is decreased by roughly $11 to $12, representing a reduction of 15 to 20 per cent depending on the process being used. When such an increase in the size of the plant is combined with a shift from the partial-oxidation process based on coal to the steam-reforming process using natural gas, the cost of ammonia production is reduced by as much as 50 per cent.

Although economies of scale will normally contribute to lower unit costs of production, there will sometimes be other cost considerations favouring the construction of well-placed small-sized plants, in spite of probable higher costs of construction and operation per unit of capacity. For example, larger sized plants have the disadvantage of marketing their output over a larger geographical area, resulting in higher shipping costs, particularly to the more distant points served. In some instances, the savings in shipping costs associated with smaller sized plants serving a restricted area may be sufficient to offset the higher unit cost of production, making the smaller plants competitive with those of a larger capacity.

F. PLANT SIZE AND FERTILIZER DEMAND

Countries which have now reached a level of fertilizer demand sufficient to consume the output from larger sized fertilizer plants are in a position to exploit the benefits of economies of scale. In many of the developing countries, however, fertilizer demand is not yet sufficient to justify large plants. Unless the country has ready access to foreign markets for fertilizers produced in excess of home-market needs, the smaller sized plants may result in a lower cost of production than the development of a large plant that is operated at one-half or two-thirds of capacity. Even then, however, the cost of production is likely to be considerably higher than that in the more developed countries, which are already benefiting from economies of scale. Quite generally, therefore, as long as fertilizer requirements in the developing countries are small, conditions will favour the continued reliance on international trade as the lowest cost method of obtaining fertilizers. However, when fertilizer demand expands sufficiently to provide a market for the output of larger plants, the benefits of large-scale production can be achieved, and the development of an indigenous fertilizer industry can be more economically justified.

G. ECONOMIES OF SCALE AND EXPORT PRICING

Because of economies of scale, there will be a strong incentive to construct and operate large-scale fertilizer plants, even though their capacities may be larger than [illegible] necessarily [illegible]. Unless such a plant were operating near full capacity, [illegible] of the savings [illegible] economies of scale might disappear. Nevertheless, constructing a larger plant might result in lower unit prices to domestic consumers provided the surplus could be exported even at a price somewhat below the average cost of production. For example, one may assume that a country requires 100,000 tons of ammonia, which can be produced by a plant of that size at an average cost of $56 per ton. Were it to operate a 200,000-ton plant at full capacity with the cost of production averaging $48 per ton, it would effect a reduction in cost of $8 per ton of fertilizer produced. As long as an export market could be found for the surplus production of 100,000 tons at a price in excess of $40 per ton, the price of the domestically consumed ammonia could be less than the unit cost of production from the smaller plant, while total production costs could still be covered.

Even though the capacity of a large-scale plant may exceed the existing demand in some countries, there may be considerable justification for building such a plant because of expected increases in demand in future years. Until demand had grown sufficiently to consume the output of the larger plant, however, it would be desirable to operate the plant at full capacity, provided an export market could be found for the surplus production at a price which at least covered the operating cost of the plant. Complete shut-down of the plant for large parts of the year or full-time operation at a level well below full capacity, even if technically feasible, might be more costly alternatives.

H. EFFICIENCY OF PRODUCTION

To develop an efficient fertilizer industry, the labour force employed must have a fairly high level of training in the special skills required in fertilizer production. Initially, the developing countries are almost certain to face serious shortages of personnel having such skills. As a consequence, a lower level of efficiency in plant construction and operation can be expected to contribute to higher construction and operating costs, and thus to higher unit costs for the fertilizers produced. This may be manifested by long periods of time required in plant construction, high costs of maintenance and repair of plant equipment and a larger number of shut-downs of plant operation. Even though hourly or daily wage rates in many developing countries are low, an inadequately trained labour force may result in high labour costs.

A country embarking on the development of a fertilizer industry thus faces the need to develop a sufficiently large core of well-trained personnel to minimize the losses caused by such inefficiencies. This includes the personnel required in plant management, as well as those needed in its technical operation. As one of the first actions in the development of a fertilizer industry, it may therefore be necessary either to send a basic core of personnel to the industrially developed countries to acquire the necessary training and experience, or to import from those countries a sufficient number of well-qualified people to oversee the design, construction and operation of the initial plant and [illegible] the larger number of employees [illegible] represents additional expenditures which contribute to the high cost of fertilizer production in the early stages of development of a fertilizer industry. However, the added cost per unit of output may be small if significantly higher levels of efficiency in plant operation are attained.

I. AVAILABILITY OF CAPITAL

Most developing countries face severe capital restrictions and have many pressing needs for the limited capital available to them. Few are endowed with ready means of earning sufficient foreign exchange to meet the many pressing development needs. Those that have large gold reserves or that are in a position to acquire large amounts of foreign exchange through increased exports are in a relatively favourable situation, inasmuch as their decision to import or produce their required fertilizer is less restricted by capital limitations. Others, however, that have limited prospects for expanding their exports of such natural resources as oil and minerals, or of agricultural products and manufactured goods, face a more acute problem in supplying the fertilizers needed for agricultural development. In any case, the problem of supplying the fertilizers must be resolved for no fertilizer programme can be successful unless those quantities of fertilizer needed can somehow be provided.

J. FOREIGN EXCHANGE FOR THE IMPORTATION OF FERTILIZERS

Reliance on the world market as a source of all fertilizer supplies will result in serious drains on the available foreign exchange for most developing countries. This will be particularly true in future years if rapid increases in fertilizer consumption are to be achieved. In a large country, for example, India, if all the fertilizers consumed in 1960/1961 had been imported, foreign exchange outlays for this purpose would have approximated 80 million dollars. By contrast, if India should expand its fertilizer consumption by 1980 to an average of 30 kilogrammes per hectare of arable land, 4.7 million tons of nutrients would be required. The foreign exchange necessary to purchase this vast quantity of fertilizer might easily total 800 million to 900 million dollars, assuming 1961 wholesale prices for fertilizers. Unless the country could increase its foreign exchange earnings sufficiently or could allocate an increasingly larger share of its available foreign exchange for fertilizer purchases, difficulty would be encountered in importing such increased amounts of fertilizers.[8]

Much the same situation will be faced by many of the smaller countries. While the total amount of fertilizers required may be relatively small by comparison with that in India, [illegible] foreign exchange [illegible] [illegible] [illegible] required supplies are likely [illegible] essential to achieve the level of [illegible] production. Under such circumstances, there [illegible] to be considerable incentive to develop [illegible] fertilizer industry of sufficient capacity to produce [illegible] amount of the fertilizer needed. Conversely, [illegible] develop a domestic fertilizer industry may [illegible] justified therefore even though the cost of [illegible] produced fertilizers might be high, at least initially.

K. FINANCING THE DEVELOPMENT OF A FERTILIZER INDUSTRY

The financial feasibility of importing the required fertilizers must also be weighed against that of developing a fertilizer industry. In countries which are industrially less developed, much of the capital equipment required must be obtained from abroad. Depending on local circumstances, between 25-50 per cent of the total investment must generally be spent on imported capital goods. In countries with little or no basic industries, the proportion could be even greater. For the development of a fertilizer industry, therefore, large amounts of foreign exchange will also be required. Again using the example of India, if all fertilizer supplies were to be domestically produced, total plant investment by 1980 might well reach 2,500 million dollars. Assuming that one-third of the total might be required to import capital equipment, nearly 1,000 million dollars of foreign exchange would be needed.

Even though additional foreign exchange might be required to import some of the raw materials essential to the production of fertilizers, total requirements of foreign exchange are likely to be far less than if all fertilizers were to be imported in future years.

L. OVERCOMING CAPITAL SHORTAGES

In view of the shortages of domestic capital, particularly of the foreign exchange required for importing equipment, developing countries may be somewhat dependent on foreign investments to finance such capital expenditure programmes as the development of a fertilizer industry. Possible external sources of capital are international organizations (e.g., the World Bank and the Inter-American Development Bank), the Governments of more capital-intensive countries, or private industries of the more advanced free-enterprise nations. In some of the developing countries, however, investment opportunities are not yet sufficiently attractive to induce private investment from the industrially more developed countries. Where danger of nationalization of private enterprise is high, inflation is rampant, profit potentials are restricted or withdrawal of profits by the foreign investor is prohibited, conditions discourage foreign investors. There is little doubt that many of the developing countries could attract far greater amounts of capital if conditions were more conducive to foreign investors. In some instances, governmental actions have been or are being taken to

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[8] Considering that 1 ton of fertilizer will frequently produce 8 to 12 tons of grain, some countries might gain by importing more fertilizer and less food. At existing world fertilizer and food-grain prices, the same expenditure of foreign exchange might result in a larger total food supply. In other words, where foreign exchange earnings are limited, it is frequently preferable to allocate it to the importation of capital or producer goods rather than consumer goods.

ease import restrictions, to provide tax concessions to investors, to ensure adequate supplies of low-cost power or by other means to provide increased incentives to private investors. The tendency exists for investments to be attracted to those countries which offer the least risk and the greatest potential for profit. In other countries, private investments in fertilizer plants may be limited unless governmental action is taken to stimulate and promote the development of the fertilizer industry.

M. Political-economic considerations

For nationalistic reasons many newly developing countries, particularly those having recently gained independence, are likely to favour the growth of the fertilizer industry, somewhat irrespective of economic considerations. The desire to be as free as possible from a dependence on world trade and from the political dependencies that may arise, may sometimes be regarded as more important than other factors of a more immediate economic nature. Even then, however, the rate of progress in the development of an indigenous fertilizer industry will depend on the adequacy of the capital available for this purpose from both domestic and external sources. The interplay of political forces which may influence international trade relationships may encourage or discourage both local and foreign investments. Thus, political considerations are almost certain to be a factor affecting decisions to import or to produce the fertilizers required.

Decisions based primarily on political considerations will, in most instances, have long-run implications of an economic nature. Development of a fertilizer industry based on the infant-industry argument may sometimes prove to be justified from an economic viewpoint when longer time periods are considered. In the early stages of development of a fertilizer industry, inefficiencies may cause the industry to be unable to meet world competition. With the passage of time, however, a well-directed fertilizer industry, even though uneconomic in its infancy, might achieve a sufficient level of strength and efficiency to become economically sound. On occasion, therefore, political-economic arguments may prove over time to have economic validity.

In any case it must be acknowledged that political considerations must be taken into account in the development of plans to provide the necessary fertilizer supplies, either through importation or domestic production. At the extreme, it is possible that political considerations might lead to establishment of an indigenous fertilizer industry quite irrespective of economic considerations. More generally, however, the effect of political factors may be only to impose limitations within which criteria of a more direct economic nature become operative.

N. Regional co-operation

In areas of the world where smallness of national markets makes the cost of domestically manufactured fertilizers high, regional co-operation among countries can serve as an effective means of promoting economic development. Co-operative planning and development of a regional fertilizer industry may permit, in some instances, full exploitation of the economies of large-scale production, which could not be achieved if each such country were to strive independently for self-sufficiency in its fertilizer supply. For this reason, countries within a region, each of which has too limited a requirement for any of the basic fertilizer nutrients to permit construction and operation of large-scale fertilizer plants, might well investigate the possibilities of the joint development of fertilizer projects which would permit exploitation of the economies associated with large-scale production. Net gains might well be realized by all partners in such a co-operative venture. Not only would unit cost of production of fertilizers be reduced, but total capital investment would be less than that required if each country independently attempted to become self-sufficient in its fertilizer supply. Such co-operative ventures may take either of two forms: (*a*) capital and other resources might be pooled and facilities constructed on an agreed site; or (*b*) trade agreements might be negotiated whereby fertilizers produced in one country might be exchanged for other products from neighbouring countries. In any case, such co-operative endeavours, wherever they can be successfully negotiated, offer opportunities to all member countries for more rapid development of an efficient fertilizer industry.

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IV. DEMAND FOR FERTILIZERS

World consumption of chemical fertilizer nutrients for 1963/1964 was 36,380,000 tons, compared with the 1953/1954 consumption of 17,800,000 tons (1). The increase in consumption over the ten-year period was at a compounded annual rate of 7.4 per cent. In 1963/1964, the developed countries consumed 90 per cent of the nutrient tonnage and their compounded annual ten-year rate of increased consumption was 7.0 per cent. In contrast, the annual increase in consumption, compounded yearly, was 11.6 per cent for the developing countries.

The purpose of this chapter, however, transcends an analysis of current consumption rates and trends. The purpose, in short, is to discuss how to obtain an increased demand for fertilizer for use in increased food production, particularly in the developing countries.

A. FERTILIZER CONSUMPTION GOALS

Just how much increased demand for fertilizers is needed? The answer appears to be a matter of meeting future consumption requirements. To gauge somewhat the magnitude of how much the increased demand for fertilizer may be, one may consider briefly the fertilizer consumption levels to be expected in 1970 and 1980 if world consumption of fertilizers increases at the 1954-1964 growth rate. At this rate of increase, 56.4 million tons would be consumed in 1970 and 117.9 million tons in 1980. In other words, consumption in 1970 could be 30 per cent above current levels and three times as high by 1980.

The pattern of increased world consumption of fertilizer will shift considerably in the future. Of necessity, there should be a greater percentage increase in consumption in the developing countries than in the developed countries. The spread in the rates of increase — 7.0 per cent *versus* 11.6 per cent during the last ten years — will become more marked as time passes.

Most developed countries are already applying large quantities of fertilizer per unit of cultivated land. Some are producing surplus food-supplies for export. Producers of export surpluses may find future prices such that increased applications of fertilizer per land unit may result in reduced profits. At the same time, it seems evident that the developing countries cannot expect to increase their food imports to the point that the bulk of their food-supplies will be imported.

In view of the increasing food requirements of the developing countries, the real question is not so much one of world fertilizer needs, but rather one of what the developing countries will need. Estimations of their future food requirements must be based on assumptions relating to population growth, *per capita* income levels and dietary needs. Fairly firm estimates, which consider all three factors, of food requirements of the developing countries in 1970 are not available (2). Even so, reasonably reliable fertilizer consumption estimates for the future are difficult to make because of the lack of average data on fertilizer crop response for countries and crops. Therefore it seems preferable to study fertilizer consumption goals on the basis of projections of recent consumption trends including adjustments for decreasing rates of increases in fertilizer consumption in developing countries.

On the basis of the past growth rates shown in table 14, the developing countries would consume 7.1 million tons of fertilizer in 1970 and 21.4 million tons by 1980. The rates of increased consumption necessary to achieve such consumption in 1970 and 1980 in the developing countries would not appear to be excessive, although, no doubt, they will be challenging.

TABLE 14. FERTILIZER CONSUMPTION IN 1964 AND ESTIMATED CONSUMPTION IN 1970 AND 1980, BASED ON ASSUMED COMPOUNDED RATES OF INCREASE FOR THE DEVELOPED AND THE DEVELOPING COUNTRIES

Area	*Consumption 1964 (thousands of tons)*	*Compounded rate of increase 1954-1964 (percentage)*	*Estimated consumption (thousands of tons)*	
			1970	*1980*
Developed countries[a]	32,684	7.0	49,255	96,490
Developing countries[b]	3,696	11.6	7,140	21,397
WORLD	36,380		56,395	117,887

[a] Including Canada, Europe and all of the Union of Soviet Socialist Republics, Japan, Oceania, South Africa, the United Arab Republic and the United States of America.

[b] Including all of Africa, Asia and Latin America, but excluding the developed countries listed in foot-note *a* and mainland China, North Korea and North Viet-Nam.

Estimates of future fertilizer consumption in the developing countries vary widely. Steward estimated fertilizer consumption at 28.3 million tons in 1980, without any attempt to tie his estimate directly to food requirements (3). Brown placed the fertilizer consumption need at 34 million tons in 1980 for the developing countries based on certain assumptions with regard to food requirements and the grain response to fertilizer (4). Brown's estimate, which is the higher, includes all of Asia, whereas Steward's excludes mainland China and Japan. However, both estimates point up the general magnitude of desirable fertilizer consumption levels for the developing countries. Thus, one must conclude that a consumption level of over seven times the 1964 level appears to be feasible by 1980.

1. [illegible] affecting [illegible] demand [illegible]

It is one thing to develop [illegible] fertilizer consumption goals for developing countries. It is quite another thing to achieve such increases. In the first place, the basic objective is increased food production. This means that the primary concern is with increasing the farmers' demand for fertilizers to use on staple food crops. Thus, one makes a delineation between food and non-food crops. It may be much easier to obtain greater and hence increased demand of fertilizer on non-food crops, such as certain export and high value crops, than on staple food crops.

In the second place, the transfer of an idea originating with a few relatively advanced officials to a large heterogeneous group is always difficult. For example, in India, a few planners and policy makers are responsible for developing fertilizer goals for the country. Moreover, before these goals are translated into an effective demand for fertilizer to use on food crops, about 65 million cultivators must be convinced that it is to their benefit. This is the translation problem in every developing country.

In the third place, it must be economically advantageous for the farmer to use fertilizer. If it is, he still must be convinced before he enters the market and creates a demand for fertilizer.

In general the factors conducive to increased production of food crops in a developing country are also conducive to increased fertilizer consumption. Some of these factors affect fertilizer demand only indirectly, hence they may best be discussed more fully in a general production treatise. Such factors include sound crop-pricing policies, equitable tenure systems, adequate crop storage, transportation and marketing systems, many types of research, adequate and reasonable credit, the availability of consumer goods, the availability of essential modern technological inputs in addition to fertilizer and the education of farmers in modern farming methods.

To demonstrate just how these indirect production factors may influence the demand for fertilizers, a few aspects of these factors have been selected for illustrative purposes: (*a*) food price controls at levels favourable to consumers, (*b*) farm credit policies, and (*c*) the consumer goods appeal to farmers.

The practice of protecting the consumer through quite low retail prices of staple food products, set by the Government, is quite common in developing countries. This political expedient (of low prices for urban consumers) means either unattractive farm prices or government farm subsidies as offsets. To induce increased farm production, farm prices must be at levels high enough to give farmers an incentive to produce. By the same token, farm prices of food products must be high enough to make it advantageous to use fertilizers before the demand for fertilizers can be expected to increase.

Where commercial inputs for farm production are essential, pre-output financing is necessary for many farmers in most developing countries. Sound production credit principles have been fairly well established in most developed countries. Adequate, timely, organized credit [illegible] generally [illegible] of an [illegible] scheme. The point here is that [illegible] credit must be available before many farmers in developing countries can and will buy fertilizers. Inversely, lack of credit may limit the extent to which the demand for fertilizers may be increased.

In economic development literature, one of the conditioning factors often considered highly desirable in the interest of increased agricultural production for the market is that of an adequate supply of consumer goods in the local producing areas of the developing countries. Relatively inexpensive goods when locally available and on display create an incentive to many farm families to produce more for the market. If this desire to buy consumption goods is sufficiently strong, then the demand for fertilizers may be increased as a means to an end. A brief elaboration on the salient aspects of this factor is discussed in section H of this chapter.

2. *Factors affecting more directly farmers' demand for fertilizers*

The remainder of this chapter is devoted to a discussion of the factors which have a more direct bearing on the demand for fertilizers. The emphasis is on how to increase the demand for fertilizers for the purpose of increasing food production in the developing countries. While the approach is essentially positive, it has been deemed advisable to delineate somewhat as to the relative effectiveness of the different measures.

3. *Possibility of demand being limited by fertilizer supply*

Limited supplies of fertilizers in a given country may have the effect of limiting the effective demand. Obviously, even though a potential demand exists, actual purchases are limited by the amount of fertilizer which is imported and produced domestically. When supplies of fertilizer fall far short of the total demand in a country, food-crop applications are likely to suffer, compared with applications of fertilizer on non-food crops, which are produced on a comparative economic advantage basis. While in the strictest sense, fertilizer supplies are not determinants of the demand for fertilizer, such supplies are crucial.

A programme to increase the demand for use of fertilizers on food crops may well give early consideration to problems of supply. Several years may be required before adequate supplies are assured. The timing of intensive educational programmes to persuade farmers to use fertilizers must the synchronized with the time when fertilizer supplies will be consistently adequate, year after year.

4. *Fertilizer statistics and analyses essential*

Fertilizer statistics and their economic analyses are essential tools in the process of stimulating fertilizer consumption. Development of the demand for fertilizer in a country should proceed along sound economic lines, and this is practically impossible without adequate, reliable data. Current and continuing analyses, objective in nature, of pertinent data serve as a bridge of understanding between planner and farmer. Confidence of the producer that it pays to use fertilizer may derive from this understanding, on the other hand, the objective analyst has the responsibility of pointing out the pitfalls which the individual farmer may need help in avoiding.

Among the special services that Governments of developing countries may provide are the collection, analysis and reporting of essential agricultural statistics. These serve as the basis for estimating the current demand for fertilizers and permit sounder long-run planning. Minimum statistical requirements cover: (a) fertilizer supply data — sources, types, costs and prices, stocks and distribution; (b) crop production data — acreages, yields and production; and (c) prices and values — prices received and paid by farmers and farm output distribution and values.

In addition, there is great need of microeconomic studies covering crop and grazing-land responses to fertilizer applications, the interrelationships of modern technological applications or the lack of them, and other economic research needed for analysis and planning.

It may be desirable for an agency in the Government of each developing country to have the responsibility of analysing fertilizer problems and needs. The need for objective analyses to serve as basis for policy determinations is so great that such analyses cannot be left to chance. A blueprint for such a governmental agency will have to be worked out in terms of local conditions. It is suggested that such an agency should have status, a dependable budget and the opportunity to operate objectively.

What are the functional areas of such an agency? First, there is need to know the current effective demand level for fertilizers. Each year, careful planning must anticipate total and local fertilizer needs, delivery and storage problems, and credit requirements well in advance of the periods of application. The fertilizer industry determines and meets the current demand satisfactorily in most developed countries. Methods developed in Japan and Taiwan may have value in several of the developing countries.

The Japanese have a built-in method of determining effective annual demand for fertilizer through their method of organizing and financing fertilizer distribution. The system works as follows:

> "... Advance orders are placed by farmers with their buraku and village co-operatives. In placing his order, the farmer applies for a loan against the security of the proceeds of his coming rice crop (which must be marketed through the co-operative). With this loan, credited to him in his account with the co-operative, he pays for the fertilizers when received. The co-operative in turn issues a promissory note to the prefectural credit federation, using the farmers' loan certificates as collateral. The prefectural credit federation discounts these promissory notes at the Central Co-operative Bank for Agriculture and Forestry, which when necessary uses them to obtain loans from the Bank of Japan. Thus the individual co-operatives and the prefectural association need virtually no funds to handle fertilizers, while the co-operatives are able to offer a large and secure order to fertilizer manufacturers. When each individual farmer's rice is marketed through the co-operative, his loan is paid off as a first charge against his proceeds ..." (5).

This plan of operation promotes [illegible] assures availability of fertilizers [illegible] carries considerable [illegible] use fertilizers through its credit and [illegible] features.

In Taiwan, the farmers sell rice to and buy fertilizers from farmers' associations. At harvest, a farmer exchanges a bag of rice for a given amount of fertilizer to be used on his next rice crop.[1] The system obviates both cash and credit, assures the farmer his fertilizer supply ahead of planting time and eliminates the risk of a drop in the price of rice at harvest. The farmer's early "purchase" of fertilizer forces the national analyst to estimate the effective demand immediately after the consumption data for the preceding crop are available. In Taiwan, fertilizer consumption statistics emerge as a by-product of the distribution system.

Secondly, besides current demand analysis, there is the larger area of analysis of fertilizer price, demand and supply, with special emphasis on long-run and planning aspects. Continued research of physical crop responses to fertilizers is essential, taking into consideration all potentially significant variables. Equally essential are the economic interpretations of results of physical research. The economics of fertilizer analyses, however, must go much further and serve as a discipline in bringing into proper perspective all the factors bearing on sound and efficient fertilizer use.

Thirdly, there is need for an outlook and forecasts pertinent to fertilizer supplies, application trends and food production prospects. Long-run planning, in terms of effective demand projections, should be predicated on sound analysis — not on expedient political objectives.

How far a new developing country can go in increasing the demand for fertilizer is problematical. It is certain that a statistical and analytical agency is essential as a part of the process, but its size and scope will be dependent on funds and its effectiveness on the availability of trained personnel.

5. *Effect of price levels and policies on fertilizer consumption*

Low unit fertilizer costs paid by farmers and high unit food-crop prices received by farmers are, in general, favourable factors conducive to the increased use of fertilizers. The former affects the denominator and the latter the nominator in the crop value/input cost ratio. Governments may set or control prices and, to this extent, they influence the ratio and in turn affect the demand for fertilizer. Also, Governments sometimes influence fertilizer costs and farm prices through the use of subsidies.

It does not follow, however, that all price-control and subsidy measures are equally effective in the influencing of fertilizer applications on food crops. The competitive situation between producers of food crops and producers

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[1] For several years, it was a matter of one bag of ammonium sulphate for a bag of rice. More recently, the farmer has been getting a slightly better exchange. See Food and Agriculture Organization of the United Nations, *The State of Food and Agriculture* (Rome, 1963), chapter IV, p. 29.

[illegible] developing countries.

B. [illegible]

Currently, fertilizer prices at the farm gate average considerably less in the developed countries than in the developing countries. Most of the plant capacity is still located in the former countries, notably in western Europe, Japan and the United States of America. Transportation and handling costs, plus the low volume of the import purchases, largely account for the higher unit costs of fertilizers in the developing countries. It is highly desirable that steps be taken to reduce fertilizer costs where it is most badly needed because obviously lower fertilizer prices will stimulate increased total consumption and probably increase the demand for fertilizers to use on food crops.

There is considerable evidence indicating that some downward trend in average world prices of fertilizers at the farm-gate is likely over a period of years. Unit production costs may decline somewhat with greater use of mass production techniques. Improved production techniques *per se* also point towards lower unit costs.

Moreover, a relative increase in fertilizer production in or near the developing countries is likely. To illustrate, association of new fertilizer plants with oil and gas fields in Asia Minor, and Africa may offer competitive possibilities as new nitrate sources. Greater utilization of phosphate rock and potash deposits in Africa further illustrate the point. The net result should be at least reduced transportation costs. Even greater reductions in transportation costs may result from locating new plants at inland points near fertilizer consuming areas — if otherwise feasible — because of the high cost of land transportation.

As developing areas now using very limited amounts of fertilizer expand their rates of consumption, farm prices in such areas should reflect substantially lower unit costs because of increased efficiencies and lower profit margins. Application of mass methods in fertilizer distribution, as well as in production, make for substantially lower unit prices to producers.

C. Effects of fertilizer subsidies

Governments of developing countries often have fertilizer price-control programmes, including subsidies, for the purpose of promoting increased fertilizer consumption. Greater use of such programmes is likely as pressures for increased food production mount. These controls and subsidies vary from country to country, more in form than in general intent.

Several types of fertilizer subsidies are used. A country may attempt to maintain farm-gate prices at the same level throughout the country by subsidizing transportation costs. Another country may attempt to promote larger domestically produced supplies by subsidizing an infant fertilizer industry. Still another country may aim directly at increased food production by subsidizing only the fertilizers to be used on specified food crops. Again, certain types of fertilizers may be subsidized while others [illegible] and. Perhaps the [illegible] subsidize all fertilizers [illegible] on the basis of an [illegible].

As a developing nation seeks to increase the effective producer demand for fertilizer as a means of increasing farm production, it often seems both politically and economically expedient to resort to subsidies. However, once a subsidy programme is begun, it becomes politically difficult to phase out. Likewise, there may be fear that fertilizer consumption, and hence agricultural output, would decrease if subsidies were discontinued. If fertilizer is subsidized, then should the other inputs, such as improved seeds, plant protection chemicals and small equipment, also be subsidized? The administration of several subsidy programmes may become quite involved. Moreover, payments of subsidies tend to place a heavy drain on government finances.

From a national policy point of view, sound fiscal and economic policies require assurance that a farm subsidy more than pays for itself in increased farm productivity. The primary objective of subsidies being discussed here is to obtain increased food production, as distinguished from non-food production. Possibly such a subsidy may accomplish its objective less well than a subsidy with the objective of increasing total agricultural production.

The effectiveness of fertilizer subsidies aimed at increasing fertilizer consumption, and hence demand, for the express purpose of increasing food production is largely dependent on two things: (*a*) the competitive demand for fertilizer among food and non-food producers, and (*b*) the extent of the fertilizer supply available for the entire farm market in the country. A general fertilizer subsidy reduces unit costs of fertilizer to all producers. If the fertilizer supply is limited, however, a bidding up of prices may occur, with the result that producers with the most favourable crop value/input cost ratio obtain most of the fertilizer on the market. The subsidy thus is partially offset and the highest bidders use the fertilizer.

Most food crops are not ordinarily classified as high-value crops. In many instances, they are not classified as primarily cash crops, and there is little demand for fertilizers for use on non-cash crops. Traditionally, export crops have consumed most of the fertilizer used in developing countries. They are generally classified as high-value crops, though less so as world surpluses of export crops depress their prices.

Substantial applications of fertilizer on food crops produced for sale may occur if unit prices received by farmers for them are sufficiently high. The very high Japanese farm price for rice illustrates how a minimum price was set high enough to account partially for making rice a high-value crop in that country. Of course, fertilizer was in good supply. However, it should be noted that Japan placed rice producers in a favourable competitive position to buy fertilizer without a direct subsidy; instead, Japan subsidized the retail price of rice.

Another factor in fertilizer use is the crop response to fertilizer applications. Responses vary considerably among the different crops, as do responses for the same crop in different areas. Responses to applications of fertilizer on rice have proven very satisfactory in Taiwan, hence the demand for fertilizer for rice is substantial[2] A subsidy in this case can be effective in increasing per hectare applications, provided the fertilizer supplies are available.

Specialized subsidies on fertilizers earmarked for use on food crops probably will not result in appreciable increases in food production because such earmarked fertilizers may be diverted. For instance, rice and maize farmers in the Philippines are assured of a profit by selling their subsidized fertilizer purchases intended for rice and maize to sugar-cane producers at a price somewhat below the price sugar-cane producers have to pay on the open market

Rationing of a short supply of fertilizers, with or without subsidies, has also been advocated as a method of assuring the use of fertilizers on food crops. If not diverted, the effect could be to increase the demand for fertilizers for food production. However, the same diversion tendency, as in the case of fertilizers specially earmarked for food crops, exists because of the higher marginal value of fertilizer to producers of high-value crops.

The value of fertilizer subsidies as a tool for increasing the demand for fertilizers to use on food crops is not altogether clear. Fertilizer subsidies are likely to vary considerably in the extent to which they influence food production. What is the position on subsidies on other cash inputs ? Perhaps there are other approaches to inducing producers to increase fertilizer applications and the use of other inputs on food crops which are more soundly based in economics.

D. EFFECTS OF HIGHER FOOD CROP PRICES

Another government policy tool for stimulating increased fertilizer use on food crops, available to the developing countries, is commodity price controls or price supports. Best understood by the farmer, perhaps, is a guaranteed minimum unit price for a farm commodity, payable on delivery at a local point. When the minimum guaranteed price is sufficiently high, it offers a strong economic inducement to producers to use fertilizer and related inputs.

The major drawback is that the low-income urban population tends to be priced out of the market, and this has political repercussions when staple foods are involved. Subsidizing of staple-food prices for consumers may be a necessary complementary policy

Space precludes a detailed survey of farm pricing policies of the developing nations. It suffices to note that there are many price controls of one sort or another affecting the producer's returns for his crop or crops. However, not many price controls or guaranteed minimum prices are set at levels distinctly favourable to producers throughout a country[3]

A minimum producer price on a staple food crop, set at a low level favourable to consumers, is not likely to result in increased market supplies. In fact, producers are likely to remain resigned to producing primarily to supply family needs. Thus, if the price is quite low, even though all other factors are favourable, there is little basis for assuming that a substantial demand for fertilizers for use on crops can be created

A guaranteed minimum producer price set at higher levels is increasingly more conducive to increased farm production, which is the basis for a demand for fertilizer and related inputs[4] This is so because higher producer prices for a crop result in a more favourable crop value/cash input cost ratio. Just how high producer prices for food crops must be to accomplish the increased fertilizer/higher production result is likely to be different in each country. A trial-and-error period of several years may be required in most countries

Three aspects of set or guaranteed minimum producer prices perhaps deserve some comment because they may have a bearing on the demand for fertilizer. The first is that of price stability *per se*. Some literature in development economics supports the contention that an assured producer price, especially in the general medium range, has considerable appeal to farmers because of the elimination of price uncertainties. This seems reasonable and some increased marketings may even occur at fairly low crop-price levels. However, these marginal increases in production are likely to occur without the use of such valuable, but costly, inputs as fertilizer and plant-protection chemicals. Once the crop price level is high enough to provide an attractive crop value/input cost ratio, there is a basis for expecting an increase in the demand for fertilizer and the related inputs. Perhaps, one must conclude that both assurance and level are essential producer-price ingredients in terms of the objective of increased fertilizer/higher food production

Secondly, there is the point that guaranteed minimum prices must be applicable throughout the year. Of course, they may be scaled to cover differences in short- and long-time storage. The most important marketing time immediately follows the harvest, and this is when "guaranteed" minimum prices must be effectively sustained. A breakdown of such a price programme is likely to have negative effects on the demand for fertilizer

Thirdly, a producer price policy, if it is to be effective in increasing the demand for fertilizer, requires backstopping. If a Government guarantees a price, it must be prepared to buy in at that price most of the crop offered for sale. This calls for many things — payments, handling, storage crop flow, grades and standards — all of the

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[2] Use of modern technological inputs and practices in rice production in Taiwan largely account for the high crop responses to fertilizer applications. This did not come about in a day. Much research and many demonstrations were involved over a period of many years. Basically, it has been a matter of educating farmers in modern farming practices. Other developing countries may not be as far along in these matters.

[3] The exceptions of Japan and Taiwan in the case of rice have previously been noted. Japan has made such progress that it is no longer classified as a developing country

[4] No attempt has been made to define "low" and "high" prices. These are relative terms. The level of what would be considered low producer prices for rice in Japan and the United States of America, for example, might still be substantially higher than prices received by farmers in recent years in Burma and Thailand

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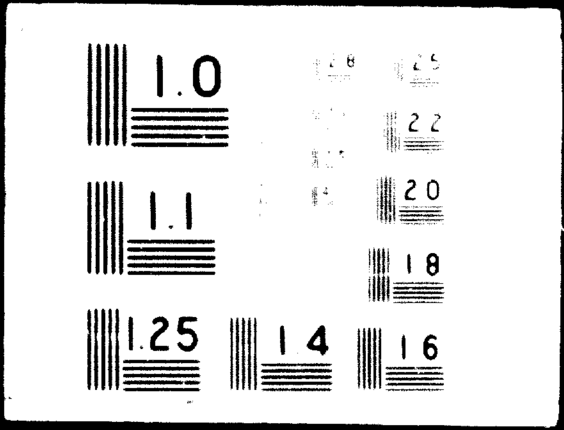

things involved in the orderly marketing, financing and management of such programmes. The demand for fertilizers can be very adversely affected because of the risk and loss of confidence by producers if a crop price policy is ineffective through lack of backstopping.

In broad economic development terms, in a developing country, with the bulk of its people engaged in agriculture, neither economic growth nor improved general welfare is probable without increased farm production. Hence, increased production, particularly of food crops to replace food imports, takes high priority. What are the tools for accomplishing this basic objective? Certainly, a realistic approach may well involve farm price levels for staple foods high enough to induce producers to apply fertilizers and the other modern technological inputs.

E. THE CREDIT ASPECT

Farm production credit was discussed above as an essential factor in production economics. Certainly, producer credit for financing farm operations in general would seem essential in almost all countries, and it would seem crucial in the developing countries in the financing of purchasers of fertilizer and other related inputs. Country X has taken many steps to increase food production, including an extension programme to educate farmers in the use of fertilizer. Reports from that country indicate that farmers cannot finance fertilizer purchases. Thus, this one omission may be the main factor limiting increased food production.

Attention is called to section D of this chapter, where some policy and organizational aspects of fertilizer financing are discussed.

F. EDUCATION OF FARMERS TO USE FERTILIZERS ESSENTIAL

In a sense, the preceding discussion has been concerned with the development of favourable factors and conditions under which producers have a chance of profiting from fertilizer applications, especially on food crops. The final step in increasing the demand for fertilizers is to convince producers that it is to their advantage to use fertilizers. This is a large task because of the difficulties of overcoming the problems of illiteracy, adherence to traditional farming practices, controlling mores and social customs, lack of applicable research, lack of trained leadership and governmental and resource deficiencies.

To persuade, sell and convince individual producers to use more fertilizers, and hence, to create a demand for it, because it helps produce more food, is largely a matter of education and research. What does the farmer need to know about fertilizers, and what are the ways through which he can be convinced that it is to his self-interest to use fertilizers?

A programme of "fertilizer" education involves several objectives. First, the farmer needs some basic understanding about the place and value of fertilizers. How plant nutrients are replaceable, characteristics of the primary and, to a lesser extent, the secondary and minor nutrients, problems of leaching and fixation, why balanced applications are essential and some idea of fertilizer usage in other areas — all are parts of this basic education.

Secondly, understanding of the interactionary nature of fertilizers is important and, in turn, the interactionary relationship of fertilizer with the other modern technological inputs and practice, e.g. improved seeds, plant protection chemicals and practices, irrigation and drainage, and improved cultural practices. The fact that these practices may be limiting factors to crop responses to fertilizer means that producers must include them, as far as practical, in their new technology.

Thirdly, the farmer must have sound advice and guidance in applying fertilizer and the other inputs to local conditions and on his own soils. Just as the farmers' general education about fertilizers is based on research, the advice he gets about applying modern technology to his own soil and crop problems must come largely from research. Lack of such localized research may be the weakest link in the educating process.

Fourthly, the producer needs analytical data showing probabilities of costs and physical and monetary returns resulting from his applications of fertilizer and other inputs, and information on the mechanics of credit, fertilizer deliveries and marketing procedures. Obviously, such localized servicing requires numerous well-trained advisors in a developing country.

A serious effort to achieve these educational objectives requires long-range planning and involves large budgets, organization, capable personnel and the use of many different educational media and teaching techniques. Adequate budgets and capable personnel are self-explanatory and will not be discussed here. It suffices to note here that developing countries must anticipate these problems or else their "fertilizer" educational programmes may prove largely ineffectual.

Many countries currently have an extension service which may be utilized to carry the major responsibility for educating farmers about the value and use of fertilizers. Where such an organization exists, it is likely to have the best set of resources, including trained personnel and a knowledge of sound teaching techniques, to do this rather specific teaching job.

Because of the importance of educating farmers abou fertilizers, the subject is given further treatment in section J of this chapter. Emphasis is given to three things: (*a*) organization and responsibility with special reference to extension services; (*b*) teaching media and methods; and (*c*) the steps involved in getting a farming practice adopted.

Utilization of agricultural youth clubs, known as 4-H Clubs in the United States of America, to educate young farmers in the value and use of fertilizers, may have special merit. This approach can be thought of as a corollary or a supplement to the main educational approach. The adaptability of youth to new ideas is an important psychological consideration. The association of profitable returns from increased food production with the ability to buy some locally available consumer goods may have strong appeal to farm youth.

Working through young farm people, step by step, to obtain greater use of fertilizers is a way of convincing older people, as well as the young people themselves. When supported by local adult leadership the effects of 4 H Club programmes can be very far reaching

In recent years, the Food and Agriculture Organization of the United Nations (FAO) has developed a world-wide programme of field trials and demonstrations in fertilizer use under farm conditions. The main purpose has been to convince the farmer and his neighbours of the value of fertilizer applications through (a) comparisons with adjacent control plots, (b) measurement of actual crop yield responses to the fertilizer and (c) calculation of crop value returns (monetary) in proportion to the total costs of the fertilizer. Demonstrations have been going on in India under a similar programme for over thirteen years. The FAO programme under the Freedom From Hunger Campaign (FFHC), began in 1961 and now extends to eighteen countries in three developing regions of the world. The numbers of such trials and demonstrations carried out in the five years of the programme vary from a few hundreds in countries like Dahomey and Togo to many thousands in Nigeria and Turkey. Mimeographed reports from FAO are available, showing the results of these trials and demonstrations, the analysis of which is now proceeding.

G. ROLE OF THE FERTILIZER INDUSTRY

It is worth noting that in working towards an increased farmer demand for fertilizer to apply on food crops in developing countries, the private fertilizer industry has much to offer. Contributions in research, in both production and distribution methods and techniques, in more concentrated plant-nutrient packages and in selling and counselling farmers, continue to come from fertilizer associations, corporations producing and marketing fertilizers and individuals associated with the industry.

The Freedom From Hunger Campaign has enlisted the co-operation of other international organizations, national Governments, citizen groups and various non-governmental organizations. Among the non-governmental organizations, that of the fertilizer industry has become a valuable collaborator in promoting fertilizer use to increase food production. Among other things, the industry in the developed countries possesses capital and other assets capable of partial utilization in the developing countries. Further, in the FAO programme, there is recognition that the private fertilizer industry has much experience and know-how in both production and marketing. Especially to the point, with regard to ways of increasing the demand for fertilizer, is industry's experience and know-how in the marketing of its products.

Competition among fertilizer companies, as in the United States of America, has been very salutary. It has forced efficient and aggressive marketing. The volume marketed is always an important factor in analysing profits. For this reason, local, area and district salesmen direct educational programmes in trying to interest both individuals and groups of farmers in the use of fertilizer.

Fertilizer salesmen, to be effective, must know their products, be up to date in research results and be reasonably acquainted with the plant-food needs of the various local soils. Their very aggressiveness makes them valuable in the educational process of teaching farmers to use or to use more fertilizer.

In general there is little danger of private fertilizer company salesmen overselling farmers. First, farmers have a built-in resistance to applying fertilizer at optimum rates. Secondly, the fertilizer companies have long-run and long-time profit objectives. They cannot afford mistakes, hence, the advice given to farmers is carefully screened. Repeated farmer buying of fertilizers from the same company, year after year, is likely to be based on confidence.

Naturally, it is to the interest of business firms producing, distributing and selling fertilizer to farmers to push sales. For best long-run results, they have educational programmes that demonstrate the economic benefits of fertilizer use when instructions and advice are followed. Such educational programmes are found in the western European countries, in Japan and in the United States of America. Developing countries may well encourage the fertilizer industry, as well as FAO, to run similar educational programmes in fertilizer use, whether or not each Government's own educational and promotional programme is considered adequate. Utilization of as many sound teaching avenues as possible is needed to educate farmers to use, and to use more fertilizer.

H. THE CONSUMER APPEAL

An adequate supply of consumer goods in local producing areas may offer an incentive or a psychological inducement to farmers to produce more for the market. The local availability of consumer goods and services suggests to farm people that they can share in the economic benefits of increased farm output.

Such consumer goods should be selected in terms of value and appeal, and prices must be low enough that they are within the means of the low-income population strata. To illustrate, much publicity has been given to the transistor radio. It is said that it has become so widely used in many low-income areas that the definition of illiteracy needs modification. Items of personal adornment, simple musical instruments, clothing, hand-tools and simple hardware, picture-books, aspirin and many other things may have appeal and be within the means of the emerging subsistence farmer and his family. As purchasing power increases, more expensive items will have appeal, for example, bicycles, sewing-machines, better clothing, dishes, wrist watches, wedding jewellery, simple pieces of furniture and durable toys.

One further point is that some planning by Governments may be required, depending on how far private initiative goes in making such consumer goods locally available at reasonable prices. A few carefully selected items displayed and retailed through co-operatives or local governmental offices may be necessary to develop interest and, it is hoped, to lead to increased crop production for the cash market.

I. PRODUCER CREDIT

What are some of the policy and organizational aspects of providing credit for producer purchases of fertilizer?

It is clear that careful planning is necessary. The most essential part of the machinery for processing farm production credit is, perhaps, the local offices or agencies. Multipurpose co-operatives are given high priority by many as the preferred type of local agency. While the village or combination village agency need not necessarily be a co-operative, the agency must operate efficiently and have a low overhead if producers pay the operational costs.

The local credit agency may well be part of a larger local agency which stores and distributes fertilizers, seeds, insecticides and other inputs, and then buys and moves the farmers' products to market. The exact pattern is not so important. Efficiency and maintenance of low overhead operational costs at the local level are the important things.

One aspect of credit, which ties in with the producer's repayment ability, is that of qualifying producers for loans. All the preliminaries for processing loans can be well out of the way long before the lending season starts. This includes, of course, clearance of loan regulations and eligibility rules. Good practice requires that loan applications, accompanied by fertilizer requirements, be processed weeks ahead of the actual crop-seeding time. A farmer is entitled to know well ahead of any fertilizer delivery date if his loan has been agreed to.

Knowledge of the local demand for fertilizer weeks ahead of the last deliveries will allow last-minute adjustments in local supplies. Advance notices to national distribution centres will allow the making of some corrections of imbalances within the nation.

J. ORGANIZING AND TEACHING FARMERS

A dedicated organization, or organizations, is essential in promoting farmer education in fertilizer usage. More than one organization may be required because the educational process involves teaching and demonstration, as well as research. Efficient use of existing governmental agencies may be possible. At the same time, the fertilizer industry itself may play an important role in the educating process.

It may be desirable to limit assignments to each organization to those parts of the educational programme which each is most capable of executing well. A local co-operative can do much, for example, but it can scarcely replace the agronomically trained "county" agent in technical matters. Workshops in India for local village leaders are useful, but short courses do not make trained technicians who are capable of advising individual farmers about precise fertilizer applications.

The extension service is a widely recognized type of organization for teaching, advising and serving farmers. Such an organization may well be a part of the answer to the question of how to educate farmers in fertilizer use if it is adapted to the conditions and needs of the country. Quite often, research in fertilizer response is conducted by a research agency of a State or the central Government's ministry of agriculture. Again, the research may be under university or agricultural college auspices. Which governmental agency carries the responsibility for agricultural extension and research is not too important so long as there is freedom of action. It is highly desirable to dissociate extension and research from compulsory policies and police methods. Of course, it is most desirable that the programmes be practical and be pursued objectively.

In between teaching and research is the area of examples, models and testing. This is the area of demonstration plots and farms, field-trials, pilot studies, soil laboratories and soil testing. The extension service often carries the responsibility for performing these functions, except, possibly, the operation of soil laboratories. Again, the exact nature of the organization is less important than the manner of programme execution. Put another way, administration and trained personnel may be paramount.

Too often, semi-experimental demonstrational programmes are spread too thin to allow adequate supervison by technically trained personnel. Improper fertilizer applications, inaccurate records and even fertilizer diversions are known — but possibly infrequent — irregularities. Negative effects on farmers can result.

While budgets, organizations and trained personnel are necessary to carry out a successful fertilizer education programme, it is the programme itself which counts, and this is where the emphasis should be. Every media and approach to ways of encouraging farmers to use fertilizer should be considered. At the same time, it is well to recognize that funds and trained personnel may be limiting factors and this forces selectivity in approaches and methods.

Extension services in the more advanced countries have developed many effective teaching techniques. Group meetings, discussion groups, radios, newspapers, bulletins and publications, clubs, personal contacts, films, slides and telephones are some of the media used. Blackboards, flannel-boards, charts, graphs, pictures, leaflets, workshops, short courses, visual aids, demonstrations, talks, tours, signs, cartoons, specimens and the written word are among the teaching methods used through the media cited above. Because of the problem of illiteracy, some of the more sophisticated media and methods may not be generally effective. Clearly, only well-considered adaptations are likely to get results.

Academic teaching is simple compared with motivating farmers in a developing country to use fertilizer and the other essential inputs because, in many respects, they are a heterogeneous group of people. Different things must be overcome: ignorance; fear; lethargy; negative attitudes; and tradition itself. The teaching process must remain simple and be based on common sense; and, above all, proved psychological techniques should be utilized to the fullest.

Conceptually, before an idea is accepted, the person concerned must:

(*a*) Be aware of it;

(*b*) Become interested;

(*c*) Decide whether or not the new idea is good;

(*d*) Try out the idea;

(*e*) Adopt the new practice (6).

Awareness can be instilled through almost any medium. Several media may well be utilized. Presentations for this purpose which are short in wording but dramatic in appeal may be preferred. The main thing would appear to be repetition and follow-up.

When the farmer shows interest, he is ready for more information. The real educational process begins. At this stage, items for news media should make points and not just consist of striking appeal phrases. Short success stories of increased production from use of fertilizers may prove useful. The use of local meetings and discussion groups can be helpful at this stage, and such meetings appear most essential in the next stage. Tours to see some demonstration plots comparing crops with and without fertilizer and other desirable inputs are appropriate.

In the subsequent stage, when the farmer is deciding if the new idea is good, perhaps the approach should be more precise and detailed. Indeed, the teaching may stress both physical and economic returns from fertilizer use. This is the time to use all the media through which the psychology of example can be "exploited". Results of research, field-days to study field-trials and the experiences of local leaders, especially those of good farmers, are things to stress.

When farmers indicate an inclination to try out the new idea, the teaching should become more individual and more locally oriented. This is the time to draw on localized experimental research and on technicians who can advise individual farmers on fertilizer and crop problems. Poor advice at this stage can be costly to the programme and to the objective of increased food production. Success in stage "four" is the best way to "sell" stage "five".

The final step, namely adopting the new practice, must be "sold" at the local level. Well-[illegible] and [illegible] leaders in local organization carry much weight with other farmers. Some extension specialists contend that getting the rank and file of farmers to accept new practices is best done through the few [illegible] who are the first in successful idea adoption. The [illegible] of such local leaders probably should [illegible] of the first priority.

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V. MARKETING, DISTRIBUTION AND PRICING OF FERTILIZERS

A. MARKETING

It is recognized that the production of fertilizer in developing countries is easier than its marketing. Various factors inhibit the use of fertilizer by farmers. The cost of its production in the developing countries of the world is comparatively high, in many cases at least 50 per cent higher than in an industrialized country. The farmer in a developing country, therefore, pays more unless fertilizer prices are subsidized, which is seldom the case. Prices he obtains for his products are low. As a result, the cost/yield ratio is, in general, less favourable to the farmer than in developed nations. Combined with this factor, the marketing practices and such distribution factors as availability when needed also contribute to the restricted use of fertilizer by farmers. Availability of credit, lack of a knowledge of suitable farm practices and lack of experience in what fertilizers to use and in what quantities also add to the difficulties.

In developed countries where the "free-enterprise" system exists and where farmers are educated and well-informed on the benefits of fertilizer "input", the forces of supply and demand come freely into play. Stocks of different types of fertilizers suitable for the area are always available close to the farms. Credit facilities are easy to obtain. Fertilizer prices are reasonably low, and prices of farm produce are stable. Fertilizer distributors are willing to make balanced mixes for any particular need and are willing to give advice. Even the spreading of the fertilizer in the field is undertaken by some distributors. Aggressive salesmanship is practised, and the farmers who are driven by the "profit motive" are willing to invest in the use of fertilizers. Thus, there is a steady growth in fertilizer consumption and demand. Production facilities keep up with the demand. In some developed countries, e.g., Japan and the United Kingdom, which are net importers of food-supplies, the national Governments subsidize fertilizer prices to give more incentive to increased usage, culminating in increased food production.

In countries where the economy is "centrally planned", the aim of the farmer is to achieve maximum production to cater to the food needs of the country. Fertilizer distribution is done by the State; and prices, types of fertilizers to be used, quantities to be used etc. are planned. In addition to the willingness of the farmer to use fertilizers and to produce more, there is persuasion from the State and, in some cases, incentives for increased use, higher production and improved yields.

In many developing countries, the position is "mixed" that is, there are systems where the "free-enterprise" element exists side by side with an element of "central planning". Such planning is necessary to conserve precious foreign exchange and also to foster development in areas which will be most beneficial to the public interest and where the private sector does not have initiative or sufficient capital. In many such developing countries, fertilizer production and distribution are centrally planned. The experience has been that it is one thing to draw up plans and even to put up production facilities, but quite another when it comes to distribution and farmers' use, so considerable are the difficulties. In some countries, fertilizer prices are fixed by the Government and distribution is handled by co-operatives. It has been felt in certain countries with a large land area and a large population that some flexibility in the price structure and the distribution channels might increase the use of fertilizer. Fixing the maximum price delivered to farmers at any point in the country and allowing fertilizer producers in both the public and the private sectors to market their products under certain conditions might be one answer. Many countries experience the common difficulty of high fertilizer prices and low prices for agricultural products. Other inputs which augment fertilizer use are lacking. Farmer education and modern methods of farming are not extensive. Soil testing, agricultural extension services, credit facilities etc. are not operating.

With all such difficulties, it is, nevertheless, proper to investigate whether in developing countries the marketing, distribution and farmers' use of fertilizer can be improved upon and increased. The methods used by one fertilizer-producing company in a developing country are largely narrated in the subsequent paragraphs, which may give some lead and assistance in this field to other developing countries.

1. *Sales promotion*

This project will have an installed capacity of 66,000 tons of nitrogen and about 30,000 tons of P_2O_5 *per annum*. The products made are ammonium sulphate (20.5 per cent nitrogen); ammonium sulphate phosphate (16 per cent nitrogen, 20 per cent P_2O_5); ammonium chloride (25 per cent nitrogen); and superphosphate (16 per cent P_2O_5). The potash is imported in the form of muriate of potash (60 per cent K_2O). Various mixtures containing different ratios of N, P_2O_5 and K_2O are also prepared.

This company believes that the task of a fertilizer industry is not merely to manufacture the proper required products, but also to take an active part in the marketing and sales of fertilizers. In a developing country, where the majority of farmers are not well-acquainted with the returns of fertilizer use, it is essential that the task of farmer education should particularly be borne by fertilizer producers. A long-term programme for increasing fertilizer consumption in an area of 200 miles around the factory was developed. First, a systematic and rapid programme of education of the farmers was undertaken. Simultaneously, a marketing set-up was organized which would ensure the availability of fertilizers to the farmer within accessible distances and at the time the fertilizers are needed. A field organization was also set up to go out to the farmers in the villages and to explain the various aspects of fertilizer promotion work. The field-staff was trained in conjunction with the Agriculture Department of the state government.

2. *Demonstration*

Great emphasis was placed on the educational aspect in the promotion programme. Demonstration plots were organized with the basic objective of showing in the farmer's field, as well as in experimental plots, the increase in yield by fertilizer application. The experimental plots were so located as to arrest the attention of neighbouring farmers. Farmers' plots were selected in those cases where the farmer commanded the leadership and confidence of the locality and where he was personally enthusiastic about scientific methods of cultivation. To make the demonstration programme a success, a proper co-ordination of various farming activities and inputs was undertaken. The company now has 500 demonstration plots. These plots are selected after consultation with the local farmers and with their concurrence. They are selected also with a view to growing different kinds of crops.

3. *Agronomical services*

The company's field-staff gives advice to farmers not only on when, how and where to apply the fertilizers, but also on the use of better seeds, the use of pesticides and fungicides, proper methods of drainage, irrigation, rotation of crops, use of implements etc.

4. *Soil testing*

A central soil-testing laboratory exists in the company. The field-staff supervises the correct sampling of soils and, in addition to testing by the use of a mobile van and soil-testing kits, sends samples, if necessary, to the central laboratory. The fertilizer officers of the company, as well as the central fertilizer depot officers, have soil kits available. After the results of soil analyses are known, the farmers are informed about deficiencies in their soils and are advised as to how these should be corrected. Use of liming materials, soil-amending materials and fertilizers with different ratios of plant nutrients are recommended.

5. *Film-shows and exhibitions*

In addition to the use of documentary films produced and loaned by the central Government, the company has produced documentation in local languages. The stories have a strong educational bias and a theme in which agriculture and fertilizer use are interwoven. There are plans for producing similar documentaries in languages of other states of the country; and it has been felt that films of this type, acted by first-rate local artists, can tell a story to rural audiences interestingly, convincingly and dramatically, as perhaps no other medium can do.

6. *Fertilizer festivals*

In many developing countries of the world, local festivals have a connotation connected with tradition and folklore. The basic idea is the triumph of good over the forces of evil. Likewise, the fertilizer festival represents the triumph of science and good agricultural practices over the force of ignorance and traditionally [illegible] ways of farming.

In actual fact, these festivals are a kind of fertilizer workshop with all the outward paraphernalia of a festival worked in. They are held in different parts of the area and are attended by fifty to one hundred farmers or delegates. These delegates are selected by an executive committee of the festival, which may consist of officers of the development block, representatives of the village panchayats and social service leagues. The festivals include classes, seminars and group discussions led by experts in the field, namely, officers of the state's Agriculture Department, officers of research stations and the company's own agronomists. They deal with the various aspects of improving cultivation practices, with special emphasis on the use of balanced nitrogen-phosphate-potash fertilizers.

During these festivals, soil testing is done on the spot by mobile soil-testing units. On an average, twenty-five to fifty samples of soils are taken in one day and tested on the spot.

As a part of the festival, an exhibition is also held with the help of charts, diagrams and photographs of agricultural interest, focusing on the benefits of fertilizer use. Usually, in the afternoon, a public meeting is organized and is addressed by prominent citizens, state ministers etc. After the public meeting, a film show is arranged and here again, the theme depicted is higher agricultural productivity through the use of fertilizers. This is often followed by a cultural programme of drama, dance or variety entertainment.

It has been estimated that in one year, more than 1 million people participated in these festivals, and these programmes are held in hundreds of villages. It is also estimated that 20,000 farmers attend these seminars each year.

B. SALES AND DISTRIBUTION

1. *Sales and distribution organization*

An elaborate distribution organization has been set up to ensure that fertilizer stocks will be available to the farmers, as and when required. The network consists of fifty-three wholesale storage points called central depots. Attached to these central depots are about 2,000 retail selling points, each under an authorized representative of the company, who sells fertilizers to the farmers. The network of the sales organization is planned to ensure that, normally, a farmer can obtain his requirements of fertilizers from a depot within walking distance of two to three miles. The whole marketing organization is in the charge of the manager of depot organization.

The central depots hold stocks of fertilizers on a consignment basis. From this central depot, the authorized representatives draw their requirements.

This system of central depots and authorized representatives is being extended to three neighbouring states of the country.

2. *Field sales and service organization*

There is a well built field organization, which has agronomy experts and field salesmen who explain to the farmers the facilities offered and the benefits of fertilizer application. Every central depot has a trained agronomist, who is responsible not only for organizing sales and distribution in his area, but for carrying out liaison work. This liaison is with customers, authorized company representatives, officials of the state's Departments of Agriculture, Revenue and Community Development; with co-operative societies, associations of farmers and allied bodies, and with field assistants, fertilizer officers and sales officers. In addition, the agronomist assists in the work of selling and servicing, organizing programme of customer education, soil testing, field demonstration and the handling of customers' complaints.

3. *Co-operative societies*

Although the policy of the central Government in this developing country is to encourage fertilizer marketing and distribution by co-operative stores in the particular area where this company is active, the co-operative agencies have not played an important role. Eight of the central depots were entrusted to co-operative agencies. In the course of time, one co-operative society has opted to discontinue. These co-operative societies are provided with stocks of fertilizers on a consignment basis, so that their investment on trade is negligible. However, experience in this area, on the whole, has proved that the co-operative agencies have not come up to expectation in the matter of sales promotion. Therefore, the company has developed its own central depots. On the retail side, there are 1,293 co-operative societies as authorized representatives of the company, covering nearly 60 per cent of the retail distribution points.

4. *Storage facilities*

Fertilizer consumption is largely seasonal, while production in the factory is continuous. If, therefore, fertilizers are to be made available to the farmers at the appropriate time, a decentralized storage pattern is to be developed. This will avoid hold-ups due to transport bottle-necks during the growing season. On this basis, a series of buffer warehouses and central depot warehouses in different parts of the area served have established a total number of 360 warehouses with a total floor area of approximately 40,000 square feet. A capacity for storing 80,000 tons of fertilizer is in existence. Storage facilities are also available at railheads, important agricultural centres and transportation centres. In addition to these central storage facilities, there are 2,000 retailers with a storage floor area of 120,000 square feet and a capacity of nearly 20,000 tons of fertilizers. It is estimated that this will provide for approximately 20 per cent of the expected annual production.

A portion of the bulk supplies of fertilizers to larger consumers and estates are made directly through the factory.

5. *Transport*

The company production facilities are situated at a navigable river, are about eight miles from a harbour and are served by barges and country crafts. A railhead is available three miles from the factory. Road transport is also excellent. Thus, water, rail and road transport are in existence. In addition, in certain areas where other transport facilities are not available, the traditional methods of transport — hand-carts and bullock-drawn carts — are used. As the company does not have a railway siding inside the factory, all production leaves the factory either by road or water transport. The nearest railway point is within three miles and is used for a major portion of the outward movement. It is unfortunate that lorries have to transport the products from the factory to the railway station, thus involving additional handlings.

C. CREDIT FACILITIES

In many developing countries, one of the major factors retarding the growth of fertilizer consumption is the inadequacy of, and the delay in obtaining, credit facilities for the farmers. Considering the small size of the average land holdings, the low income and the lack of modern methods of agriculture, farmers in some of the developing countries hesitate to utilize even the existing meagre credit facilities.

The inadequacy of existing means of credit is owing not so much to the lack of proper appreciation of the problem by Governments and the authorities concerned, but more to the immensity and complexity of the problem and the paucity of funds. The resources of the fertilizer producers and traders are totally inadequate to cope with the situation. Although the commercial, private and state banking institutions are touching the fringes, they are hesitant to enter actively into the field for financial and administrative reasons. In many developing countries, as a result of efforts mainly on the part of the State, progress has been achieved through co-operative and other institutions. Credit facilities in some countries are also extended to the farmer through certain departments of the State.

Any discussion of credit facilities in the case of fertilizer distribution must distinguish two aspects of the problem. The production of fertilizers is continuous throughout the year, but the consumption is seasonal. Hence, from the time of manufacture to the time of consumption, there is an appreciable time gap. Credit facilities to the farmer would normally cover only that part of the period between the purchase of fertilizers from the retail selling point to the time when the farmer is harvesting his crop, that is, from the time of cultivation to the time of harvesting. Thus, credit facilities for the farmer differ from credit facilities to the trade, the latter covering the period between manufacture and retail selling. Accordingly, trade credit and farmer credit are two distinguishable aspects of the credit problem.

The particular company being discussed here would prefer to operate both the trade and consumer facilities, but, owing to administrative and financial limitations, it has, until now, extended credit only to the trade. All the wholesalers are consignment stockists who do not pay for stocks positioned with them, but only for stocks sold by them. Thus, credit facilities are automatically extended to the trade up to the wholesale level. A revolving credit, to the extent of $1,000 per loan, is granted to selected retailers on the basis of a fidelity insurance guarantee, a bank guarantee or a deposit of such approved securities as title-deeds and national savings certificates. In a few cases, in co-operation with co-operative banking institutions, on their guarantees, credit facilities are given to retail co-operative societies. For larger producer-co-operative societies, special credit facilities are offered on negotiated terms. A beginning has been made in extending credit facilities to farmers cultivating an area of five acres or more, under a scheme jointly developed by the company and a leading commercial banking organization.

Commercial credit facilities are available in the area at a cost of about 8 per cent. Co-operative credit also costs about the same. For the farmer, the main source of credit is the co-operative society, and the membership of the society is one restrictive factor. Even among the members, those who have not repaid earlier loans will not be eligible for fresh loans. The state does not offer credit facilities directly to the farmer. Commercial banks have not yet become active in offering credit facilities to farmers. Credit applications from farmers take a long time and much effort to process. In many developing countries, credit worthiness is still a matter of clear title of ownership of property.

In view of the problems involved in making fertilizers and fertilizer credit available to farmers, especially small food-crop farmers in developing countries, The Food and Agriculture Organization of the United Nations (FAO), under the Freedom From Hunger Campaign Fertilizer Programme, has initiated pilot schemes for fertilizer distribution, marketing and credit in a number of countries. In the schemes, small amounts of fertilizers are provided by FAO, either directly or through bilateral sources. Under FAO supervision and in close co-operation with the Government, the fertilizers are distributed to farmers for cash or on credit. Receipts from sales from a "revolving fund" administered by the Government. This fund is then used to buy additional fertilizers, expanding the scheme as experience is gained. The objective is to have a natural transition to the most suitable distribution, marketing and credit systems under local conditions. The schemes can also form the basis for the organization of facilities to provide other production requisites and to handle the marketing of crops. These schemes are proving very successful in solving these problems in the countries in which they are operating.

As far as credit to the trade is concerned, it may be stated that the credit period ranges from thirty days to four months. At the retail consumer level, it is estimated that between 50-70 per cent will be on the basis of credit allowed by co-operatives or private dealers. Only about 30 per cent or less will be sales on a cash basis. It cannot be said that the repayment of credit is 100 per cent in type. The experience has been that about 80 per cent of the repayments are made in the first year, 15 per cent in the second year and 5 per cent in the third year. The normal repayment period is from six months to one year. In a few cases, credit is extended for two years or more. Repayment usually takes place after the harvest.

A general assessment of the credit problem in agriculture, including fertilizers, is quoted from the *Report of the Conference on Productivity and Innovation in Agriculture in the Underdeveloped Countries*, held at the Massachusetts Institute of Technology in 1964:

> "Three types of production credit may be distinguished; short-term credit, for periods of a year or less; medium-term credit, for periods exceeding one year but less than five years; and long-term credit, for five years or more.
>
> "In order to be most productive, short-term credit from official and co-operative sources should almost always be 'supervised', that is, tied in with the farmer's performance. Loans should be granted on condition that the borrower agree to adopt a package of recommended inputs and practices. Second, loans should be made primarily on the basis of the increased production potential of the package rather than upon the security of land or other assets, so that credit is accessible to tenants and small farmers as well as to larger farmers. Third, as far as possible they should be made in kind in the form of the inputs themselves. Since official credit cannot possibly meet the full credit requirements of the agricultural sector, it should be channeled primarily to meet the financial needs of innovation.
>
> "In order to facilitate loan recoveries, it may be useful to link the provision of credit with marketing. However, where marketing is undertaken by a governmental or semi-official co-operative agency, care should be taken to provide the services and conveniences provided by alternative private agencies such as boarding and lodging for farmers coming to sell grain in the town, prompt payment and emergency relief. Otherwise new agencies fail to attract farmers. Alternatively, the government may provide only a storage service to farmers at a nominal charge. Official warehouses may give them negotiable warehouse receipts so that farmers may market their produce whenever they can get a good price.
>
> "It is necessary to examine the possibility of revising the current practice of charging a uniform interest rate for all short-term official credit. The introduction of differential interest rates on loans for different purposes might improve the use of loan funds and recovery rates.
>
> "The actual role of traditional moneylenders deserves careful empirical study as part of a broader study of the relative efficiency of alternative systems for providing credit. Moneylenders have many operational advantages such as intimate familiarity with borrowers, readiness to grant risky loans, quick and low-cost loan management, and a high rate of loan recovery. Since they provide such a large proportion of the total rural credit needs on such a wide scale, the aim of eliminating them is utopian. Measures should therefore be devised to build upon the advantages of their system while eliminating any monopoly power or gains enjoyed by them. One possibility that needs to be tried is the establishment of a system of rediscounting credit instruments between the farmer and the moneylender

under specified conditions. Such paper could be rediscounted by government agencies or commercial banks under certain governmental guarantees against a part of the losses. The rediscount system would increase the flow of funds through the traditional system, facilitate the entry of new moneylenders, break the islands of monopoly, and lower the level of interest rates. It might also induce commercial banks to enter the agricultural money market as wholesalers if not as retailers of credit.

"Any research studying alternative systems for providing agricultural credit should distinguish, and if possible separate, the three components of the gross interest charge — real interest, risk premium and the cost of administration and collection. Quantitative comparisons of these magnitudes will help improve the credit system.

"As a rule, provision is made for a far greater proportion of the short-term credit needs of the rural sector than of the medium and long-term needs — for land improvement, minor irrigation, equipment, and livestock — even though the longer-term needs are no less urgent and important. More research is needed to estimate the real degree of risk involved in medium and long-term loans. It may be that on the whole, they are no more risky than short-term loans. Since the traditional and commercial banking sectors fail to meet medium and long-term credit needs adequately, special new credit agencies must be created to meet them.

"The principle of linking loans with a 'package' should be fully extended to cover medium and long-term loans. Medium and long-term packages as well as short-term packages should be supervised. The new agencies will need trained personnel to draft, evaluate, and supervise medium and long-term projects. Again, commercial banks can also be induced to participate in the retail or wholesale side of longer-term lending to farmers if they are guaranteed against a part of the loss, and if they are provided with technical help from the public sector. They may also need some guarantee against losses due to inflation.

"Special study is needed to improve long-term land mortgage banking. Where land statutes, judicial decision, or traditions have clouded land titles and thus adversely affected the volume of mortgage lending, it is necessary to clarify tenure for the purposes of lending".[1]

D. Pricing

1. *General pricing policy*

The following remarks from the Conference report cited above are pertinent to this subject:

"It cannot be asserted that all farmers everywhere respond strongly to economic incentives. However, a growing volume of evidence shows that with a minimum degree of monetization, and the development of transport, a fairly large proportion of farmers do respond to them in some aspects of their behaviour. It follows that while all necessary techno-organizational measures should be taken to increase the physical outputs obtainable from given inputs, these measures should be combined with economic policies designed to take advantage of the price responsiveness of supply and factor demand wherever it is positive. In many situations, the rate of absorption of new knowledge and inputs may depend critically on the price and risk milieu.

"Any policy to improve the price milieu of developing agriculture should take into account, and, if necessary, influence the following: (*a*) the variability of agricultural prices of various crops, which affects the riskiness of farming; (*b*) the relative prices of various crops, which affect the allocation of land and other inputs among crops; (*c*) the ratio of the general level of agricultural product prices to the level of agricultural input prices, (*d*) and the ratio of the general level of agricultural product prices to the general level of nonagricultural prices.

"Although these price relationships are distinct in theory, any set of price regulations measures will simultaneously affect all of them to some extent. For example, if the government successfully establishes price floors for two or three major crops of the country, the downward price fluctuation will be restricted and relative prices, the output-input price ratio, and the terms of trade of agriculture will all be altered in some degree. Therefore, it is necessary that the price policies followed be based on a consideration of their effects on all the key price relationships.

"About the desirability of price stability, there can be little argument. Price fluctuations add immeasurably to the risks facing the cultivator and do not afford sufficient offsetting advantages to the community as a whole. A fall in the price of wheat between planting and harvesting or over a series of harvest years can render an apparently profitable investment in fertilizer or pesticides or new capital equipment uneconomic. And the adverse effects of declines may not be balanced by gains from price increases of equal number and magnitude in later years because of the limited capital that most peasant farmers possess. Hence, the need for the administration of floor prices for a few selected crops.

"Price stability cannot be willed by legislative fiat. An adequate warehouse and transportation network is required for stock operations designed to reduce price instability. Of course price stability need not, and should not, be absolute. Besides normal seasonal fluctuations reflecting carrying charges, flexibility should be allowed between fixed minima and maxima in order to remove some of the burdens of changes in demand and supply from the storage system.

"An alternative to direct price stabilization from the viewpoint of reducing risk is a system of forward markets that would enable the cultivator to ensure the price of at least a part of his crop prior to planting. But it should be remembered that futures markets in the more advanced countries have been of much more

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[1] Massachusetts Institute of Technology, Center for International Studies, *Policies for Promoting Agricultural Development: Report of a Conference on Productivity and Innovation in Agriculture in the Underdeveloped Countries* (Cambridge, Mass., 1965).

help to processors than to growers in reducing price risks. In any case the problems of making futures markets accessible to peasant farmers in the developing countries are formidable enough to rule out futures markets as an alternative to direct price stabilization operations in the immediate future.

"Studies of the effects of changes in the relative prices of different agricultural products on the allocation of the existing stock of inputs among products show that farmers respond to changes in prices by redirecting their efforts in accordance with shifts in profitability. Therefore, insofar as it is desired to increase the output of a few important food and fibre crops by a transfer of inputs among competing crops, the objective can be realized through the manipulation of the relative prices of competing crops.

"The shortages of such essential commodities as wheat, rice and cotton are so acute in some countries that in addition to other measures it is absolutely necessary to administer floor prices for these major crops both to stabilize their prices and to obtain some increases in output by improving their relative prices.

"The fixing of floor prices requires technical studies and some experimental action. The floors at the very least should prevent price crashes in case significant output increases do materialize. Preferably, they should cover the cultivating costs of at least the more efficient farmers using improved practices. If necessary, they may include an incentive element over and above the cost of cultivation. The levels fixed will have to lie somewhere between the anticrash levels and the cost of cultivation (with or without an incentive element), depending on the responsiveness of output. More investigation is needed to determine the magnitude of that response, either by examining reactions to price changes that in fact have taken place or by experimental manipulation in selected regions. Price floors should be held stable for several years — say, three — and should be adjustable or removable after each such period, and the government must make arrangements for direct purchase at the floor prices from farmers in a sufficient number of primary agricultural markets.

"When we consider the growth of the overall level of agricultural output rather than the output of individual crops, it is clear that the price ratio of outputs to inputs is as important as the relative prices of outputs, if not more so. Price ratios more favorable to cultivators can be brought about both by raising output prices and by lowering the prices of inputs to the farmer. Each course of action has its positive as well as its negative features.

"The outstanding advantage of subsidizing purchasable inputs like fertilizers, pesticides, equipment, and livestock rather than raising product prices is that the cost of the subsidy programme is directly related to the utilization of practices that increase productivity. The cost to the economy as a whole of increasing agricultural output is likely to be lower in the case of subsidies and can be borne through the tax system. More resources are available for development of the non-agricultural sectors of the economy as well as [illegible] farmers.

"The case for higher product prices [illegible] of these very arguments [illegible] that a given percentage of input subsidies [illegible] programme of product price support [illegible] agricultural sector derives a smaller net gain from the first programme than from the second. This is an important consideration for it can be argued that [illegible] current [illegible] relationships agriculture [illegible] its fair share of the national income and that [illegible] obstacle to innovation in peasant agriculture is the lack of a capital cushion to absorb the added fluctuation in income produced by many innovations, such as fertilizer in areas dependent on variable weather. A second argument for higher product prices is that input subsidies are of no avail in situations in which increases in agricultural productivity come from additions of non-purchasable inputs that are not complementary with purchasable inputs — for example the farmer's labour in better cultivation, weeding, clearing and local irrigation and drainage channels. Third, if the use of purchasable inputs is already widespread, the costs of input subsidies mount. Moreover, since non-innovators as well as innovators benefit, the argument for input subsidies on the ground that they do not increase the preference for leisure is weakened. If, however, the use of improved inputs is not widespread, it is doubtful whether the mere cheapening of inputs will by itself induce more farmers to begin to use them.

"Thus, it should be clear that a blanket preference cannot be given either to general price supports or to input subsidies. The relative efficacity of the two means of improving the price ratio of outputs to inputs depends on the existing level of input use, the technological character of the measures necessary to increase productivity, the relative importance of low cost and provision of a cushion for risk-taking to the cultivator, and a value judgment with respect to the distribution of incomes between the agricultural and non-agricultural sectors. All but the last-named aspect of the problem can be resolved by scientific empirical research in each country facing the choice between price supports and input subsidies, and even the question of rural-urban income distribution can be illuminated by such research.

"The rural-urban question is of course most important when we consider the relationship between the levels of agricultural and non-agricultural prices. In this connection it is important to remember that policy-makers may be less free to depress the terms of trade against agriculture during industrialization in democratic countries with a peasant franchise than in the already industrialized countries

"In summary, a feasible price policy mix for the near future would include floors for a few selected crops determined on the lines suggested; perhaps a programme of subsidies for fixed as well as working capital inputs; and an overall policy to prevent a serious deterioration of the rural sector's domestic terms of trade. As a part of such a policy, it would be desirable to grant tariff protection to infant industries only when their output actually attains a certain proportion, say 10 to 20 per cent of the domestic demand. (Until that time, subsidies might be granted.) This action would prevent undue and premature increases in the prices of many industrial products.

"Countries depending mainly on a single export crop would continue to need international commodity agreements to have some short-run price stability, but the provisions of these agreements must not jeopardize long-run price flexibility lest resources remain overcommitted to the crops even when demand conditions change.

"Finally, the case for export subsidies on selected agricultural commodities exported by developing countries is as economically valid as that for industry protection. Properly designed subsidies should therefore not be frowned upon by international agencies".[1]

In the particular instance of the company being discussed in this chapter, the sale and distribution of fertilizers are controlled and regulated by the State, under the supervision of the Fertilizer Control Order. Only licensed traders are allowed to deal in fertilizers. Sale and distribution of nitrogen as fertilizers are organized exclusively through public sector institutions and co-operative societies. In the State in which this company is situated, these groups have been involved with the task of distributing and selling nitrogen as fertilizers. As far as phosphatic and potash mixtures, and such multinutrient fertilizers as ammonium phosphate are concerned, the State only regulates the trade by licensing and prescribing the selling price to the ultimate consumer. For straight nitrogen fertilizers, the State has prescribed the actual prices payable by different types of ultimate consumers and the profit margin and expense margins for each link in the distribution channel. It may be noted that there is no bonus in prices if the fertilizer contains more than the prescribed plant nutrients. For example, in the case of a single superphosphate, the price is fixed for the material containing 16 per cent water-soluble P_2O_5 and if the material contains 17 or 18 per cent, any increase in price is to be negotiated. In the case of mixtures containing different ratios of nitrogen, phosphate and potash, the selling prices prescribed by the Government are based on the prices for the basic components of the mixture plus a mixing charge and profit margins for the manufacturer, wholesaler and retailer. In the area where this company is distributing fertilizers, the price policy also provides a stable uniform price for the consumer, irrespective of his location. The price includes a provision for movement and storage expenses, which takes into account the distances involved in moving fertilizers to the different retail selling locations. The price is also inclusive of the profit and expense margins allowed to wholesalers and retailers, and of the taxes imposed by the State. The prescribed retail selling prices are periodically announced in newspapers and are prominently displayed at all selling points. Through effective field supervision and customer-complaint machinery, it is ensured that the customer is never charged more than the fixed retail price.

The various elements of the ultimate prices paid by the farmers are indicated below:

(*a*) Road transport costs approximately $0.05 per tonnage mile for long distances, and $0.10 to $0.24 for short distances. For railway movement, the cost works out to $0.02 per tonnage mile. For internal water transport, the cost would be $0.02 per tonnage mile;

(*b*) Loading, unloading and stocking charges amount to $0.50 per ton;

(*c*) The storage cost is $0.10 per ton per month;

(*d*) The profit margins are 1 per cent for wholesalers and 6 per cent for retailers;

(*e*) A single-point sales tax, which is 2 per cent of value, is taken into account;

(*f*) Bagging and packaging charges are $5.00 per ton in 100 kilogramme bags and $6.00 per ton in 50 kilogramme bags. The bags used are jute with polythene lining;

(*g*) Off-season prices: during the off-seasons, a rebate is allowed. For example, from 15 January to 15 April, the rebate is $5.00 per ton during the first month, $2.00 per ton in the second month and $1.00 per ton in the third month.

The current ex-factory prices, distribution margin and retail prices of some of the products are given in table 15.

TABLE 15. DISTRIBUTION MARGIN

(*Rupees*)[a]

Name of product	*Ex-factory price*	*Distribution margin, including cost of transport*	*Retail price*
Superphosphate	202.64	40.00	242.64
Ammonium phosphate	525.00	40.00	565.00
Coffee mix (11:8:11)	360.00	40.00	400.00
Coffee mix (12:6:8)	355.00	40.00	395.00
Tea mixture (14:5:7)	375.00	40.00	415.00
Tea mixture (13:6:6:6.6)	365.00	40.00	405.00
Rubber mix (8:10:12)	320.00	40.00	360.00
Rubber mix (8:12:10)	330.00	40.00	370.00
Kuttanad Spl (9:9:9)	330.00	40.00	370.00
Standard No. 1	350.00	40.00	390.00
Standard No. 2	295.00	40.00	335.00
Standard No. 3	300.00	40.00	340.00
Standard No. 4	350.00	40.00	390.00
Standard No. 5	360.00	40.00	400.00
Standard No. 8	370.00	40.00	410.00
Standard No. 9	330.00	40.00	370.00
Standard No. 11	305.00	40.00	345.00

[a] $US1 equals 4.8 rupees.

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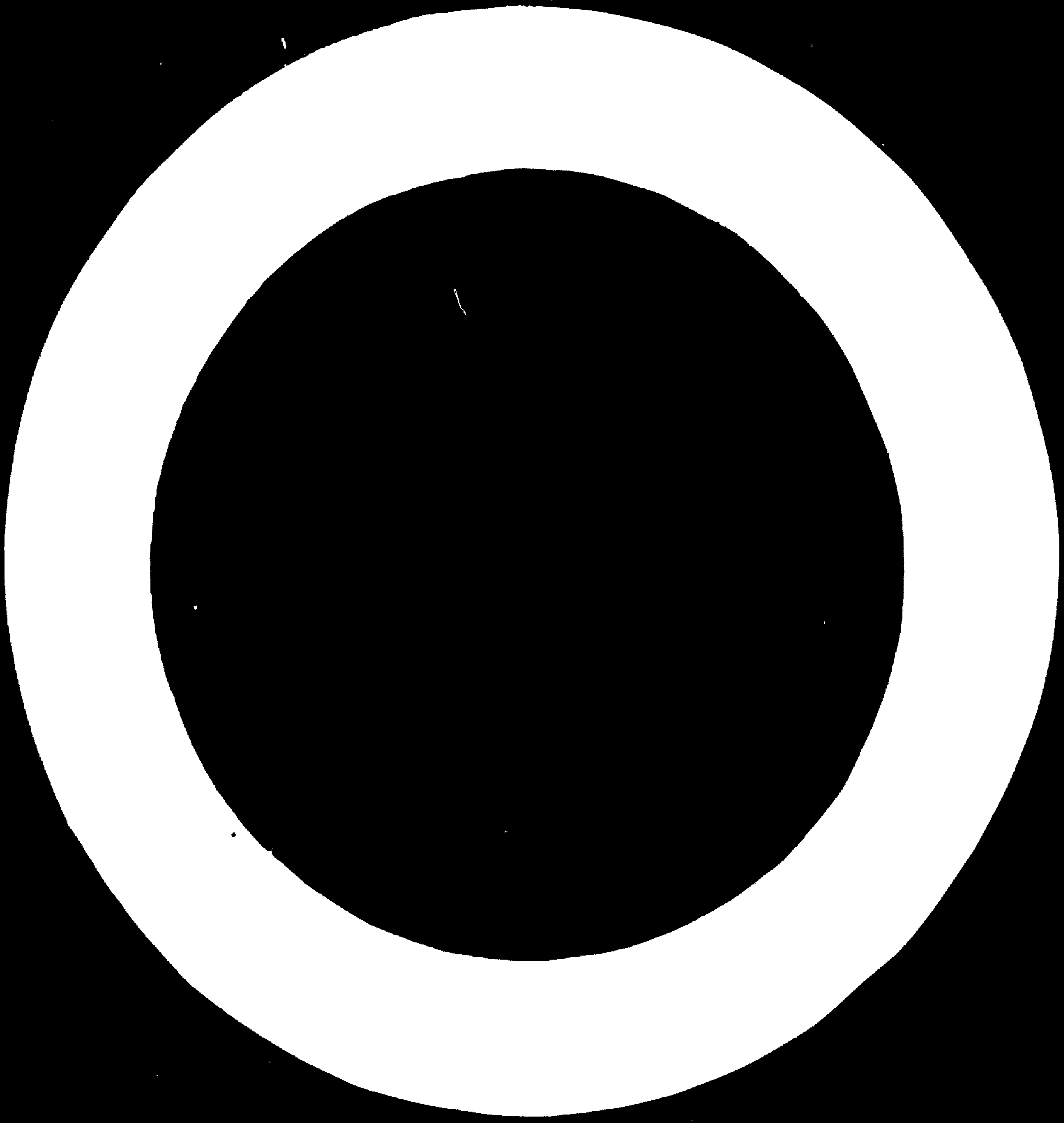
[1] Massachusetts Institute of Technology, Center for International Studies, *Policies for Promoting Agricultural Development: Report of a Conference on Productivity and Innovation in Agriculture in the Underdeveloped Countries* (Cambridge, Mass., 1965).

Part Two



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VI. GENERAL CONCEPTS AND DEFINITIONS

A. FERTILIZERS: GENERAL DEFINITION

A fertilizer is, broadly speaking, any material, organic or inorganic, natural or synthetic, that furnishes to plants one or more of the chemical elements necessary for normal growth. The list of elements recognized as being necessary for plant growth has increased over the years and now totals sixteen, as shown in table 16. The first nine elements are required in relatively large amounts and are called macronutrients. Of these, carbon, hydrogen and oxygen are supplied by air and water, and are therefore not dealt with as nutrients by the fertilizer industry. The other macronutrients are subdivided into primary elements (nitrogen, phosphorus and potassium) and secondary elements (calcium, magnesium and sulphur). The remaining seven elements are required in much smaller amounts and are known as micronutrients or trace elements (see chapter XVI).

TABLE 16. ELEMENTS ESSENTIAL FOR PLANT GROWTH

Macronutrients		Carbon
		Hydrogen
		Oxygen
	Primary nutrients	Nitrogen
		Phosphorus
		Potassium
	Secondary nutrients	Calcium
		Magnesium
		Sulphur
Micronutrients		Boron
		Chlorine
		Copper
		Iron
		Manganese
		Molybdenum
		Zinc

1. *Fertilizer availability*

A commercial fertilizer is a material containing at least one of the primary nutrients in a form assimilable or "available" to plants in known amounts. Generally, a plant nutrient is taken up by plant roots or foliage in the form of a solution in water. The primary nutrient elements form many different chemical compounds having varying degrees of solubility in water. Thus, it would seem that water solubility should provide a simple conclusive measure of the availability to plants. Unfortunately, the situation is far too complex for water solubility alone to serve as a measure of availability. All materials are soluble in water to some extent, even the most "insoluble". Certain sparingly soluble phosphate compounds have been found by plant growth tests to be available to plants, although the availability of such compounds often depends on particle size. Similarly, water solubility served satisfactorily for many years as the sole measure of availability of nitrogen compounds. With the development of slowly soluble nitrogen fertilizers like ureaform, water solubility alone became inadequate as a criterion. In the case of potassium, there is a large difference in solubility between potassium chloride, the principal compound used in fertilizers, and the insoluble natural potassium silicates, for example, the micas. Thus, water solubility alone is an adequate measure of the availability of potassium fertilizers. The development of suitable methods for analysing fertilizers for availability has claimed the attention of agricultural chemists since the beginning of the industry. The methods are constantly being revised and improved as new knowledge and new tools become available to the chemist.

2. *Fertilizer regulations*

Since a wide variety of natural and synthetic materials are beneficial to the growth of plants, a virtually unlimited number of products could truthfully be labelled "fertilizer" and marketed as such. The main drawback to uncontrolled marketing of fertilizer materials is the problem of the relative effectiveness of the product, and this depends on its composition. Unless the farmer can be sure that each lot of fertilizer he buys will have the same effectiveness as the preceding lot, he cannot be sure that he is fertilizing his crops in a rational manner, regardless of his stock of personal experience or advice from agricultural experiment stations.

Another drawback to uncontrolled marketing of fertilizer is the lack of a rational basis for pricing. Thus, a ton of low-analysis fertilizer is less valuable to the farmer than a ton of higher analysis fertilizer, so the farmer should have a simple method for determining the best buy from the existing market.

Because of the foregoing factors, regulations (some of them in the form of laws) have been established in many parts of the world to govern the labelling and marketing of commercial fertilizers at the retail level. As these regulations are intended for local conditions, they may vary from place to place, but the primary purposes are to ensure uniformity and to provide a simple method whereby the farmer can select the most economical product available to him.

Regulations add to the cost of fertilizer. In order to guarantee a given nutrient percentage, the manufacturer must provide some surplus, and the amount of the surplus depends on the degree of technical control during manufacture. Enforcement of regulations adds further to the cost of fertilizers. These costs, inherent in controlling fertilizer composition at the retail level, are compensated by the inherent benefits. Without basic regulations, the fertilizer trade would become chaotic. Like other regulations, care should be taken to limit them to the essentials.

3. *Fertilizer grades*

Throughout the world, commercial fertilizers are graded according to their content of available nitrogen, phosphorus and potassium, expressed as percentages by weight in the order named.

It has long been the custom of chemists to express the results of analysis of phosphorus or potassium compounds as oxides of the elements. Phosphorus is reported as P_2O_5 and potassium as K_2O. Nitrogen is reported as the element N. This system has become established in the fertilizer industry by long usage. Although a change from the oxide to the elemental or ionic form would improve scientific consistency, the results are reported mainly for the use of those who are not scientists.

In current practice, a "10-15-12" fertilizer is one containing, in available forms, 10 per cent nitrogen, 15 per cent phosphorus expressed as P_2O_5 and 12 per cent potassium expressed as K_2O. These percentages are guaranteed minima rather than actual content, which is usually slightly higher. When a fertilizer contains only two of the primary nutrients, the missing element is always represented by a zero in the proper sequence. For example, a fertilizer containing 15 per cent nitrogen and 20 per cent P_2O_5, but no potassium, would be "15-20-0". Similarly, a "15-0-20" fertilizer contains 15 per cent nitrogen, no phosphorus and 20 per cent K_2O. The single-nutrient materials are customarily labelled only with the percentage of the contained nutrient, for example, "60 per cent K_2O" instead of "0-0-60".

A number of refinements may be used locally. For example, the total percentage of nutrient may be stated in addition to the percentage of available nutrient.

The nutrient ratio of a multicomponent fertilizer is the proportion of the nutrients to each other. Thus, a 10-10-10 grade of fertilizer has a 1-1-1 ratio, and a 10-20-20 grade has a 1-2-2 ratio.

B. THE FERTILIZER INDUSTRY

Fertilizers are produced in plants varying in size from a simple operation run by a few people and representing a modest investment to huge plants worth millions of dollars and requiring hundreds of trained employees. Except for some types of mixed fertilizer plants (see chapter XV), all fertilizer plants are essentially chemical manufacturing operations of varying technical complexity. In general, the operating costs of a chemical plant decrease with an increase in capacity, and fertilizer plants are no exception (see chapter XXI).

In the early days of the fertilizer industry, the processes were relatively simple, and the raw materials frequently had a higher concentration of nutrient elements than the finished products. For example, normal superphosphate, (see chapter XII) has a P_2O_5 content of 18 to 22 per cent, whereas the phosphate rock used in its manufacture may contain as much as 32 per cent P_2O_5. In a situation of this kind, it is more economical to ship the raw materials to a small plant located close to a few consumers (farmers) than to locate a large plant near the source of raw materials and ship the product over the distances required to reach many consumers.

Over the years, progress in fertilizer production technology, as in the case of the chemical technology generally, has led to processes of increasing refinement and complexity. The plant-nutrient concentration of the products has increased beyond that of the raw materials, and the minimum economic size of plants has increased. Notable examples are concentrated superphosphate and ammonium phosphates (see chapters XII and XIV). As a result of the development of these new processes, there is a world-wide trend towards very large, complex, centralized plants located near the raw materials, with long-distance shipment of products to local dealers. The dealers may use these products to make mixtures suited to the local market, or they may distribute the products to consumers without further treatment.

C. FORMS OF FERTILIZER PRODUCED

Many different materials are capable of supplying N, P_2O_5 or K_2O to plants, but economics and other factors have narrowed the list so that most of the world's commercial fertilizer is supplied by a few forms of material, as shown in table 17.

TABLE 17. WORLD OUTPUT OF PRINCIPAL FERTILIZERS [a]
(Thousands of tons)

Nitrogen fertilizers	*N* 1953/1954	*N* 1963/1964
Ammonium sulphate	1,622.7	2,439
Ammonium nitrates	1,246.6	3,659
Sodium nitrate	258.9	214
Calcium nitrate	328.6	429
Calcium cyanamide	258.2	266
Urea [a]	131.8	4,095
Multinutrient fertilizers [b]	1,071.2	1,477

Phosphate fertilizers	*P_2O_5* 1953/1954	*P_2O_5* 1963/1964
Single superphosphate	4,041.6	5,058
Concentrated superphosphate	564.5	1,564
Basic slag	827.2	1,408
Other	272.7	1,020
Multinutrient fertilizers [b]	429.8	1,874

Potash fertilizers	*K_2O* 1953/1954	*K_2O* 1963/1964
Potassium sulphate	310	603.2
Muriate		
Over 45 per cent K_2O	2,887	5,246.6
20-45 per cent K_2O	798	594.0
20 per cent K_2O or less	123	85.6
Other	95	204.8
Multinutrient fertilizers [b]	0	46.0

SOURCES: Food and Agriculture Organization of the United Nations: 1953/1954 data are from *Fertilizers: An Annual Review of World Production, Consumption and Trade, 1959* (Rome, 1960), tables 10, 12 and 14; 1963/1964 data are from *Fertilizers: An Annual Review of World Production, Consumption and Trade, 1964* (Rome, 1965), tables 13 and 15 and appendix table XX.

[a] Including other fertilizers not classified elsewhere.

[b] Including ammonium phosphates.

During the ten-year period covered by the data in table 17, some significant changes have occurred in the world fertilizer industry. Ammonium sulphate has been displaced as the principal source of fertilizer nitrogen by urea, and ammonium nitrate is now the second most important nitrogen fertilizer. Single superphosphate is still the predominant form of phosphate fertilizer, but basic slag has been displaced from second to fourth place by multinutrient fertilizers (now in second place) and concentrated superphosphate (now in third place). Muriate of potash still dominates the potash fertilizers, but the lower grades have decreased in importance and practically all the world's potash is now in the form of grades exceeding 45 per cent K_2O.

The foregoing changes have been brought about by increased production, throughout the world, of synthetic ammonia and urea; and by increased production of ammonium phosphates (particularly in the United States of America) and of nitrophosphates (particularly in Europe). Improved technology in the beneficiation of potash ores has resulted in the large-scale production of potassium chloride closely approaching absolute purity, which is 63.17 per cent K_2O.

D. NATURAL ORGANIC FERTILIZERS

Large quantities of natural organic fertilizer materials are still used in many parts of the world. Such materials include animal and human excreta, wood ashes, sewage and by-products of commercial food processing, such as slaughter-house waste, fish scrap and oil-seed meals. The by-products of food processing largely vanished from the fertilizer trade about thirty years ago because of their usefulness as animal feeds — a higher priced market than that for fertilizers.

Natural organic fertilizers not only supply plant nutrients directly — they also stimulate desirable biological activity in the soil and improve soil texture. The disadvantages of natural organic fertilizers are that they are seldom available locally in the quantities needed for maximum yield of crops, and large-scale collection and distribution are uneconomical because of their low percentages of plant nutrients and their generally unfavourable physical condition. Another disadvantage is their indefinite non-uniform composition, which raises problems in determining rational rates of application for different soils and crops.

Some of the foregoing disadvantages can be overcome by such simple processing as drying, pelletizing and enrichment with synthetic fertilizers. Usually, such operations are less economical than the regular manufacture of synthetic fertilizers unless a part of the cost is chargeable to waste disposal. For example, the processing of sludge from a large municipal sewage plant located in a crowded area can be charged in part to disposal.

Some speciality fertilizers for horticultural or garden use are formulated with natural organic materials. Such non-farm fertilizers can be marketed at premium prices and are outside of the scope of this manual.

E. DEFINITION OF FERTILIZER TERMS

The following definitions of terms in common use in the fertilizer industry are restricted to those which are not adequately covered in Webster's [illegible] *Dictionary of the English Language* (1961).

Ammoniated superphosphate: [illegible] superphosphate with ammonia [illegible] solutions containing other nitrogen compounds.

Ammonium phosphate sulphate: a product made by treating with ammonia a mixture of phosphoric acid (H_3PO_4) and sulphuric acid (H_2SO_4). It consists mainly of a mixture of ammonium phosphate and ammonium sulphate.

Ammonium phosphate fertilizer: a solid or liquid product made by treating phosphoric acid (H_3PO_4) with ammonia. It consists mainly of monoammonium phosphate, diammonium phosphate or mixtures of the two.

Ammonium sulphate nitrate: a double salt composed of ammonium sulphate and ammonium nitrate in equal molecular proportions. It contains about 26 per cent N.

Basic slag: a by-product of the manufacture of steel from phosphatic iron-ores. It contains at least 12 per cent P_2O_5, of which at least 80 per cent is available to growing plants. The particle size (United States of America) is at least 70 per cent through a No. 100 sieve and 90 per cent through a No. 50 sieve (see definition of slag).

Blended fertilizer: a multinutrient fertilizer made by mechanically mixing two or more granular fertilizer materials. Also called bulk-blended fertilizer.

Bulk fertilizer: a solid or liquid commercial fertilizer delivered to the farmer in a non-packaged form to which a label cannot be attached.

Citrate-soluble phosphate: that portion of the total P_2O_5 which is not dissolved by water extraction, but is dissolved in a subsequent extraction of the water-insoluble portion with a neutral solution of ammonium citrate (United States of America).

Fertilizer complex: an integrated group of two or more chemical-processing plants for producing intermediates for use in the on-site manufacture of fertilizers.

Fertilizer material: usually a single nutrient fertilizer, such as superphosphate. Some two-nutrient fertilizers, such as ammonium phosphates, are also called materials.

Formula (fertilizer): a list of the kind, nutrient content and amount of stock materials required to produce a given weight of mixed fertilizer of a given nutrient content.

Furnace (or thermal) phosphoric acid: a relatively pure orthophosphoric acid (H_3PO_4) made by burning elemental phosphorus in air and absorbing the combustion products in water.

Granular fertilizer: a product, the greater part of which consists of particles with mean diameters of 1 to 4 millimetres. This corresponds to material retained between 5- and 16-mesh Tyler Standard Screens. A more rigid definition which is under consideration in the United States of America is as follows: a uniformly granular fertilizer is one in which 95 per cent or more remains on any sieve with openings between 2.38 millimetres (8 mesh) and 0.841 millimetres (20 mesh), and in which the largest particle passes through a sieve having an opening no larger than four times that of the sieve retaining 95 per cent or more of the product.

Liming material: a material containing calcium or magnesium, capable of neutralizing soil acidity.

Micronutrient (or *trace element*): a chemical element required in minute amounts for normal growth and development of plants. Includes boron, chlorine, copper, iron, manganese, molybdenum and zinc.

Muriate of potash: a fertilizer grade of potassium chloride.

Mixed fertilizer: a solid (granular or non-granular) or liquid fertilizer containing at least two, and usually three, primary nutrients in definite predetermined percentages.

Nitrogen solution: an aqueous solution containing ammonia, ammonium nitrate or urea, singly or in combination. Used directly as liquid fertilizer or as an intermediate in the manufacture of ammoniated superphosphate or mixed fertilizers.

Nitrophosphate: a fertilizer prepared by treating phosphate rock with nitric acid, usually followed by ammoniation.

Primary fertilizer elements: a group of three chemical elements required in relatively large amounts for the normal growth and development of plants. The group is composed of nitrogen, phosphorus and potassium.

Secondary fertilizer elements: a group of three chemical elements required in relatively large amounts for the normal growth and development of plants. The group is composed of calcium, magnesium and sulphur.

Slag (agricultural): a fused silicate by-product of smelting operations, capable of neutralizing soil acidity when ground to proper fineness.

Superphosphate: a product made by treating phosphate rock with either sulphuric acid ("normal", "single" or "ordinary" superphosphate), phosphoric acid ("concentrated" or "triple" superphosphate), or a mixture of these acids ("enriched" superphosphate) followed by ageing of the acidulate. The principal nutrient compound present in superphosphate is monocalcium phosphate.

Superphosphoric (or polyphosphoric) acid: a solid or, usually, a viscous liquid composed of a mixture of orthophosphoric acid and polyphosphoric acids. Made by burning elemental phosphorus in air and absorbing the combustion products in dilute orthophosphoric acid, or by evaporating water at elevated temperatures from orthophosphoric acid solution. The P_2O_5 concentration is usually in the range of 69 to 83 per cent, on an impurity-free basis. On mixing with water, superphosphoric acid hydrolyzes to orthophosphoric acid.

Wet-process phosphoric acid: an impure orthophosphoric acid made by treating phosphate rock with sulphuric acid.

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VII. PRODUCTION OF AMMONIA

A. DEVELOPMENT OF THE INDUSTRY

Nitrogen is an essential component of most fertilizers. Although an adequate supply of this material is available in the atmosphere all over the world, it must be converted into a fixed form before it is suitable for plant use. Ammonia (NH_3) is the principal form in which fixed nitrogen is available for the manufacture of fertilizers in the world today. It contains 82.2 per cent nitrogen. In 1960, world production of ammonia was about 13 million tons, with almost 11 million tons used for the manufacture of fertilizers. In the United States of America alone, the current annual capacity is about 12 million tons, and by the end of 1968 it is expected to exceed 18 million tons.

Only three industrial processes have been developed during the past 165 years for the fixation of atmospheric nitrogen. These are: (*a*) the electric-arc process for the production of nitric acid; (*b*) the process for the manufacturing of calcium cyanamid; and (*c*) the process for reacting hydrogen with atmospheric nitrogen to produce ammonia. The electric-arc process and the process for manufacturing calcium cyanamid became obsolete because they could not compete economically with the process for synthesizing ammonia.

The production of ammonia by reacting hydrogen with atmospheric nitrogen is the basis for the nitrogen fertilizer industry today. The first full-scale ammonia plant was placed on stream in 1913 for Badische Anilin-und Soda-Fabrik A.G. (BASF) by Fritz Haber and Carl Bosch at Oppau, Germany. The process became known as the Haber-Bosch process. Although several other processes have been developed since 1913, the main differences between the Haber-Bosch process and other processes are the method for the preparation of synthesis gas, the purification of synthesis gas, the design of the ammonia converter and the method for recovering ammonia from the converter effluent gas.

Prior to 1945, coal or coke was the major raw material used for the production of hydrogen required for ammonia synthesis. During the past twenty years, there has been a continuing trend towards the use of petroleum products. Most of the plants built during the past fifteen years were designed for the use of natural gas or heavy oil as feed-material; during the past five years, naphtha has become the most popular feed-material in areas of the world where natural gas is not available. Many of the old plants have been converted to the use of petroleum products. Petroleum feed-materials are now used to produce over half of the world production of ammonia and over 90 per cent of that produced in the United States of America. Practically all of the ammonia plants in the United States are now based on natural gas, which is available in most areas of the country through transcontinental pipelines.

Major expansion of the ammonia industry began in 1963. The demand for nitrogen-based fertilizers throughout the world and the prospects for increased consumption in future years stimulated fertilizer producers to build many new ammonia plants. During the last three years, a trend has developed towards building large single-train plants with capacities of 600-1,500 tons per day. However, in contrast to this trend was the development of small-scale packaged plants with capacities of 60-120 tons per day.

During the past twenty years, many improvements have been made in the technology and design of ammonia plants. Significant improvements have been made in plant equipment, catalysts and instrumentation. These developments have contributed to substantial reductions in the capital cost and operating costs for ammonia plants.

B. RAW MATERIALS

All processes for manufacturing ammonia utilize atmospheric air as the source for nitrogen. Hydrogen can be produced from almost any hydrocarbon or carbonaceous material. However, careful consideration must be given to the choice of raw material because ammonia-plant operating costs are greatly influenced by the cost for producing hydrogen. Several reasons for the trend towards the use of gaseous or liquid hydrocarbon materials in preference to such solid fuels as coke, coal or lignite are: (*a*) the discovery of large deposits of natural gas and oil in various areas of the world, subsequently resulting in a price advantage for these materials over solid fuels; (*b*) lower transportation costs; (*c*) development of efficient ammonia processes; and (*d*) lower capital and production costs, and comparative ease of operation for plants designed for the use of gaseous or liquid hydrocarbons.

The change towards the use of gaseous and liquid hydrocarbons in preference to solid fuels occurred in the United States of America prior to 1950, when natural gas became available in large quantities and offered a price advantage over coke. This trend later spread to Japan and, more recently, to the United Kingdom of Great Britain and Northern Ireland. Many of the ammonia plants in Europe have continued to follow the traditional pattern of using coal, lignite and coke-oven gases as the sources for hydrogen.

Most of the developing countries are following the trend towards the use of natural gas when it is available, or of importing naphtha or oil. In 1959, about 85 per cent of the ammonia produced in India was based on coke and coal, whereas it is anticipated that about 75 per cent of the total production in 1970 will be based on fuel oil, naphtha and natural gas, with the use of coke and coal decreasing to about 20 per cent. However, several developing countries have large deposits of coal or lignite, but do not have deposits of natural gas or crude oil. It can be expected that some of these countries will continue to use coal or lignite as feed-material for ammonia production, especially those which have a large surplus of labour or have encountered difficulty with foreign exchange of currency.

1. *Natural gas*

Natural gas is present in various regions over the world. Its composition varies, depending on the geographical location and the type of deposit. Essentially, the gas is mainly methane mixed with higher hydrocarbons, gaseous impurities and inerts. Natural gas can be classified as "associated" or "non-associated". Associated gas occurs with crude oil; it is liberated from the oil when pressure is reduced in the gas-oil separator plant. The composition of associated gas varies with the pressure at which the gas is released from the oil, its methane content decreases as pressure on the crude oil is decreased. Non-associated gas is not liberated from crude oil, but comes directly from the well; it is composed mainly of methane, with small amounts of ethane and higher hydrocarbons.

Natural gas usually contains 60-96 per cent methane and 4-40 per cent ethane and other higher hydrocarbons of the paraffin series. The crude gas may contain dust and gaseous impurities, such as hydrogen sulphide and other sulphur-bearing compounds. These impurities must be removed before the gas is suitable for use as feed-stock for ammonia synthesis. Usually, the dust is removed by filtration and the sulphur compounds are removed by scrubbing with a suitable solvent.

It is desirable that natural gas used as raw material for ammonia synthesis contain a high concentration of methane. Methane (CH_4) provides a lower ratio of carbon to hydrogen than does ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}) and other higher hydrocarbons present in natural gas. In the ammonia process, all the carbon in natural gas is subsequently converted to carbon dioxide or carbon monoxide, which must be removed in the gas purification step prior to ammonia synthesis. Therefore, smaller and less expensive purification units are required for plants which use natural gas feed with a consistently high methane content. Extensive information regarding the quantity and quality of the natural-gas supply should be available prior to the design and construction of the ammonia plant.

Table 18 shows the reserves, production and life index of the natural-gas supply in various areas of the world. Most of the large natural-gas reserves are in oil-producing regions. Currently, there is no evidence of a world shortage of natural gas. However, high costs are involved in transporting the gas to potential markets in countries where no natural gas exists. In the United States of America, natural gas is transported in pipelines which are thousands of kilometres in length. Pipelines are now used for transporting natural gas from reservoirs to consuming areas in many other countries. This trend must continue in order to utilize gas which is available in areas with no local market.

During the last few years, transporting of liquefied natural gas by refrigerated tankers has gained popularity. The capacities of the tankers range from about 14,000 to 28,000 tons. The approximate cost for transporting liquefied natural gas by refrigerated tankers is given in table 19.

Table 20 shows the price of natural gas in various countries of the world. In chapter XXI, figure 66 shows how ammonia production costs are influenced by the price of natural gas.

2. *Naphtha*

During the last five years, naphtha has become one of the more important raw materials for ammonia synthesis. Suitable naphtha feed-stocks are straight-run liquid petroleum distillate fractions with a final boiling-point no higher than about 215° Centigrade. For economic reasons, the sulphur content of the naphtha should be as low as possible. Sulphur compounds act as poisons to catalysts used in the ammonia process and therefore must be removed. The use of cracked naphthas is usually not recommended because of the difficulty which might be

TABLE 18. NATURAL-GAS RESERVES AND PRODUCTION IN VARIOUS AREAS OF THE WORLD

Country	*Reserves, end of 1961*	*Production 1961*	*Non-associated gas* [a]	*Life index (years)* [b]
	(Millions of cubic metres)			
Africa				
Algeria	1,415,851	1,416	1,204	1,000
Angola	198	—	0	—
Congo [c]	142	—	0	—
Gabon	850	—	0	—
Libya	104,773	113	11	927
Morocco	283	28	0	10
Nigeria	7,079	340	0	21
Senegal	170	—	0	—
Tunisia	283	—	0	—
United Arab Republic	12,035	396	40	30
TOTAL	1,541,664	2,293	1,255	672

TABLE 18 *(continued)*

Country	*Reserves, end of 1961*	*Production 1961*	*Non-associated gas* [a]	*Life index (years)* [b]
		(Millions of cubic metres)		
South America				
Argentina	169,902	4,814	2,166	35
Bolivia	7,079	170	85	42
Brazil	9,911	850	425	12
Chile	50,971	2,549	1,275	20
Colombia	39,644	2,322	766	17
Equador	2,124	113	0	19
Peru	20,530	1,104	110	19
Trinidad	33,980	2,917	0	12
Venezuela	934,462	33,980	3,058	28
TOTAL	1,268,603	48,819	7,885	26
Middle East				
Abu Dhabi	84,951	—	0	—
Bahrain	3,681	227	0	16
Iran	1,840,606	7,079	1,062	260
Iraq	637,133	7,079	0	90
Israel	1,133	28	19	40
Kuwait	934,462	7,787	0	120
Neutral Zone	56,634	538	0	105
Qatar	212,378	1,416	0	150
Saudi Arabia	1,274,266	8,070	0	158
Syria	2,265	—	0	—
Turkey	991	28	0	35
TOTAL	5,048,500	32,252	1,081	157
Asia and Far East				
Borneo [d]	12,743	510	0	25
Burma	4,248	85	26	50
India	21,096	113	0	187
Indonesia	56,634	2,265	0	25
Japan	14,159	850	765	17
Pakistan	424,755	821	813	517
Papua	12,743	—	0	—
Philippines	28	—	0	—
Taiwan	283	28	22	10
Thailand	28	—	0	—
TOTAL	546,717	4,672	1,626	117
North America				
Canada	1,019,413	20,190	15,748	50
Mexico	283,170	10,137	7,603	28
United States of America	7,787,179	382,280	267,596	20
TOTAL	9,089,762	412,607	290,974	22
Western Europe				
Austria	24,069	1,699	1,359	14
Federal Republic of Germany	42,476	708	552	60
France	254,853	5,663	5,550	45
Italy	141,585	6,796	6,456	21
Netherlands	600,321	595	589	1,009
United Kingdom	142	28	28	5
TOTAL	1,063,446	15,489	14,534	69

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[a] Natural-gas production from sources which are not associated with crude oil.

[b] Life index computed by dividing reserves at end of 1961 by production in 1961.

[c] Refers to the Congo (Brazzaville) and the Congo (Léopoldville).

[d] Refers to the whole island of Borneo.

TABLE 19. APPROXIMATE COST FOR TRANSPORTING LIQUEFIED NATURAL GAS [a]

(Dollars)

Distance (kilometres)	*Approximate cost per ton*
2,574 [b]	4.9
4,500	8.5
6,000	11.3
8,000	15.0
10,308 [c]	19.3

[a] Transported by refrigerated tanker of 16,000-ton capacity.

[b] Approximate distance from Algeria to north Europe.

[c] Approximate distance from Persian Gulf to Japan.

TABLE 20. EXPORT AND IMPORT PRICES OF NATURAL GAS FOR SEVERAL COUNTRIES OF THE WORLD

(Dollars)

	Price range per thousand cubic metres
Importing countries	
France:	
Lacy area	12.36-17.66
North	21.19-22.95
India:	
Assam (well-head)	4.94- 7.06
Italy:	
North	10.59-15.89
South	7.06- 7.77
Japan:	
Niigeta	17.66-21.19
Tokyo	26.49-33.55
Pakistan:	
Well-head	5.30- 5.65
Karachi	10.59-14.13
Taiwan:	
Chinshui	14.13-17.66
United Kingdom	21.19-28.25
Exporting countries or area	
Persian Gulf	0.35- 1.77
Algeria:	
Well-head	3.53- 3.88
Sea coast	6.36-10.24
Borneo [a]	7.06-10.59
Indonesia	8.83-12.36
Nigeria	4.24- 6.36
Trinidad	3.53- 5.30
Venezuela	2.47- 5.30

[a] Refers to the whole island of Borneo.

TABLE 21. TYPICAL ANALYSIS OF STRAIGHT-RUN LIGHT NAPHTHA

Test	*Analysis*
Sp. Gr., 15.6°/15.6° C	0.669
ASTM distillation	
IBP, °C [a]	37.2
FBP, °C [b]	118.9
Heating value, lower, kcal/kg	10,340
Composition (weight percentage)	
Sulphur	0.03
Hydrogen	15.97
Carbon	84.00
Butane	3.30
Pentanes plus	96.70
Aromatics	5.00
Naphthenes	9.00
Paraffins	86.00

[a] Initial boiling-point.

[b] Final boiling-point.

encountered in the removal of the sulphur. A typical analysis of straightrun light naphtha suitable for use as feed-material for ammonia production is given in table 21.

Naphtha is produced during the refining of crude oil and can be processed further to yield gasolene. However, during the last ten years, the demand for the production of gasolene from naphtha has declined because of an increase in use of diesel oil and kerosene as sources of energy. Therefore, with an excess supply of naphtha available in the world today and in the foreseeable future, the market price has declined sufficiently to give naphtha an economic advantage over other liquid or solid raw materials suitable for ammonia synthesis. Naphtha is now the preferred raw material in all areas of the world where natural gas is not readily available.

The range in price of naphtha at north European ports is given in table 22. In chapter XXI, figure 66 compares the costs of producing ammonia with naphtha and with natural gas, and shows how production costs are influenced by the prices of these raw materials. If the market prices of other liquid and solid raw materials continue to remain stable, naphtha will retain its economic advantage as long as its price does not exceed about $26 per ton.

TABLE 22. PRICE OF NAPHTHA AT NORTH EUROPEAN PORTS

(Dollars)

	Cost per ton			
	Caribbean source		*Middle Eastern source*	
Item	*High*	*Low*	*High*	*Low*
Price, f.o.b.	21.60	17.70	19.70	15.70
Freight	3.80 [a]	2.20 [b]	6.60 [a]	4.20 [b]
TOTAL COST	25.40	19.90	26.30	19.90

[a] Average for 1963.

[b] Average for 1960-1965.

Although naphtha is highly volatile and flammable, it presents no serious storage or transportation problems. Safety measures similar to those required when handling gasolene are adequate. Naphtha can be transported by pipeline or by such bulk carriers as trucks, barges or ships. No refrigeration is required.

3. *Heavy fuel oil*

Beginning about 1950, heavy fuel oils, e.g., bunker C and navy special, became popular as raw materials for the production of ammonia synthesis gas in countries where natural gas was not available. A partial-oxidation process was used. Earlier difficulties encountered in use of the heavy oils were associated with problems resulting from carbon and sulphur removal from the raw synthesis gas. These problems have been solved by the development of improved methods for removing carbon and more efficient solvents for sulphur removal.

Almost any type of oil can be used as raw material for the partial-oxidation process, the choice depending on economic factors. A typical analysis of a heavy fuel oil suitable for use as feed-stock is given in table 23.

TABLE 23. TYPICAL ANALYSIS OF HEAVY FUEL OIL

Test	*Analysis*
Sp. Gr., 15.6°/15.6° C	0.97
Viscosity, SSU at 37.8° C	3,500
Pour-point, ASTM, °C	15
Heating value, lower, kcal/kg	9,829
Composition (weight percentage)	
Conradson carbon	10.20
Ash	0.07
Sulphur	3.50
Hydrogen	11.30
Carbon	84.60
Nitrogen	0.40
Oxygen	0.13

The only significant difficulty encountered in transporting or handling the heavy fuel oil is its high viscosity. Heat must be applied to keep the heavy oil in a liquid state and to reduce its viscosity.

At the current time, heavy fuel oils cannot compete economically with naphtha as raw materials for ammonia synthesis. Whether heavy oils can regain an economic advantage depends on the results of future research and development work on the partial oxidation process for ammonia production, and on the future availability of naphtha at a competitive price.

4. *Coal and lignite*

As mentioned previously, coal and lignite became less important as feed-stock for ammonia production when processes for using petroleum materials were developed. Only twenty-five years ago, coal (usually in the form of coke) was the major raw material for ammonia synthesis. In 1939, over 90 per cent of the world ammonia capacity was based on coal. Now, practically all new plants are designed for use of natural gas, naphtha or fuel oil, and many of the older plants have been converted to the use of these materials. No plants are now operating on coal or coke in the United States of America. However, several plants in Europe and Asia use coal gasification processes.

Coal is not an attractive raw material for ammonia production. Even in developing countries where cheap coal is available, it cannot compete economically with liquid or gaseous petroleum materials. Usually the deposits of the more competitive coal reserves have high ash content and low calorific values, with the best coal generally being reserved for metallurgical purposes. The processes required for coal gasification are elaborate, and plant investment, maintenance and operating costs are higher than for petroleum-based plants.

Table 24 shows the coal production for several of the developing countries.

TABLE 24. COAL PRODUCTION IN SEVERAL COUNTRIES OF THE WORLD

Country	*Thousands of tons produced in 196[illegible]*
Afghanistan	49.4
Burma	0.1
China	
Taiwan	3,962.0
Mainland	425,000.0
India	52,610.0
Indonesia	657.0
Iran	200.0
Japan	52,600.0
Malaysia	7.0
Pakistan	831.6
Philippines	147.8
Republic of Korea	5,352.0
Republic of Viet-Nam	27.3
Thailand	147.0
TOTAL	541,591.2
TOTAL, less mainland China	116,591.2

The price of coal will usually vary from approximately \$5 to \$8 per ton at the mine. The cost for lignite containing about 50 per cent moisture (heating value, about 2,800 kcal/kg) will approximate \$3 per ton. Lignite is currently being used for manufacturing ammonia in Greece, India, Thailand, Turkey and the Federal Republic of Germany. Table 25 shows the analysis of low-grade coal and lignite mined in India.

In future years, the popularity of coal as a raw material for ammonia production may increase because coal reserves are thought to be more plentiful than petroleum reserves, and the cost of coal has not advanced as rapidly in recent years as the cost of natural gas.

TABLE 25. ANALYSIS OF LOW-GRADE COAL AND LIGNITE MINED IN INDIA

Test	*Singareni coal*	*Neyveli coal*
Moisture	3.70	52.00
Volatile matter	26.69	2.28
Ash	29.97	22.40
Fixed carbon [a]	39.64	23.32
Heating value, kcal/kg [b]	4,877	2,560

[a] By difference.

[b] Air-dried basis.

TABLE 26. AVAILABILITY OF LIQUEFIED PETROLEUM GASES IN DIFFERENT AREAS OF THE WORLD

	Millions of tons available from				
	Natural gas [a]				
Area	*Associated*	*Non-associated*	*Total*	*Refinery gas*	*Total*
Europe	0.3	0.8	1.1	6.3	7.4
Africa	0.3	0.1	0.4	0.3	0.7
Middle East	10.0	--	10.0	1.9	11.9
Asia	0.9	0.1	1.0	2.2	3.2
TOTAL	11.5	1.0	12.5	10.7	23.2
South America	13.2	0.4	13.6	4.3	17.9
GRAND TOTAL	24.7	1.4	26.1	15.0	41.1

[a] Associated natural gas occurs with crude oil, whereas non-associated gas comes directly from the well.

5. *Liquefied petroleum gas*

Liquefied petroleum gas is propane and butane separated by liquefication from natural gas or from refinery gas; it might contain pentane and higher hydrocarbons. Therefore, the principal sources of liquefied petroleum gas are oil refineries and natural-gas processing plants, and it has not yet become an important raw material for production of ammonia.

Table 26 shows the amounts of liquefied petroleum gas available in several areas of the world; the total estimated quantity available in Europe, Africa, South America, the Middle East and other Asiatic countries is about 41 million tons. For comparative purposes, North America has a total potential availability of about 42 million tons.

The market price of liquefied petroleum gas is governed mainly by local supply and demand conditions, with no extensive international trading. In northern Europe, prices range from $25 to $35 per ton. It is not likely that this material will be used extensively for ammonia production in the near future because of the availability of natural gas and naphtha. Liquefied petroleum gas will continue to offer an advantage over naphtha for use as bottled gas and for enriching town gas for heating purposes because of its higher calorific value.

6. *Electrolytic hydrogen*

Pure hydrogen can be produced for ammonia synthesis by electrolyzing water, with oxygen produced as a by-product. The source of nitrogen is an air-separation plant which also produces by-product oxygen. The cost of producing ammonia from electrolytic hydrogen depends on the price of electricity and the value of the by-product oxygen.

Canada, Japan and Norway are among those countries where electrolytic hydrogen is used for ammonia synthesis. However, it is reported that several electrolytic hydrogen-based plants in Japan have changed to oil gasification. During the Second World War, electrolytic hydrogen provided a source for heavy water; and after extraction of deuterium, the by-product hydrogen was used for ammonia synthesis.

In recent years, relatively large ammonia plants based on electrolytic hydrogen have been built in the United Arab Republic (100,000 tons of nitrogen *per annum*) and in India (70,000 tons of nitrogen *per annum*). A small ammonia plant (40 tons per day) based on electrolytic hydrogen was built at Alwaye, India, and it is planned to utilize the by-product oxygen at this facility in the production of additional synthesis gas by a naphtha partial-oxidation process.

It is not likely that large ammonia plants based on electrolytic hydrogen will prove economical in the near future. In some very special cases, small plants might be justified.

7. *By-product hydrogen*

The most important source of by-product hydrogen is coke-oven gas. The gas is rich in hydrogen content (up to 50 per cent) and contains some ammonia which can be recovered as *aqua* ammonia, ammonium sulphate or ammonium phosphates. The ammonia-free gas is scrubbed to remove carbon dioxide and sulphur compounds, and is dried; the remaining hydrocarbon impurities are removed by liquid nitrogen wash. An air-separation plant is required for purifying coke-oven gas and, consequently, is economically attractive to steel mills which need oxygen for the operation of blast-furnaces.

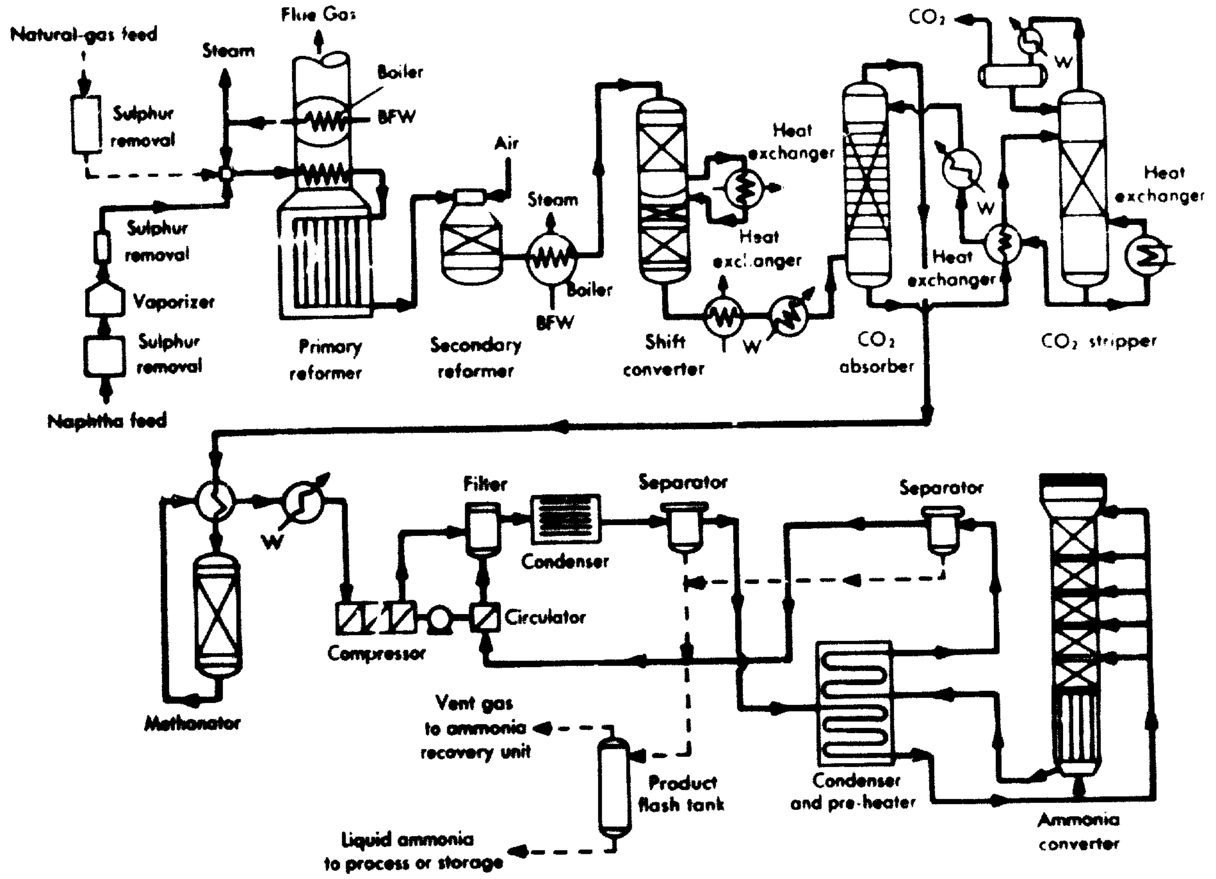
Other sources of by-product hydrogen are chlorine-caustic plants, petroleum refineries and plants producing ethylene, acetylene and butadiene.

In the developing countries, chlorine-caustic plants are usually small and thus will not produce sufficient hydrogen to justify ammonia synthesis. A chlorine plant with a capacity of 500 tons per day will supply sufficient hydrogen for the production of about 60-65 tons of ammonia per day.

C. MANUFACTURING PROCESSES

The major steps involved in manufacturing anhydrous ammonia are: (*a*) gas preparation; (*b*) carbon monoxide conversion; (*c*) gas purification; and (*d*) ammonia syn-

Figure 3. Flow diagram for synthesizing ammonia by the steam-reforming process



thesis. An engineering firm can offer prospective customers a choice of several processes for each of the major steps.

Practically all of the ammonia plants built during the last fifteen years have used the steam-reforming process or the partial-oxidation process for the gas preparation step. During the last ten years the steam-reforming process has developed to the extent that it is now the most popular process. Plants designed for use of this process are relatively easy to operate; and investment, operating and maintenance costs are comparatively low.

Figure 3 shows a flow diagram for a modern ammonia plant utilizing the steam-reforming process. Natural gas or naphtha can be used as feed-stock.

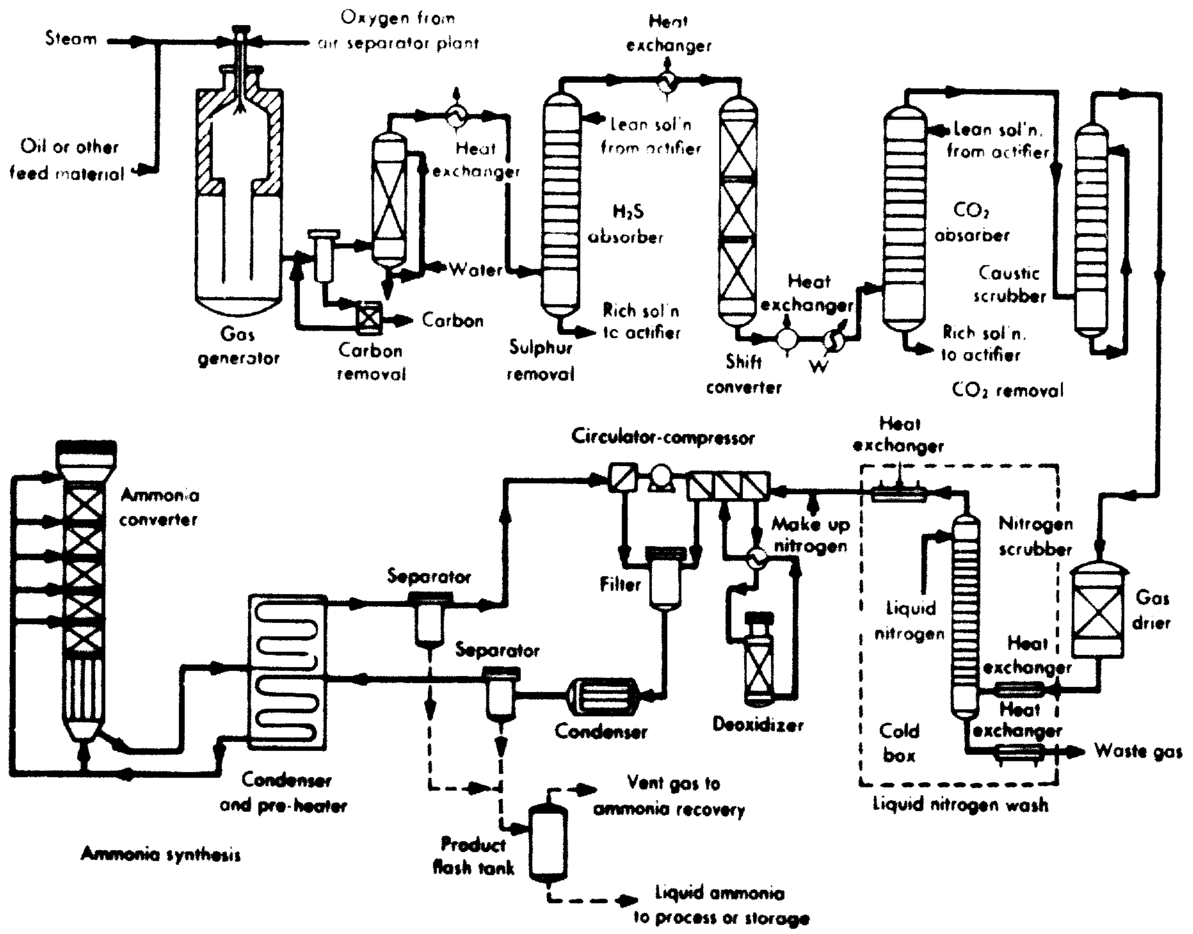
The steam-reforming process can be designed for use with any one of several modern types of gas purification systems, with no limitation on capacity up to at least 1,500 tons of ammonia per day.

Before building an ammonia plant, careful consideration must be given to factors which affect investment and operating costs. A large part of these costs is associated with compressing the purified make-up gas. Prior to 1962, single-train plants were limited in capacity to about 400 tons per day; these plants were designed for use of reciprocating compressors to compress the make-up gas to about 280 kg/sq cm. A total of sixteen new ammonia plants with capacities ranging from 1,000 to 1,500 short tons (equivalent to 907 to 1,360 metric tons) per day are scheduled to be operating in the United States of America by 1968. These large single-train plants will use centrifugal compressors instead of the reciprocating type and will synthesize ammonia at pressures in the range of 140 to 210 kg/sq cm. The use of centrifugal compressors instead of the traditional reciprocating units will significantly reduce plant investment and operating costs. However, the economy offered by centrifugal compressors is limited to the larger plants designed to produce approximately 600 short tons (equivalent to 544 metric tons) per day. In chapter XXI, figure 64 shows the operating costs for plants of different capacities. The operating cost data are based on plants using the steam-reforming process and natural gas as feed-stock; the data are based on use of reciprocating compressors for plants designed for production of less than 600 tons of ammonia per day and centrifugal compressors for those designed to produce over 600 tons per day.

Figure 63 shows the investment costs for plants of different capacities designed for using the steam-reforming process with natural gas and naphtha as feed-stock. The cost data are based on battery limits plants designed by engineering firms in the United States and constructed in the Gulf Coast area. When naphtha is used as feed-stock instead of natural gas, additional facilities are required for the removal of sulphur and a larger purification unit is required for removal of carbon dioxide. Therefore, as shown in figure 63, investment costs are higher for plants designed for use of naphtha as feed-stock.

A comparison of production costs for plants of different capacities, based on natural gas and naphtha feed-stocks, is shown in figure 65. These data show that production costs decrease rapidly as plant capacities are increased from 100 tons per day to about 400 tons per day, and continue to decrease slowly as plant capacities are increased to as much as 1,000 tons per day. Figure 66

Figure 4. Flow diagram for synthesizing ammonia by partial-oxidation process



shows how the costs for natural gas and naphtha feed-stocks influence the cost for producing ammonia in plants designed for production of 400 short tons per day, using the steam-reforming process.

Figure 4 shows a flow diagram for an ammonia plant utilizing the partial-oxidation process. This process offers the advantage of being applicable for utilizing a variety of feed-stocks, ranging from natural gas to heavy fuel oil and crude petroleum. One disadvantage to the process is that an air-separation plant is required to provide oxygen, thus increasing investment costs about 25 per cent above the cost of the same size plant designed to use the steam-reforming process. Also, the design and operation of single-train plants of this type becomes complicated as the capacity is increased to approximately 300 tons of ammonia per day. At the current time, plants utilizing the partial-oxidation process cannot compete economically with the larger plants using the steam-reforming process.

Efficient operation of the ammonia plant requires close, reliable analytical control. During the past few years much progress has been made towards the development of industrial gas analysers suitable for monitoring the process gas streams. Infra-red analysers are used in modern plants to measure, on a continuous basis, the methane content of gas leaving the reformer units or partial oxidation units. The infra-red analysers are also used to measure carbon dioxide and carbon monoxide in gas at various stages of the purification step and make-up gas to the ammonia synthesis step. The industrial gas chromatograph is suitable for measuring all components in the various process gas streams. Thermal-conductivity gas analysers are reliable for measuring hydrogen in any gas stream and ammonia in gas to and from the synthesis converter. Analysers of the para-magnetic type are suitable for measuring oxygen in flue gas from the primary reformer or the purity of oxygen from an air-separation plant.

1. *Gas preparation*

As mentioned previously, the major processes for preparation of ammonia synthesis gas are steam reforming and partial oxidation. However, several variations of each type of process are available. Several variations of the coal-gasification processes are also available. Each process produces a gas rich in hydrogen and carbon monoxide; the carbon monoxide is later converted to carbon dioxide generating hydrogen by reaction with steam in the shift converter.

(a) *Steam reforming*

Steam reforming of natural gas is usually carried out in two stages by use of primary and secondary reformers containing a nickel catalyst. The catalyst in the primary reformer is contained in tubes heated externally. The secondary reformer contains a single bed of catalyst. Feed to the primary reformer consists of a mixture of steam and natural gas. A controlled amount of air is added to the process gas stream as it enters the secondary reformer to provide sufficient oxygen to reform residual methane and to supply the required volume of nitrogen to maintain a 3:1 ratio of hydrogen to nitrogen in the ammonia synthesis make-up gas. Reactions between steam and natural gas (primarily methane) to produce hydrogen are:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$
$$CH_4 + 2H_2O \rightleftharpoons CO_2 + 4H_2$$

The usual composition of gas leaving the secondary reformer is (volume percentage dry basis): CO_2, 10.4; CO, 10.0; H_2, 57.2; N_2, 22.1; and CH_4, 0.3.

Steam is produced by heat recovered from flue gas leaving the primary reformer furnace and process gas leaving the secondary reformer.

Sulphur compounds must be removed from the natural gas to prevent poisoning of the reformer catalyst. Usually, the gas is passed through beds of iron oxide to remove hydrogen sulphide and then through activated carbon for removal of organic compounds of sulphur.

Prior to about 1952, natural-gas reformers were designed for operation at pressures no greater than about 2.5 kg/sq cm because of the danger of tube failure. New alloys and improved methods of fabrication have now made pressure operation common practice. Modern reforming units are designed for operation at pressures of about 28 kg/sq cm. This development has improved the economy of ammonia production by conserving pressure of the incoming natural gas, eliminating the need for compression of process gas for the purification step, reducing the size of plant equipment needed and decreasing the volume of required catalysts. All the major engineering firms offer designs for the high-pressure steam reforming of natural gas.

The main differences between the process for the steam reforming of natural gas and that for the steam reforming of naphtha are: special techniques and equipment are required for removing sulphur compounds from naphtha; equipment is required for vaporizing naphtha; a special catalyst, which is more resistant to poisoning by sulphur is used for reforming naphtha; and a larger capacity purification system is required for the removal of carbon dioxide.

The Imperial Chemical Industries (London) performed most of the earlier research and development work on the naphtha-reforming process. The Chemical Construction Corporation and other engineering firms offer processes or process modifications for the reforming of naphtha.

Ammonia producers now recognize that plants based on coal gasification cannot compete with those based on hydrocarbons and that economy favours the large-capacity plants. Recently, Imperial Chemical Industries Limited, the largest nitrogen producer in the United Kingdom, announced their plan to utilize the naphtha-reforming process in a modernization programme which involves the construction of three new units, each of which is designed to produce 900 tons of ammonia per day. Shellstar, Ltd. (Shell Chemical Company and Armour and Company) recently announced their plan to build a large ammonia plant in England (900 tons per day), based on naphtha reforming.

(b) *Partial oxidation*

Although several processes have been developed for producing ammonia synthesis gas by partial oxidation, the two most significant ones were pioneered by Texaco Development Corporation and the Shell Development Company. Feed materials to the gas generator are steam, oxygen and the hydrocarbon feed-stock. The gas generator operates at a pressure of about 30 kg/sq cm.

Advantages which the partial-oxidation process offers over the steam-reforming process are: no catalyst requirement; lower heat requirements; toleration of impurities in the feed-stock; and adaptability to a wide range of hydrocarbon feed-stocks. When the process was first developed, it had the advantage of pressure operation, but this advantage was eliminated by pressure reforming. One important disadvantage to partial oxidation is the high cost of the air-separation plant required to produce oxygen for the process.

When heavy fuel oil or crude oil is used as feed-stock, the generator off-gas contains sulphur compounds which are removed by scrubbing with a suitable solvent, e.g., diethanolamine solution, before the gas enters the shift converter. Considerable difficulty was experienced by some of the earlier plants with carbon carry-over in the process gas from the generator. This problem has been solved by improved carbon recovery units.

Whether the partial-oxidation process can regain advantage over the steam-reforming process depends on the results of future research and development work. Current studies involve increasing the operating pressure of the generator in an effort to regain the compression advantage over the steam-reforming process.

(c) *Autothermal*

The Autothermal process, developed by Haldor-Topsoe and Soc. Belge de l'Azote, is a combination of steam reforming and partial oxidation. All the heat required for the operation is generated at the top of the reactor vessel by reaction between oxygen and the hydrocarbon feed-stock. Feed-stocks range from natural gas and naphtha to refinery gases and liquid petroleum gas. The reactor feed-materials consist of steam, air, oxygen and the hydrocarbon feed-stock. The reactor vessel contains beds of special nickel-base catalyst. Air is the source of nitrogen. The process operates at pressures of about 17 kg/sqcm or higher without difficulty.

The Autothermal process offers the advantage of not requiring catalyst tubes, which can present problems in the operation of the high-pressure steam-reforming process. However, one disadvantage is the need for an air-separation plant to provide oxygen for the process.

(d) *Gasification of coal*

Many processes have been developed for the gasification of coal. Two of the more important are the Lurgi process and the Koppers-Totzek process. Both processes use steam, oxygen and coal or lignite as feed-materials.

In the Lurgi process, a mixture of steam and oxygen is passed into a bed of coal maintained at about 985° C. Although gas flows continuously from the generator, coal in the form of small lumps is fed in batches. This process is employed in ammonia plants operating in the Republic of Korea and Turkey.

The Koppers-Totzek process requires pulverized coal as feed-stock. A mixture of oxygen and coal-dust is passed into the gas generator where steam is introduced. The operating temperature is 1,100° to 1,400° C. Gas flow is continuous. This process offers the advantage of operating with gaseous or liquid hydrocarbon feedmaterials as substitutes for coal. Plants using the Koppers-Totzek process are operating in France, Japan, Spain and several other countries.

2. *Carbon monoxide conversion*

Gas leaving the preparation unit is mixed with steam and passed through a converter containing a catalyst, where the carbon monoxide is converted to carbon dioxide generating hydrogen by the water-gas shift reaction:

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

For economic reasons, it is important that the conversion of carbon monoxide to hydrogen be as high as possible. Variables which affect conversion are: concentrations of carbon dioxide, carbon monoxide and steam in the gas entering the shift converter; catalyst temperature; pressure; catalyst activity; and gas space velocity.

Modern shift converters operate at pressures of about 14 kg/sq cm or higher, whereas plants built prior to 1950 converted carbon monoxide at near atmospheric pressure. Plants operating at elevated pressure require less catalyst for a given level of carbon monoxide conversion.

Before the advent of the high-pressure operation, the only carbon monoxide conversion catalyst available was a mixture of iron and chromium oxides. This catalyst is not active below about 350° C and is usually operated in the range of 350° to 450° C. By careful control of catalyst temperature, carbon monoxide leaving a conversion unit of this type can be kept below 1.5 per cent. A modification of the basic design involves the use of two-stage carbon monoxide conversion, with carbon dioxide removal between the two stages. Removal of carbon dioxide from the gas leaving the first stage reduces its adverse effect on equilibrium and results in the lowering of the carbon monoxide in gas leaving the second stage to about 0.3 per cent. Plants of this type require carbon dioxide absorbers before and after the second-stage converter.

Recently a catalyst composed of zinc, chromium and copper oxides, which is active at 175° to 250° C, was developed. This low-temperature catalyst will reduce carbon monoxide in the converter outlet gas to 0.2 per cent or less.

Modern carbon monoxide converters are designed to utilize both a high-temperature catalyst and a low-temperature catalyst. Zinc oxide can be used to absorb hydrogen sulphide from gas before it enters the low-temperature catalyst bed to protect the catalyst from poisoning by this impurity. The converter units should be designed to allow bypassing of the low-temperature catalyst during start-up or other abnormal periods of operation.

3. *Carbon dioxide removal*

Process gas entering the purification step contains a large amount of carbon dioxide which must be removed. Most of the old ammonia plants use water as the scrubbing agent. The scrubbing operation is performed at about 18 kg/sq cm, and the carbon dioxide in the gas stream is usually reduced to about 1 per cent. There are several disadvantages to using water as a solvent for carbon dioxide. First, since it is relatively inefficient, there is a high power cost for pumping the large volume of water required. Secondly, hydrogen absorbed by the water is lost unless a recovery system is installed. Finally, the carbon dioxide evolved from the water when the pressure is released is not suitable for use in the manufacture of urea because of the presence of hydrogen and other inert gases. Several new processes have been developed in recent years for the removal of carbon dioxide from synthesis gas. All of the new processes employ solvents, which are more efficient than water for absorbing carbon dioxide.

(a) *Monoethanolamine*

Probably the most effective solvent for removing carbon dioxide from synthesis gas is a 15-20 per cent solution of monoethanolamine. The solution is circulated continuously through absorber and stripping towers. Usually the monoethanolamine scrubber is designed to reduce the carbon dioxide content to about 200-300 parts per million; in plants where liquid nitrogen wash is used for the final purification step, the system is designed to reduce the CO_2 content to about 50 parts per million.

Purity of the CO_2 released from the monoethanolamine in the stripping tower is usually about 99 per cent, which is satisfactory for the production of urea.

Disadvantages to the process are corrosion problems encountered by many plants and the relatively large amount of heat required for regenerating the solution.

(b) *Hot potassium carbonate*

This process utilizes an aqueous solution of hot potassium carbonate as the absorbent. The solution is not as effective as monoethanolamine for removing carbon dioxide from synthesis gas, but the heat and cooling-water requirements are much less.

Three modifications of this process have been developed which improve absorption of carbon dioxide and reduce corrosiveness of the solution. These are the Giammarco Vetrocoke, the Catacarb and the Benfield Additive processes.

The Vetrocoke process uses a mixture of potassium and sodium carbonates, with arsenic oxide and other inorganic additives to effect more efficient removal of carbon dioxide. Thus, the Vetrocoke process is more nearly comparable to monoethanolamine in its absorption characteristics and retains the advantage of lower heat requirements. The use of air stripping for regeneration of the solution will further reduce the amount of heat required.

The Catacarb process and the Benfield Additive process utilize a hot carbonate solution containing promoters which improve carbon dioxide absorption and inhibitors to retard corrosion.

(c) *Sulphinol*

A recent development by the Shell Development Company is the sulphinol process. The operation of this process is similar to that of monoethanolamine. The scrubbing solution consists of a mixture of tetrahydrothiophene dioxide (trade name, Sulfolane) and diisopropanolamine. This process offers several advantages over monoethanolamine including a lower heat requirement for regeneration, a lower degradation rate, a higher capacity for absorption of CO_2 and the fact that it is less corrosive to carbon steel.

(d) *Fluor solvent*

The Fluor Corporation investigated several organic solvents for CO_2 including: propylene carbonate; glycerol triacetate; butoxy diethylene glycol acetate, and methoxy triethylene glycol acetate. The Fluor solvent process is recommended primarily for purifying gases containing high concentrations of carbon dioxide at high pressures.

4. *Final gas purification*

Process gas leaving the carbon dioxide scrubbing system contains small amounts of carbon oxides, which must be reduced to less than 10 parts per million before the gas is suitable for ammonia synthesis. Three processes which are available for use are methanation, copper solution and liquid nitrogen wash.

(a) *Methanation*

The methanation process involves heating the gas stream to about 300° C and passing the hot gas through a nickel-base catalyst. Under these conditions, the carbon oxides react with hydrogen to form methane and water:

$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O$$

$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O$$

The water is removed from the gas after it leaves the methanator; methane is not removed because it does not harm the ammonia synthesis catalyst. The equipment cost for methanation is comparatively low, and there is no operating cost except for the initial charge of catalyst. The main disadvantage to this process is the hydrogen loss by reaction with carbon oxides and the loss of hydrogen from purging required to control the concentration of methane in the recirculating gas of the synthesis loop.

Methanation is most economical in plants that utilize a low-temperature catalyst for carbon monoxide conversion and monoethanolamine for carbon dioxide removal, thus limiting the carbon oxide content of gas entering the methanator to about 0.35 per cent.

(b) *Copper solution*

Copper solution is the oldest of the processes used for final gas purification. The absorbing agent is a solution of cuprous and cupric ammonium acetate, cuprous and cupric ammonium formate, or a mixture of the two.

A typical analysis of plant copper solution is (grammes per litre): total copper, 116.4; cuprous copper, 93.3; cupric copper, 23.1; total ammonia, 144.2; carbon dioxide, 96.2; acetic acid, 39.6; formic acid, 6.6. The process gas is scrubbed with cold copper solution at obout 120 kg/sq cm to reduce the carbon oxide content to less than 5 parts per million.

Operation of the copper solution process is much more complex than the methanation process, and the corrosiveness of the solution results in higher maintenance costs. Very few copper solution systems have been designed for ammonia plant use during the last ten years.

(c) *Liquid nitrogen wash*

Liquid nitrogen wash removes not only the carbon oxides, but also argon and methane. This results in a synthesis gas so free of impurities that very little purging is required. Because of the cost of the air-separation plant required for producing liquid nitrogen, this type of purification system is generally specified only for plants which include the partial-oxidation process for gas preparation. Feed-gas to the nitrogen scrubber must be free of carbon dioxide and moisture. These impurities are removed by scrubbing the feed-gas with caustic, followed by drying with a desiccant. A deoxidizer unit protects the ammonia synthesis catalyst from trace amounts of oxygen present in the purified gas leaving the nitrogen scrubber by reacting the oxygen with hydrogen to form water.

5. *Ammonia synthesis*

Ammonia is synthesized by the reaction between hydrogen and nitrogen at elevated pressure and temperature in the presence of a catalyst:

$$3H_2 + N_2 \rightleftharpoons 2NH_3$$

The catalyst which is universally used is composed of iron oxides and contains promoters of aluminium, potassium, magnesium and calcium oxides. The catalyst is not active until the iron oxides have been reduced. Both oxidized and prereduced catalysts are available from manufacturers, but final reduction takes place after it is charged into the plant converter.

Variables which affect ammonia conversion are pressure, temperature, hydrogen-nitrogen ratio, argon and methane concentration, space velocity and catalyst activity. The equilibrium is favoured by higher pressures and lower temperatures.

In the past, most ammonia converters were designed to operate at space velocities of 10,000 to 20,000 cubic metres of effluent gas per hour per cubic metre of catalyst. Modern converters operate at much higher space velocities, with the current limit being about 50,000.

Since the reaction rate increases as the catalyst temperature increases, temperature control is an important factor in the operation of the synthesis converter. Unfortunately, it is necessary to operate near the temperature at which deactivation of the catalyst occurs, and materials of construction suffer damage in order to attain an acceptable conversion efficiency. Only a few processes operate above 540° C.

The main difference between the two general types of ammonia synthesis converters which are in use today is the method of temperature control. One type employs multiple beds of catalyst with provisions for cooling the gas between the beds by means of cooling coils or quenching with cold gas. Examples of this type are converter designs by the M. W. Kellogg Company and Fauser-Montecatini. The other type of converter utilizes gas flow and heat exchangers to control the temperature

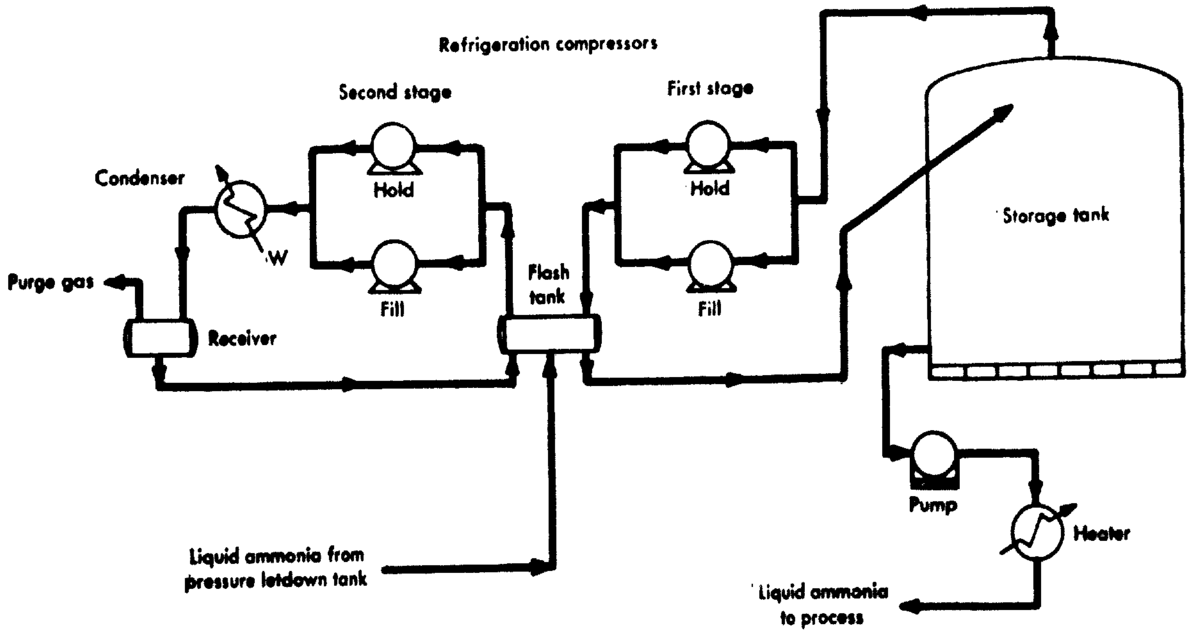


Figure 5. Facility for storage of anhydrous ammonia at atmospheric pressure

of the catalyst bed. The processes of the Chemical Construction Corporation, Mont Cenis, Claude and the Tennessee Valley Authority employ converters of this type of design.

The Claude process, which originally operated at about 1,000 kg/sq cm, has been modified for operation at lower pressures to allow recycling of the converter effluent gas. The Casale process, which operates at about 500 kg/sq cm, provides for a unique aspirator type of ejector system to circulate the recycle gas, in place of a circulator compressor.

Engineering firms are now considering ways to avoid the mechanical and fabricating problems associated with the design of single-train plants with capacities above 1,000 tons per day. A recent development by Topsoe is the radial-flow converter said to be capable of producing well above 1,000 tons per day, with the possibility of attaining 2,000 tons per day.

D. LOW-PRESSURE STORAGE OF AMMONIA

The rapid growth of the ammonia industry during the past few years has resulted in a need for large-capacity storage facilities. The recent development of storage tanks with capacities of 4,000 to 30,000 tons, which operate at slightly above atmospheric pressure, was the answer to this need. Figure 5 shows a flow diagram for a typical atmospheric storage facility.

The storage facility consists of the following equipment: flash tank; storage tank; refrigeration compressors; ammonia condenser; ammonia receiver; ammonia pump; and ammonia heater.

Liquid in the storage tank is maintained at slightly above atmospheric pressure (usually 0.02 to 0.06 kg/sq cm) and near its boiling-point (about −33° C). Ammonia vapour from the storage tank is compressed to about 4 kg/sq cm. The compressed gas flows into the flash tank, where it is cooled by contact with liquid ammonia. Vapour from the flash tank is compressed to about 16 kg/sq cm and passed through a water-cooled condenser; the condensate is collected in a receiver. Inert gases are released from the receiver. Liquid ammonia flows from the receiver to the flash tank and then back to the storage tank. Before ammonia from the storage tank is used for process or loaded into tank cars for shipment, its temperature is raised to 5°-15° C by passing it through a heat exchanger. The heat exchanger may use hot water or steam as the heating medium. Instrumentation provides completely automatic operation.

Two types of storage tanks are in use — one of double-wall construction, the other of single-wall construction. The investment cost for the double-wall tank is greater than that for single-wall construction, but maintenance costs are lower.

Investment costs and operating costs for atmospheric storage facilities with capacities ranging from 6,000 tons to 16,000 tons are shown in figure 69.

In the future, it is anticipated that many large storage facilities will be built in remote geographical areas, and ammonia will be transported to these locations from the large-capacity plants. The ammonia can be transported by rail or waterway. Figure 67 shows costs for shipping ammonia by rail; figure 68 shows costs for transporting ammonia by ocean-going ships. Many large plants will be located on coastlines and rivers to take advantage of lower costs for transporting ammonia by large refrigerated barges at atmospheric pressure.

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VIII. CRITERIA FOR PRODUCTION *VERSUS* IMPORTATION OF AMMONIA

In the last two or three years, considerable interest has been aroused in the bulk transport of anhydrous ammonia in ocean-going ships. For long-haul shipment to be economically feasible, several conditions must be met.

First, ammonia has to be made at a tidewater location, using cheap natural gas in a large plant and at a minimum cost. Secondly, it has to be transported in suitable ocean-going ships at the lowest cost possible. Thirdly, appropriate facilities must be prepared in the receiving country. In addition to port terminals for unloading, facilities to convert the ammonia into solid fertilizers may be required; alternatively, a system for direct application of ammonia to the soil can be developed.

In respect to ammonia, developing countries of the world fall into three broad categories. These are: (*a*) small countries which have cheap hydrocarbon resources, e.g., natural gas, and which have a small internal market; (*b*) large countries which have a substantial internal market, but which do not have abundant and cheap hydrocarbon resources; and (*c*) countries which have neither large internal consumption nor plentiful hydrocarbon resources. The happy situation where a large internal market is coupled with abundant and cheap natural gas seldom exists. Hence, the idea has developed of making ammonia in areas of the world where a low cost is feasible and transporting it to countries with a large internal market for conversion into solid fertilizers. This has attracted the attention of many developing countries, and various investigations and studies have been made on the economics of production *versus* importation of ammonia. Some typical examples of countries with large and cheap resources of raw materials for ammonia production are Algeria, Bahrain, Indonesia, Iran, Libya, Nigeria, Saudi Arabia, Trinidad and Venezuela. Examples of large countries with big internal markets are mainland China, India and Pakistan. Small developing countries without a large internal market and lacking abundant and cheap natural resources should seriously consider the alternatives before launching a fertilizer project. A key question for decision is whether to build an ammonia production plant (which is very capital intensive on a small scale), or to consider building less capital-intensive facilities to prepare fertilizers based on imported ammonia. The foreign-exchange requirements for importing capital equipment for ammonia plants should, of course, be weighed against the foreign-exchange costs of importing ammonia. The ultimate decision must be grounded on the over-all national interest and, specifically, on how best to provide cheap fertilizers to the farmers. Regional, interregional and international co-operation in this field present a challenging opportunity for both the developing and the developed countries of the world.

A. PRODUCTION COSTS OF AMMONIA

Typical production costs are given below (table 27) for ammonia at a tidewater location in a country with cheap natural gas, compared with production costs in a country lacking cheap natural gas, but using naphtha from petroleum refineries. In the latter case, naphtha is in excess, as the imbalance between motor-fuel consumption and the consumption of kerosene and diesel fuel happens to be large.

TABLE 27. PRODUCTION COSTS OF AMMONIA IN PLANT WITH CAPACITY OF 200,000 TONS PER ANNUM

(Dollars per ton)

	I *Location in a country using natural gas*	*II* *Location in a country using naphtha*
1. Gas for raw material (21,000 cu ft/t at $0.10 per thousand cubic feet)	2.10	—
2. Gas for heating and [illegible] drive (15,000 cu ft/t at $0.10 per thousand cubic feet) . .	1.50	—
3. Naphtha (0.8 ton/ton at $20.00 per ton)	—	16.00
4. Electric power (for I: 30 kWh at 5 mills per kWh; for II: 700 kWh at $0.01 per kWh)	0.15	7.00
5. Other operating costs	4.00	5.32
6. Capital charges at 20 per cent of capital cost	13.60	17.70
TOTAL	21.35	46.02

Notes:

1. Estimated construction costs by a European, American or Japanese construction firm include ocean freight. Capital cost does not include customs duties, pre-construction costs, licence fees, "know-how" fees, interest on capital during construction or the cost of housing or other amenities for staff or workers. Working capital is not included.

2. "Other operating costs" include catalysts, process chemicals, miscellaneous supplies, water, steam, operating and maintenance labour, administration and overhead.

3. Capital charges include 10 per cent depreciation, 7 per cent interest on total capital and 3 per cent for maintenance materials. Capital charges on working capital are not included.

The estimates of cost of production show that where cheap natural gas is available, ammonia can be produced at less than 50 per cent of the cost by using naphtha at international prices.

Assuming storage and terminal charges covering both loading and unloading ends to be about $6 per ton, and ocean transportation charges for a 5,000-mile distance to be $10 per ton, it is possible to land ammonia at around $37 per ton, compared with the production cost of $46 per ton at a location using naphtha. There is suffi-

TABLE 28 APPROXIMATE COST OF TRANSPORTING AMMONIA IN REFRIGERATED OCEAN-GOING SHIPS

Loading/discharging	*Steaming distance (nautical miles)*	*Estimated transport cost (dollars per ton)*
Trinidad/Wilmington, N.C.	1,703	4.5
Trinidad/London	4,010	9.3
Trinidad/Melbourne	9,130	21.2
Kuwait/London	6,545	15.8
Kuwait/Madras	2,612	6.1
Kuwait/Manila	5,166	11.0

cient difference in these two costs to warrant considering the importation of ammonia in preference to local production.

Table 28 shows the approximate cost of transportation of ammonia in refrigerated ocean-going ships.

B. TRANSPORTING LIQUID ANHYDROUS AMMONIA

The experience of a large company in the United States of America, with both production and ship transport facilities, was outlined in a paper prepared for the United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries, held in Teheran in 1964. In regard to the the advances made in this field, the paper stated:

> "In recent years, a major technical and economic breakthrough has been accomplished in the development of a means of transporting liquid anhydrous ammonia at −28° F at, essentially, zero pressure. This technical achievement has made it economically feasible to transport shiploads of anhydrous ammonia over long distances at a relatively low unit cost per ton".[1]

Specially designed anhydrous ammonia cargo vessels are used to transport this commodity to various parts of the world.

In addition to the ability to transport anhydrous ammonia economically by tanker, there has been an equally significant technical and economic breakthrough in the production of this product. In 1957, the company under discussion erected a small plant at Point Lisas, Trinidad, with an annual capacity of 35,000 tons of anhydrous ammonia, which was converted to ammonium sulphate and urea. It was planned to market these products in the Caribbean area. The plant site offered many advantages: the availability of natural gas, a key raw material, at a reasonable price; the generation of electric power through the use of natural gas as a primary fuel; a deep-water harbour adjacent to the site; and favourable labour and political conditions. Therefore, when it became economically feasible to ship anhydrous ammonia throughout the world, the above-mentioned factors favoured the expansion of production in Trinidad and Tobago to supply the growing market for anhydrous ammonia. Consequently, an expanded plant with a production capacity of 230,000 tons *per annum* was put into operation in January 1964.

The report also stated that the company was constructing still another large production unit, which would also have an annual production capacity of 230,000 tons of anhydrous ammonia. The total anticipated output of 495,000 tons *per annum* would make the company's Trinidad plant one of the largest anhydrous ammonia production centres in the world.

Prior to sale, the ammonia is stored locally in terminals owned wholly or in part by the producer or wholly by others. The producer has recently formed a company to distribute ammonia for direct soil application in Denmark, where this practice is becoming widely used. Currently, 20,000-25,000 tons of anhydrous ammonia are annually applied directly to the soil in Denmark.

The use of ammonia for direct application is also increasing in northern France and Sweden, and has been introduced into other European countries. Terminals have been established in the United Kingdom of Great Britain and Northern Ireland (in the Thames Estuary) and in the United States of America (Tampa, Florida); similar terminals are under construction in Canada and Finland. These terminals are owned by others and are linked with chemical plants in the vicinity. The anhydrous ammonia is sold to the chemical plants for conversion into various kinds of nitrogen fertilizers and nitrogen-phosphate-potash mixed fertilizers.

C. ESTABLISHING FERTILIZER INDUSTRIES IN DEVELOPING COUNTRIES

The report cited above continued:

> "The establishment of low-cost bulk ammonia shipment opens a completely new approach for developing countries to become basic manufacturers of their fertilizer requirements and to establish an industrial complex that can employ their people usefully as well.
>
> "Many developing or newly emerging nations clearly realize the importance of sound agricultural development to their over-all development. Agriculture's most essential contribution to the economic development of a country is to provide the additional food required for a growing population, as well as its needs for fibres, building materials and other industrial raw materials of agricultural origin." [1]

An outline is given below of a plan which, in the author's opinion, can contribute greatly to the solution of two major problems confronting developing countries — the task of feeding their ever-increasing populations and the task of finding gainful employment for much larger numbers of workers.

In establishing a fertilizer industry, a developing country should first assess its own needs for these products. In addition to the lack of modern farm machinery, there are other inhibiting factors which must be considered carefully: the attitude of the farmer and his knowledge of fertilizer use, as well as his limited knowledge of, or

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[1] *Report of the United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries* (United Nations publication, Sales No.: 66.II.B.5), "The economics of international distribution of anhydrous ammonia", by W. J. Haude, vol. II, chap. 8, paper 7.

reluctance to try, the available improved crop varieties and agricultural chemicals. All these factors deter the growth of fertilizer use, thus tending to lengthen the time required to bring fertilizer consumption levels in economic balance with the proposed output of any fertilizer plant that might be constructed. There is, of course, the possibility of several countries in an area combining their requirements, or, alternatively, the manufacture of fertilizers for exportation might be considered. It should be noted, however, that both of these courses may entail considerable risk and difficulty.

There are many small ammonia synthesis plants which have, because of the economies of ammonia production, become high-cost producers requiring a substantial government subsidy in order to survive. The high cost of ammonia produced in relatively small-scale units is chiefly due to:

(*a*) The high capital cost of installation;

(*b*) Small intial market for plant output; this in turn, minimizes efficient production, which depends on full-volume, continuous operation;

(*c*) Lack of plentiful, low-cost hydrocarbon feed-stock, required for ammonia production;

(*d*) Relatively high-cost imported oil or hydrocarbon feed-stocks;

(*e*) High cost of electric power or lack of power generating facilities add materially to the original capital investment and production cost;

(*f*) Lack of technically trained personnel to operate the plant.

However, the above-mentioned deterrents could be minimized if a new fertilizer industry were based upon the concept of a refrigerated ammonia terminal and adjacent production facilities to convert the anhydrous ammonia to such products as nitric acid, ammonium nitrate, calcium ammonium nitrate, nitrogen solutions, urea, ammonium sulphate and finished nitrogen-phosphate-potash multinutrient fertilizers. Such a complex would be so devised as to supply the country's specific fertilizer needs.

Far less total capital investment would be needed for a complex of this nature than that required to install ammonia synthesis facilities. It would also avoid the necessity of constructing a rather costly small-volume ammonia plant to serve a slowly growing market.

The company in question has recently evaluated the potential of a number of developing countries for utilizing this type of complex, and it appears to be economically feasible under a wide range of conditions.

The company has established a fertilizer manufacturing facility based upon this concept. At its plant, Trinidad anhydrous ammonia is discharged from an anhydrous ammonia tanker to a 20,000-ton refrigerated storage tank. The plant facilities consist of a nitric acid plant, an ammonium nitrate unit, calcium ammonium nitrate facilities and a plant for the manufacture of a number of different nitrogen solutions to be used both for manufacturing compound fertilizers and for direct application to the soil.

While the size of this plant and the types of product manufactured are particularly suited to the agricultural demands of the east coast of the United States of America, such facilities could be employed in a developing country on a somewhat smaller scale to produce finished products in accordance with the agricultural needs of that country.

D. REFRIGERATED ANHYDROUS AMMONIA TANKERS

In January 1964, the first sea-going tanker designed expressly for the international shipment of anhydrous ammonia as a refrigerated cargo was launched in Rotterdam, the Netherlands. In June 1964, the tanker began transporting anhydrous ammonia from Point Lisas, Trinidad and Tobago to terminals on the eastern seaboard of the United States of America. This tanker was designed to carry either a complete cargo of anhydrous ammonia at a temperature of -28° F, or a complete cargo of propane at a temperature of -44° F, with both cargoes being transported at an atmospheric pressure ranging essentially from 0.5 to 2.5 pounds per square inch gauge. The characteristics of the vessel, as noted in the report previously cited, are as follows:

(*a*) Over-all length, 513 feet;

(*b*) Moulded breadth, 69 feet, 6 inches;

(*c*) Moulded depth, 41 feet;

(*d*) Draught in sea-water, 24 feet, 8 inches;

(*e*) Trial speed at full draught, 17 knots;

(*f*) Dead weight, 9,850 long tons;

(*g*) International gross registered tons, 10,001;

(*h*) International net registered tonnage, 6,061.

This tanker was built under special survey to conform to the highest class, +A1 (E) of the American Bureau of Shipping, with a special notation that the cargo holds were suitable to carry cargoes of liquefied petroleum gas at atmospheric pressure and temperature as low as -50° F; it meets the full requirements of the United States Coast Guard for ships carrying cargoes of anhydrous ammonia and the liquefied petroleum gases of propane, butane and butadiene.

Further details of the tanker's construction are given below:

"The hull is of all-welded construction made of normal ship's steel. The ammonia cargo is carried in four insulated individual cargo holds, which are made of a normalized carbon steel. This steel has been especially heat-treated to improve its notch toughness, that is, its ability to resist a brittle fracture at temperatures between -20° to -50° F. Each hold is surrounded by a secondary barrier that is capable of containing the chilled cargo, should a leak inadvertently occur in one of the primary cargo holds. A bone-dry inert gas is circulated through the void space that exists between the cargo hold and this secondary barrier. This void space is maintained at approximately 0.5 psig with inert gas to prevent the infiltration of moist sea air into the environment surrounding the chilled cargo tanks.

"The four holds have a combined capacity of 9,300 short tons of anhydrous ammonia, which has a specific gravity of 0.68 at an operating temperature of -28° F.

"The cargo is loaded onto the tanker from shore storage tanks at a temperature of −27° to −28° F. Heat gain into the cargo holds and into the loading lines is removed by a process known as the auto-refrigeration of the cargo. This means that the cargo vapours which are released from the free liquid surface are withdrawn into the first stage of a two-stage compressor and condensed at approximately 200 pounds pressure against a sea-water coolant. The condensed liquid ammonia is flashed back to atmospheric pressure into the cargo tanks to maintain these holds at their steady-state temperature of −27° to −28° F." [1]

While the tanker is being loaded in Trinidad, two identical York Marine Pak refrigeration units (located in the midship deck-house) are in operation. However, when the vessel is in the sea-way in either a fully loaded or a ballast condition, only one unit is used on an intermittent basis to maintain the low temperature level required.

Cargo is discharged by four deep-well Bingham pumps, which are capable of emptying the tanker in twelve hours. In addition to the pressure and vacuum relief-valves which are standard equipment, the cargo tanks are equipped with a liquid-level indicator, temperature probes and pressure-sensing equipment.

In the event of a fracture in the cargo container, a continuous sampling Beckman analyser would immediately detect the presence of a leak into the inert gas stream and would sound an alarm. The temperature probes, which are equipped with alarm overrides, sense any abnormal increase or decrease in temperature in the void space.

A special control room adjacent to the aft deck-house contains the instrumentation for control of the cargo pumps and for surveillance of the cargo system.

The tanker has air-conditioned quarters for a crew of thirty-eight men.

The MAN K8Z70/120D diesel engine, which develops 9,600 metric brake horsepower at 135 revolutions per minute, is capable of propelling the vessel at a speed of 17 knots, as was demonstrated in the trial runs.

Another tanker of the same type has recently been launched and will shortly enter regular runs on anhydrous ammonia service.

E. REFRIGERATED STORAGE OF ANHYDROUS AMMONIA

The company has had much experience in storing anhydrous ammonia under pressure as a liquid in standard spheres or hortonspheres and in the form of *aqua* ammonia in large carbon steel tanks of the oil-storage type. These units have certain limitations, particularly if the quantities to be stored are in excess of 6,000 short tons. The hortonspheres also have a size limitation and, currently 3,000 short tons is the approximate maximum that can be stored in a single unit because of excessive physical size and resulting cost. It is clear that *aqua* ammonia at 28 per cent ammonia content would require an exceedingly large number of storage tanks to contain 6,000 tons of anhydrous ammonia equivalent. In addition, *aqua* ammonia requires suitable recovery facilities for the anhydrous ammonia for use in other processes or applications. Furthermore, as *aqua* ammonia is a dilute solution, shipment of this material incurs a rather high cost penalty, owing to the large amount of water being transported.

The company has also had considerable experience in using railroad pressure tank cars and is now shipping anhydrous ammonia in single-unit tank cars which can carry 72 short tons. Trucks with a carrying capacity of between 12 and 20 short tons of anhydrous ammonia are also currently in service.

A technological and economic study to compare the storage of ammonia in large tanks in the form of *aqua* ammonia, in pressure spheres and in refrigerated tanks, proved and clearly established the point at which pressure storage spheres become uneconomical because of their size limitation and the large numbers of units which would consequently be required to store, say, 20,000 tons of anhydrous ammonia. One refrigerated storage tank can store the same amount and entails a considerably lower capital investment. The company has constructed or now has under construction five 20,000-ton refrigerated terminals, three 16,000-ton units, two 15,000-ton units and one 12,000-ton tank. Operating experience with these units has been very good, confirming the original conclusions that the refrigeration technique is the most economical system for large tonnage storage.

A developing country which would like to take advantage of this method of storage, owing to the country's small through-put of 12,500 to 30,000 tons *per annum*, might well consider the construction of a refrigerated terminal with a capacity of 10,000 or 14,000 short tons. According to the most recent quotations, a 14,000-ton terminal would require a capital investment of $735,000, while a 10,000-ton terminal would require an investment of $600,000. A breakdown of the investment required for a 14,000-ton terminal is given in table 29.

TABLE 29. CAPITAL COSTS FOR A 14,000-TON AMMONIA TERMINAL

	Cost $	*Percentage of cost*
Storage tank	253,600	34.5
Insulation	120,500	16.4
Compressors	95,600	13.0
Electrical	44,800	6.1
Foundations, buildings etc.	220,500	30.0
TOTAL	735,000	100.0

SOURCE: *Report of the United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries* (United Nations publication, Sales No.: 66.II.B.5), "The economics of international distribution of anhydrous ammonia", by W. J. Haude, vol. II, chap. 8, paper 7.

For easy access from the ship to the terminal, it is, of course, necessary that the terminal site be adjacent to suitable deep-water harbour facilities. However, such a location is essential for other reasons as well. It is necessary to keep the anhydrous ammonia ship's unloading line to a minimum length in order to minimize its cost and to reduce the mechanical work placed upon the anhydrous ammonia in pumping it through the longer line. The line friction and mechanical work results in a rise in temperature and a flashing of the ammonia as it discharges into the terminal tank. These vapours must be recompressed and returned to the storage tank as liquid, thus increasing the operating costs of the terminal refrigeration system.

Approximately one acre of land is required for a 14,000-16,000-ton terminal. The company's terminal in Tampa, Florida occupies 1.5 acres, consisting of a 16,000-ton storage tank, refrigeration machinery, tank-truck and railroad tank-car loading and weighing facilities, and a small office.

The question of supporting the storage facilities must be considered. The foundations required to support the storage tank and compressors, including any special requirements, are determined by the soil conditions of the location. In Tampa, Florida, the site was filled by dredging for the adjacent waterway. In driving the necessary piling for the intended load, the length was determined by actual soil-boring tests. Approximately 400 pilings support the main storage structure, with the pilings extending approximately 20 inches above normal ground level. After the pilings were trimmed, a 36-inch reinforced concrete slab was poured on top of them, resulting in a pedestal effect with a free air space of 20 inches between the bottom of the slab and the ground. The free air space prevents freezing of the moisture in the soil, thereby causing the formation of an iceberg, which could heave and cause a failure of the tank foundation.

In some locations, it has been found that the soil-bearing conditions are sufficiently high enough to permit pouring of the 36 inch concrete slab directly on the ground. In those cases, a suitable electric-heating grid was installed in the concrete foundation slab to prevent ground freezing.

The tank is constructed of a normalized carbon steel and is guaranteed Charpy tested at 15-foot pounds at —50° F, with an allowable stress of 21,000 pounds per square inch. The top and bottom of the tank are constructed of carbon steel of an ASTM A-201B type with an allowable stress of 18,000 pounds per square inch. The stress values given above are based on 0.3 of ultimate strength or 0.6 of yield strength, according to standards of the United States of America. The company believes this to be a rather conservative approach, and this belief has been confirmed as no difficulties have been experienced in the many installations now in operation.

All horizontal welds are made with automatic welding machines, while all vertical shell welds are fully X-rayed, except near the top where minimum plate thickness is used and spot X-raying is employed.

Although there are no established code specifications for this type of tank, the company has been following code procedure as detailed under API-620, where applicable.

All nozzle connexions are made from carbon steel of the ASTM A-333 type. Insulation of the tank is Pittsburgh-Corning Foamglas, 5 inches thick. The first course of insulation is 2.5 inches thick and is set up in hot asphalt with the edges dipped and set into place with the side next to the tank dry. The tank wall must be free of moisture. An air gap of one-half inch is allowed between the first and second 2.5 inch courses of Foamglas insulation. The second course of insulation is also dipped in hot asphalt and set in place, it is held in place by stainless-steel bands placed on 2-foot centres and machine stretched. Allowances are made for the necessary expansion joints in each layer of installation, and the expansion joints are sealed with a vapour barrier

After banding, the surface of the second course is spray-coated with an asphaltic mastic After this mastic has dried, the entire surface is covered with 0.020 inch thick corrugated aluminium sheeting which is held in place with pop rivets and suitable banding for further weather protection of the insulation. The tank roof is insulated in the same manner, but instead of using corrugated aluminium, the surface is covered with glass-cloth and is finished with a mastic coating.

The Pittsburgh-Corning Foamglas used has a K factor of 0.37 BTU/hr sq ft °F/in. A heat leak factor of 10.2 BTU/hr sq ft is used for this type of insulation, which is applied in the manner previously described.

The holding compressors and filling compressor are adjacent to the tank. Since the entire system is graphically panelled with all controls and instrumentation, one man can easily operate the unit; in fact, the operation in Tampa is completely automatic and can be made to operate unattended. The operator is needed primarily to load tank trucks and railroad tank-cars.

A detailed process flow diagram of the Tampa, Florida, storage terminal is shown in figure 6 on page 70.

The operating costs of a refrigerated anhydrous ammonia storage terminal vary, according to the annual through-put. A storage terminal with a capacity of 14,000 tons has a fixed capital investment of $735,000, as mentioned previously. However, this does not include the cost of the land or any extensive harbour or dock facilities. Assuming this capital investment depreciation on a fifteen-year basis and allowances for operating, labour and usual overhead charges, the terminal charges per short ton have been calculated at various annual through-put rates and are shown in table 30.

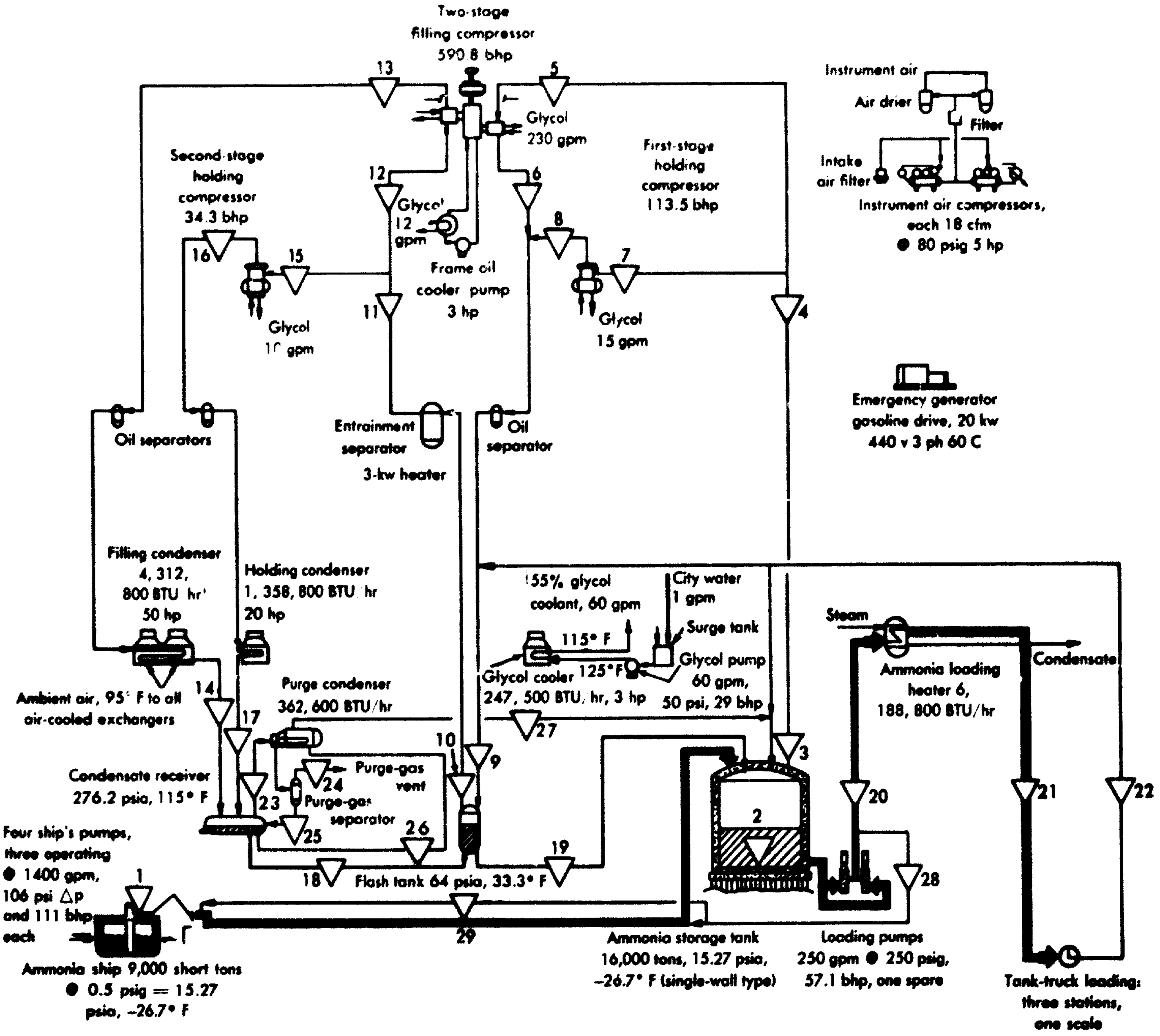
TABLE 30. ESTIMATED TERMINAL CHARGES 14,000-TON TANK

Annual through-put (short tons)	*Terminal charges per short ton (dollars)*
12,500	9.17
15,500	7.59
20,000	6.08
30,000	4.82

SOURCE: *Report of the United Nations Interregional Conference on the Development of Petrochemical Industries in Developing Countries* (United Nations publication, Sales No.: 66.II.B.5), "The economics of international distribution of anhydrous ammonia", by W. J. Haude, vol. III, chap. 8, paper 7.

Figure 7, on page 71, compares the corresponding terminal charge and annual through-put for two refrigerated terminals with capacities of 10,000 tons and 14,000 tons, respectively.

Figure 6. Process flow diagram, atmospheric ammonia storage, Tampa, Florida



SOURCE: W. R. Grace & Co., Nitrogen Products Division, Memphis, Tennessee.

F. DATA ON ANHYDROUS AMMONIA PLANT INVESTMENT AND PRODUCTION COST

Figures 8 and 9 present a further evaluation of the proposed scheme of basing a fertilizer industry upon Trinidad-produced ammonia.

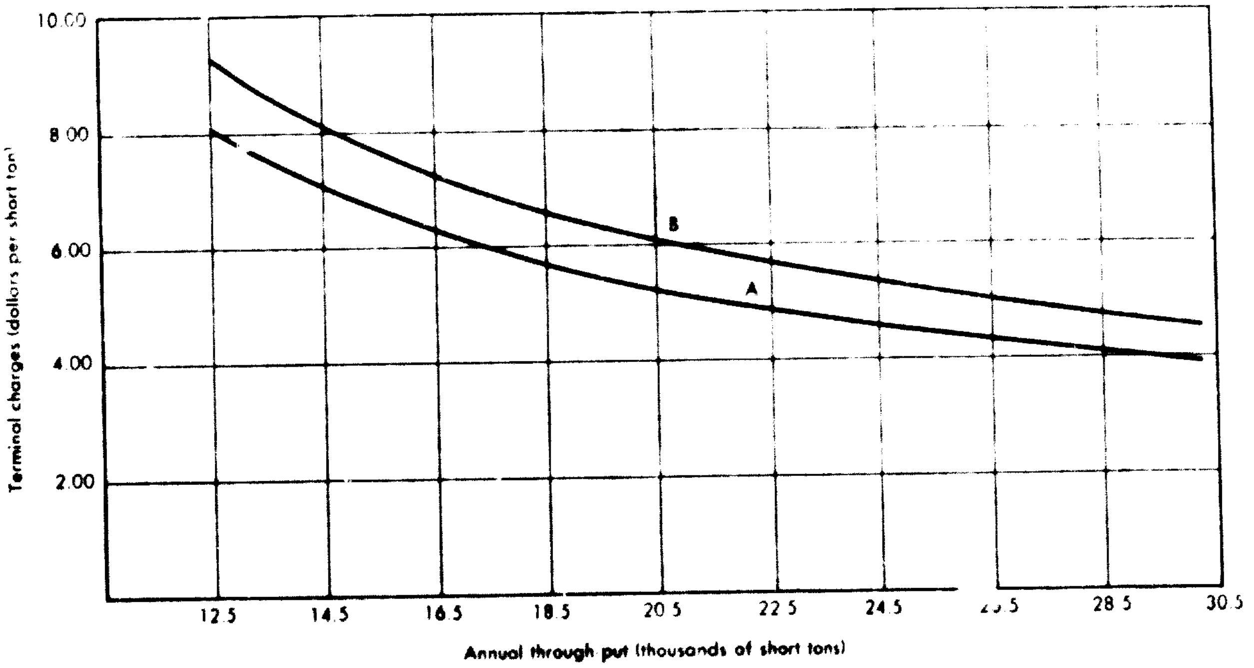
Figure 8 indicates the relationship between plant investment and plant capacity for various raw materials and processes.

A plant producing 100 short tons of anhydrous ammonia per day, or approximately 33,000 short tons *per annum*, and employing the steam reforming of naphtha as a hydrocarbon feed-stock incurs a cost of approximately $3.2 million for a battery-limits plant, according to figure 8. To this plant investment must be added the cost of the following so-called "off-site" facilities:

(*a*) Land;
(*b*) Buildings: office and laboratory;
(*c*) Shops: maintenance and stores;
(*d*) Steam generation;
(*e*) Water-wells and treatment;
(*f*) Electric-power distribution;
(*g*) Fire protection;
(*h*) Sewers, roads and railroads;
(*i*) Solid-products warehouses;
(*j*) Liquid-products storage tanks.

The experience of the company indicates that these items can add an additional 30-50 per cent to the battery-limits plant investment cost indicated in figure 8. In other words, the total cost for a plant to produce 100 short tons

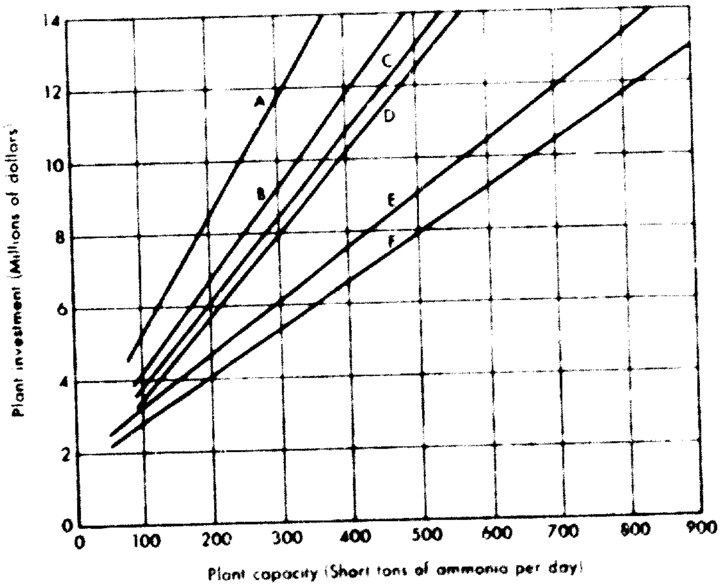
Figure 7. Terminal charges versus *annual through-put, according to capacity of refrigerated terminal*



Legend

A: Terminal with capacity of 10,000 short tons.
B: Terminal with capacity of 14,000 short tons.

Figure 8. Anhydrous ammonia: plant investment as related to plant capacity for various raw materials and processes



Source: The Sulphur Institute Washington, D. C.

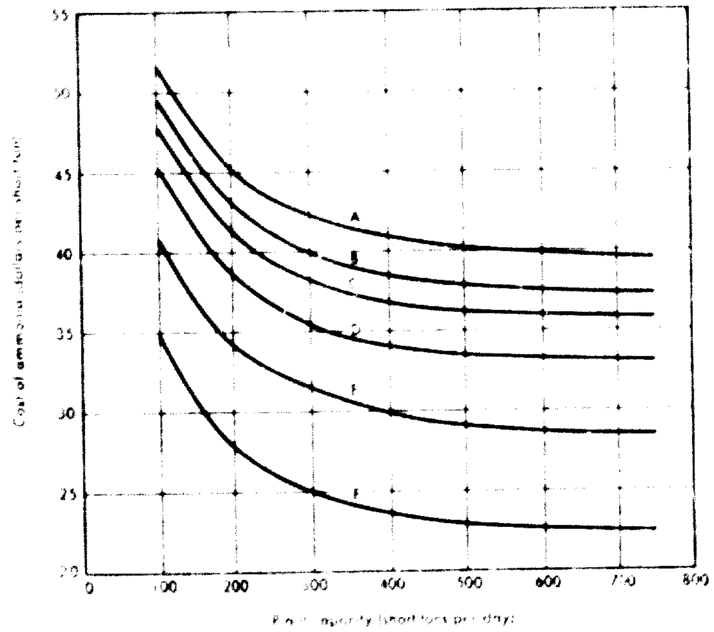
Note: Single-train, battery-limits plant.

Legend

Partial-oxidation process
- A: Coal
- B: Fuel oil
- C: Naphtha
- D: Natural gas

Steam-reforming process
- E: Naphtha
- F: Natural gas

Figure 9. Anhydrous ammonia: estimated production cost as related to plant capacity, type of raw material and process



Source: The Sulphur Institute, Washington, D. C.

Legend

Partial-oxidation process
- A: Coal, $6.50 per ton (12,000 BTU/lb
- B: Fuel oil, $0.06 per gallon (144,000 BTU/gal)
- C: Naphtha, $0.008 per pound (20,000 BTU/lb)

Steam-reforming process
- D: Naphtha, $0.008 per pound (20,000 BTU/lb
- E: Natural gas, $0.40 per thousand cubic feet (1,000 BTU/cu ft)
- F: Natural gas, $0.20 per thousand cubic feet (1,000 BTU/cu ft)

a day by naphtha steam reforming is estimated to be between $4.2 million and $4.8 million.

The cost of producing anhydrous ammonia with regard to plant capacity, type of hydrocarbon feed-stock material and process, is shown in figure 9. As may be seen, a plant producing 100 short tons of anhydrous ammonia per day *via* the steam reforming of naphtha has a production cost of $42.50 per short ton, not including depreciation and interest on capital employed.

Trinidad and Tobago, having a production capacity of nearly 500,000 short tons *per annum* and other favourable cost factors, may be regarded as one of the world's lowest cost producers of anhydrous ammonia. These low-cost production facilities combined with the unique, proved method of transportation by refrigerated tanker and refrigerated storage terminals, offers anhydrous ammonia to a developing country under a much more economical arrangement than if it had to make the investment to build its own plant. At the same time, it affords a developing country the opportunity to contribute to its industrialization by utilizing some capital in converting anhydrous ammonia to suitable forms of nitrogen fertilizers.

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IX. PRODUCTION OF AMMONIA SALTS, NITRIC ACID AND NITRATES

A. The development of nitrogen fertilizers

Nitrogen has long been recognized as an essential plant food and at one time was supplied entirely from organic sources in the form of blood, animal refuse, leguminous crops (1), vegetable wastes and similar materials. Fertilizers of this nature also contain varying amounts of phosphorus and potassium, although the individual and total nutrient values are low. Nevertheless, such materials are still used in some areas of the world in appreciable amounts for specific purposes or in the absence of more highly concentrated chemical fertilizers.

The increasing availability of man-made phosphates and potash salts in the latter part of the last century emphasized the need for adequate supplies of nitrogen to maintain properly balanced fertilizer programmes, as well as to meet rising nitrogen demands. Initially, guano from various countries, natural sodium nitrate from Chile (2), by-product ammonium sulphate from gas-works (3) and calcium cyanamide (4) were used as additional nitrogen sources, and the consumption of these materials quickly grew to substantial proportions. However, the nitrogen fertilizer industry owes its spectacular growth to the commercial production of synthetic ammonia, which was first made possible by the Haber-Bosch process (5) developed at Oppau, Germany, in 1913, when some 700 tons were produced in the first year. By 1962, world production of nitrogen from all sources approached 15 million tons *per annum*, and it is estimated that about 75 per cent of this total was derived from ammonia. The envisaged annual world production of ammonia, including the Union of Soviet Socialist Republics, during 1964 to 1965, is of the order of 14 million tons, which illustrates the stupendous growth of this major industry.

The availability of synthetic ammonia led, in turn, to the large-scale production of ammonium sulphate, ammonium chloride, ammonium phosphate, urea and nitric acid derivatives (e.g., ammonium nitrate, calcium nitrate and the nitrophosphates). In fact, the more recent availability of high-analysis nitrogen fertilizers in numerous forms has tended, in some countries, to underemphasize the simultaneous importance of adequate phosphorus and potassium. One way of ensuring balanced nutrient application is, of course, to supply plant needs in the form of multicomponent fertilizers as described elsewhere in this manual, on the basis of actual soil and crop requirements previously determined by experienced agronomists. This chapter is confined mainly to the manufacture of salts containing only nitrogen as a primary plant food.

World production and consumption figures for nitrogen fertilizers in recent years are shown in table 31, which also illustrates, in terms of nitrogen, the relative tonnages of the major salts produced.

Table 31. World production and consumption of fixed nitrogen, 1959/1960–1961/1962

(Thousands of tons)

	1959/1960	*1960/1961*	*1961/1962*
Production			
Sulphate of ammonia	3,087	3,134	3,084
Calcium cyanamide	313	302	290
Nitrate of soda	227	186	214
Nitrate of lime	424	462	467
Ammonium nitrate as such for use as fertilizer	1,419	1,669	2,124
Lime ammonium nitrate types	1,684	1,816	1,885
Ammonia and solutions as direct/indirect fertilizer	1,596	1,686	1,760
Urea for fertilizer use	578	779	979
Other forms of nitrogen	2,984	3,388	3,722
	12,312	13,422	14,525
Increase over prior year (percentage)	9.1	9.0	8.2
Consumption			
World total, all forms	12,269	13,089	14,395
Increase on prior year (percentage)	10.1	6.7	10.0
Use in agriculture by:			
Europe [a]	4,764	5,045	5,303
United States of America	2,861	3,115	3,569
Asia	2,269	2,336	2,664
Africa	325	337	401
Oceania [b]	48	60	63

Source: British Sulphate of Ammonia Federation Ltd., London.

[a] Including the Union of Soviet Socialist Republics.

[b] Including Hawaii.

B. Ammonium sulphate

1. *General information*

As can be seen from table 31, although such nitrogen fertilizers as urea, ammonium nitrate and ammonium phosphate show much higher rates of growth, ammonium sulphate continues to be made and used in very substantial quantities. This is particularly true in India and the Far East, where it is a popular fertilizer for rice paddies. Japan alone produced some 2.5 million tons of ammonium sulphate in 1961, and India and Taiwan anticipate an annual consumption of some 800,000 tons and 300,000 tons, respectively, by 1965/1966.

2. *Properties of ammonium sulphate*

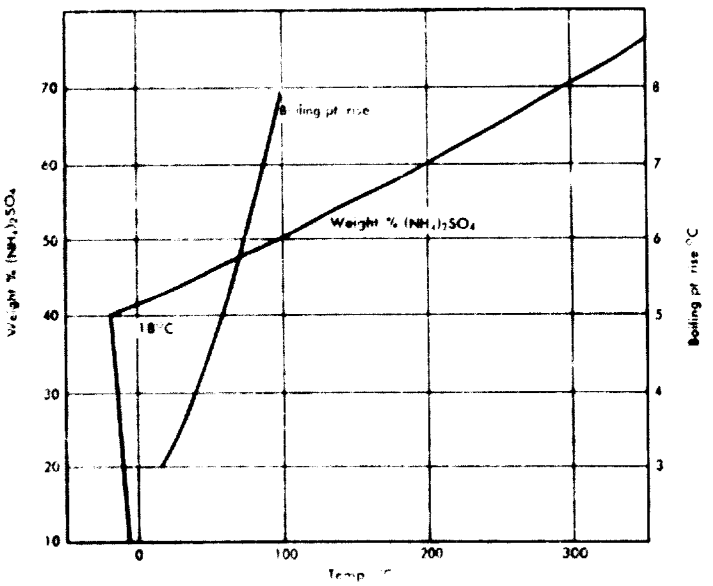
Table 32 shows the more important properties of crystalline ammonium sulphate.

Table 32. Properties of pure ammonium sulphate

Colour	White
Molecular weight	132.14
Density 20/4 C-solid	1.769
Specific gravity of saturated solutions	1.2414 at 20° C 1.2502 at 93° C
Specific heat-solid	0.345 at 91° C
Specific heat of saturated solutions	0.67 at 20° C 0.63 at 100° C
Heat of crystallization	11.6 cal/kg in 42 per cent solution
Heat of dilution	6.35 cal/kg from 42 per cent to 1.8 per cent solutions
Melting-point	512.2° C (954° F)
Thermal stability	Decomposes above 536° F
pH	5.0
Loose-bulk density	60 lb/cu ft
Angle of repose	28
Stoichiometric requirements (tons per ton of product)	NH_3 0.2578 H_2SO_4 0.7422
Critical relative humidity	At 20° C (68° F) 81 At 30° C (86° F) 81.1

The solubility system $(NH_4)_2SO_4$-H_2O is shown in figure 10.

Figure 10. Solubility data for system $(NH_4)_2SO_4$-H_2O



3. *Production methods*

Several different methods are used for ammonium sulphate manufacture, in accordance with available raw materials and local conditions.

The principal methods are:

(*a*) Reacting ammonia and sulphuric acid in a saturator-evaporator under vacuum or at atmospheric pressure and recovering the crystals *via* a centrifuge or filter;

(*b*) Scrubbing town gas or coke-oven gas with sulphuric acid in saturator units of special design and recovering the crystals by centrifuging or filtration;

(*c*) Reacting ammonium carbonate with calcium anhydrite or gypsum derived from natural or by-product sources, removing the calcium carbonate by filtration, evaporating and crystallizing ammonium sulphate from the mother liquor prior to centrifuging;

(*d*) Evaporating by-product liquors containing ammonium sulphate produced from other processes and separating the nearly pure salt by: (i) crystallization and centrifuging; or, alternatively (ii) recovering by slurry granulation on a moving bed and recycling in a drier-screening system to give granules of the required size range;

(*e*) Direct reaction between gaseous ammonia and sulphuric acid in a spray tower, to form a dry, amorphous product;

(*f*) Co-production with other ammonium salts in granulated fertilizer processes to produce phosphate, nitrate and nitrophosphate multinutrient fertilizers containing ammonium sulphate;

(*g*) Miscellaneous processes: several other processes have been proposed, e.g., the Pyritas Espanolas method (6), and various techniques for using flue gases as a sulphite/sulphate source have also been described (7, 8).

4. *Crystallization technology*

Except in special cases, such as those described in subparagraphs (*d*) (i), (*e*) and (*f*) above, crystallization is of major importance in ammonium sulphate production, as well as in the manufacture of other salts. Hence, it is appropriate at this stage to review briefly the fundamental process and design features which control crystal formation and influence plant performance (9, 10, 11, 12).

Two major considerations arise in crystallization technology; first, the formation of nuclei in a supersaturated solution; secondly, the growth of these particles to the product size-range required. In both of these stages, the driving force is the degree of supersaturation in the mother liquor, which, if allowed to rise appreciably, may induce uncontrollable nucleation. Subsequent crystal growth, however, is generally directly proportional to supersaturation, and, as a rule, is easier to control than nucleation.

When a solution is supercooled to a point just before fine, solid nuclei appear, it is termed metastable. After initial precipitation, this solution is said to be unstable or labile, and a constant addition of metastable liquor will cause each nucleus to grow into a single crystal. Thus, control of metastable conditions is a major factor in the design and operation of crystallization units; and critical items include residence time, agitation and equipment surface characteristics, as well as the pH, temperature, and soluble and insoluble impurities contained in the liquor. Hence, for continuous, stable operation, an equilibrium has to be established whereby the number of grown crystals removed equals the number of fresh nuclei formed. Under these conditions, uniformly sized crystals should result when a constant feed is supplied and average crystal size becomes a function of the production rate divided by the nucleation rate.

When the production rate is held constant, as in continuous operation, average crystal size is thus largely controlled by nucleation rate. One gram of typical nuclei may represent 1,000 million particles; hence, a continuous crystallizer must provide a way of controlling the number of nuclei and fines produced in this system and also contain provisions for classifying the product in order to minimize subsequent washing, drying and storage problems. Modern crystallizers are designed to incorporate these features and are also provided with control equipment to ensure virtually automatic operation.

After growth and classification to the required size, ammonium sulphate crystals are removed from the unit by various means, such as a salt catch-pot, an air-lift or a helical screw, and separated from the mother-liquor by a centrifuge, washed with water (and/or ammonia liquor) and dried in a rotary-shell drier prior to screening and storage. In some plants, the production of large, well-washed crystals and the use of high efficiency centrifuges eliminate the need for a drier. However, when small crystals are produced and particularly when impurities are present, drying, cooling and, perhaps, conditioning with an anti-caking agent may be unavoidable.

Other methods of crystal recovery and treatment include the use of a top-feed rotary vacuum filter-drier and also the conversion of small crystals into fragmented material of larger particle sizes by means of a compactor installation. Such machines are especially suitable for the relatively small tonnages of sulphate produced in some coke-oven by-product units. In a few instances, pug-mills or drum-type pelletizers are used to produce granulated sulphate from by-product caprolactam liquor or other waste streams containing ammonium sulphate in appreciable quantities.

5. *Chemical and physical specifications*

Fertilizer-grade ammonium sulphate specifications normally indicate a minimum nitrogen content, which is usually not less than 20.5 per cent. Limitations on free acidity and free moisture are also generally demanded, typical figures being 0.02 per cent for free H_2SO_4 and 0.2 per cent for free H_2O. Occasionally, maximum values for certain organic or inorganic impurities may also be specified for by-product material.

Crystal size-range specifications depend on customer requirements and the type of application. In recent years the preference in the United States of America and several other countries has been for the rice type of crystals, particularly for bulk-blending and aero-application, a 90 per cent retention on a 20-mesh Tyler screen being typical. To obtain crystals of this size, considerable design and operating skill is usually needed, and in some plants, additives are used to promote crystal growth (13). Compactors can also be used for this purpose, especially if crystal growth is inhibited by impurities or design limitations. An example of a smaller-size ammonium sulphate specification for general-purpose fertilizer use is given in table 33.

TABLE 33. PARTICLE SIZE SPECIFICATION FOR A TYPICAL FERTILIZER-GRADE AMMONIUM SULPHATE

Under 0.2 mm	2 per cent, maximum
0.2 to 0.5 mm	18 per cent, maximum
0.5 to 1.0 mm	60 per cent, maximum
1.0 to 3.0 mm	20 per cent, maximum
Above 3.0 mm	Nil

6. *Production details*

(a) *Combined reaction-evaporation methods*

Large tonnages of ammonium sulphate are produced from anhydrous ammonia and strong sulphuric acid in continuous saturator-crystallizer units operating either under vacuum or atmospheric pressure. In installations of the vacuum type, the heat of reaction is removed by evaporating water either present in the feed acid or added to the system for temperature-control purposes. This technique is also used for saturators of the atmospheric type; alternative cooling can be achieved in the latter by blowing large volumes of air through the slurry.

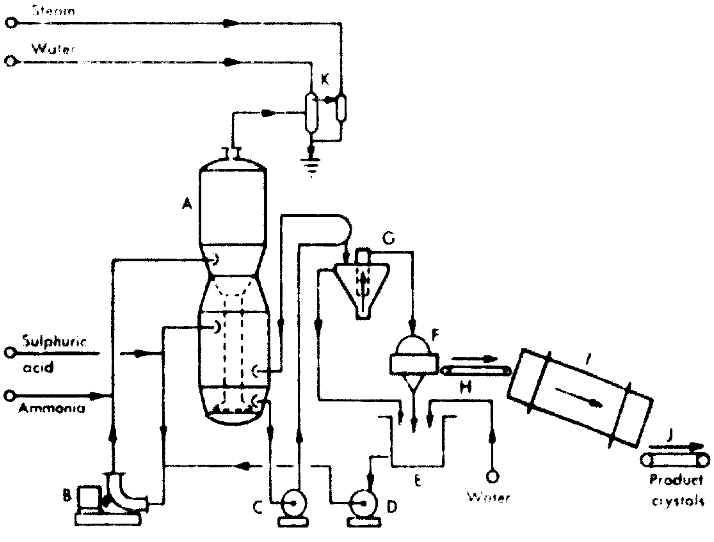
The reaction between gaseous, anhydrous ammonia and sulphuric acid car be shown as follows: $2NH_3(g) + H_2SO_4(1) \rightarrow (NH_4)_2SO_4(s) - 67{,}710$ cal/g-mole. In practice the exothermic heat of the reaction given above is approximately equal to 4,230 British thermal units per pound of nitrogen.

Units of the vacuum type are designed in accordance with the basic principles of crystallization previously reviewed and are usually built in the form of a suspension vessel surmounted by a flash chamber. Ammonia and sulphuric acid are introduced *via* a slurry recycle line, wherein they react and superheat the recirculating slurry, which is subsequently flashed in the upper chamber at a vacuum generally between 55 and 58 centimetres of mercury. The loss of water in this zone supersaturates the slurry, which recirculates to the lower suspension vessel *via* an internal pipe and comes into contact with small crystals and nuclei, thereby inducing further crystal growth in terms of size rather than in number. Slurry is recycled by thermal syphon and/or by an external pump, and as it is brought into contact with newly added reactants, the exothermic heat produced destroys undesirable nuclei and fines. Skilled design of the suspension vessel and the means of slurry withdrawal permits considerable size classification to be attained in the unit, and proper instrumentation ensures long periods of uniform operation.

This type of crystallizer is generally known as the "Krystal" or "Oslo" unit, and was developed in Norway by Isaacssen and Jeremiassen (14, 15, 16). Figure 11 illustrates diagrammatically the use of forced circulation in conjunction with this design of crystallizer for ammonium sulphate production. During operation, it is important to control the pH within fairly close limits, say, 3.0 to 3.5, since a lower value yields undesirable, thin crystals. Excessive acidity also promotes an overgrowth of crystals, especially in pipelines, and necessitates frequent redissolving, or "killing" with steam. Insufficient acidity, on the other hand, not only produces inferior crystals which are difficult to wash and store, but may cause ammonia losses as well. For these reasons, some producers maintain free acidity of between 1.0 and 1.5 grammes per litre of sulphuric acid.

Another popular type of reduced-pressure crystallizer is the draft tube baffle unit, in which a vigorous upward slurry recirculation is maintained by means of an internal impeller and draft tube (17). Growing crystals are brought to the surface of the flashing slurry, where supersaturation induces maximum crystal growth and sufficient nuclei are present to minimize scale formation inside the unit.

Figure 11. "Krystal" type of unit for ammonium sulphate production



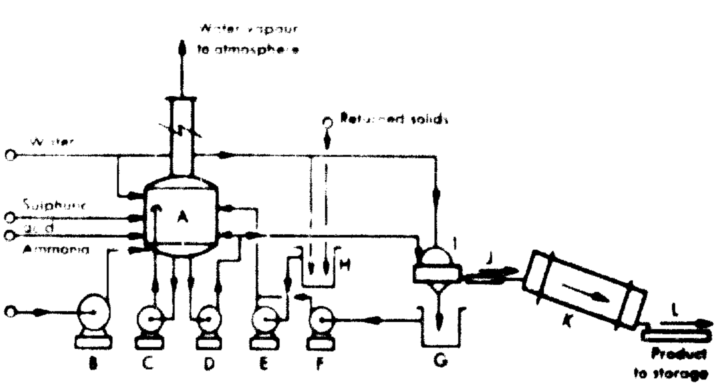
Legend

A : "Krystal" type of vacuum evaporator-crystallizer
B : Forced-circulation pump
C : Slurry-recirculation pump
D : Mother-liquor recycle pump
E : Mother-liquor tank
F : Continuous or batch centrifuge
G : Slurry concentrator
H : Drier conveyer
I : Rotary drier
J : Dried-product conveyer
K : Vacuum condenser-ejector unit

Atmospheric pressure units are of several types and are preferred by some producers to vacuum crystallizers, especially for small and medium outputs, on account of their simplicity and somewhat lower investment costs. Ammonia can be added *via* a sparger tube or a jet type of mixer. In one proprietary process, a simple absorption column incorporating a few large slotted bubble-hoods is used. Another design employs a single vessel for both reaction and crystallization, and reaction heat is removed by evaporation of water, supplemented in many cases by air-blowing, as shown in figure 12. In other designs, separate neutralizing and crystallizing vessels are used to provide easier operation and closer control. An optimum balance between cooling-air energy and crystal yield is usually obtained when crystallization temperatures are controlled in the range of 63° to 66° C.

In most cases, crystals are recovered from ammonium sulphate slurry by recycling through the continuous or the automatic batch type of centrifugal, wherein the product is screened and spin-dried, washed with water and weak ammonia, and again spin-dried before being conveyed to the drier. In some plants, continuous top-feed filters are used instead of centrifugals. As previously mentioned, for small outputs, top-feed filter-driers can sometimes be employed with advantage, since the product can be separated, washed and dried in a single machine.

Figure 12. Atmospheric-pressure process for ammonium sulphate manufacture



Legend

A : Evaporator-crystallizer
B : Air blower
C : Liquor-recirculation pump
D : Slurry-recirculation pump
E : Make-up pump
F : Mother-liquor pump
G : Mother-liquor tank
H : Sump tank
I : Batch or continuous centrifuge
J : Drier conveyer
K : Rotary drier
L : Product conveyer

As is well known, ammonium sulphate liquors are quite corrosive, and wetted parts of equipment are usually made of stainless steel or of rubber-lined mild steel. In some earlier plants, vessels constructed in wood and mild steel were employed, and corrosion was minimized by careful pH control. Modifiers intended to improve crystal size and shape include small amounts of trivalent metallic salts (14). Such corrosion inhibitors as traces of phosphoric acid or arsenical compounds are also added in some cases.

Production costs for ammonium sulphate are charted against varying costs of ammonia and sulphuric acid in chapter XXI, figure 73. Additional data are given in figure 93.

(b) *Gas-works by-product methods*

Prior to the availability of synthetic ammonia in the early 1920s, virtually all ammonia was obtained from solid-fuel carbonization plants. Typical bituminous coals used for gas and coke production contain about 1 to 2 per cent of nitrogen, and some 15 to 20 per cent of this can be recovered as ammonia, amounting to approximately 5 to 6 pounds of NH_3 per ton of coal used. Most of this ammonia is believed to be formed at temperatures in the range of 1,000° C, after coking has taken place. Hence, most by-product ammonia is usually associated with high-temperature carbonization units, e.g., coking plants for iron and steel production, where the amount of ammonium sulphate produced may be equivalent to 35 to 45 pounds per ton of steel.

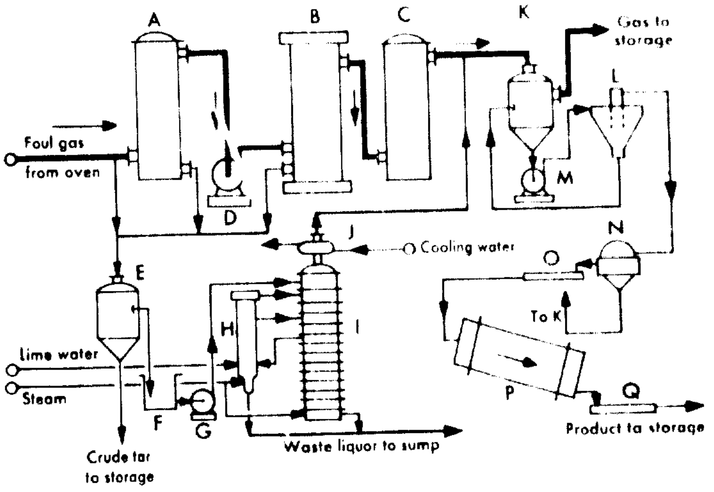
Ammonia is removed from gas for two principal reasons: first, to prevent subsequent corrosion and plugging problems in distribution mains and fittings; and secondly, to produce a useful by-product at a reasonable profit. However, in more recent years, world ammonium sulphate prices have fluctuated widely, and, from time to time, by-product material from gas-works and coke-ovens has been sold at price levels not much greater than the cost of the sulphuric acid needed as a raw material. As a result, some producers in the United States of America have converted their units to ammonium phosphate production as a more profitable alternative. Other by-products recovered from gas-washing units, because of necessity or additional financial return, include ammonium thiocyanate, ferrocyanides, pyridines and tar.

Three principal methods are available for ammonia and/or ammonium salt recovery; they are known as the direct, indirect and semi-direct processes, respectively. In the first method, the entire gas stream is cooled to remove as much tar as possible and is then passed through a saturator of the Bubbler type (or, in more recent plants, a scrubber of the spray type), wherein it is washed with sulphuric acid. The ammonium sulphate slurry produced is withdrawn, centrifuged, washed, dried and sent to storage. Advantages of this type of unit include high recoveries, relatively low investment and operating costs, low steam needs and small effluent liquor volumes. Nevertheless, in many instances, the product is unavoidably contaminated with tar and pyridines, and may be unacceptable unless, perhaps, it is recrystallized prior to sale. In addition, chlorides present in the fuel or water may react to form ammonium chloride and create additional corrosion problems, unless linings of rubber or plastic material are used. Furthermore, except in cases where a separate crystallizer is employed, flexibility with regard to size, shape and purity of product is likely to be very limited, since it becomes difficult to maintain an optimum balance between the free acidity needed to suppress impurities and the optimum pH needed to promote good crystal growth.

Earlier problems of direct operation led to the development of the indirect method, whereby the gases are first cooled by contact with recirculating wash liquor, followed in some cases by a further scrubbing with water. Combined liquors are sent to the upper section of an ammonia still of the bubble-cap type, in which contact with steam releases the "free" ammonia present as ammonium carbonate, ammonium sulphide and other easily dissociated salts. The liquor then passes to an adjoining lime leg, where treatment with lime liquor decomposes the "fixed" ammonium salts, e.g., ammonium chloride. Steam passing upwards from the base of the column strips virtually all of the ammonia gas produced, which is recovered as a crude ammonia solution or is sent to a sulphuric acid washer for ammonium sulphate production. Advantages of this method include the production of a salt substantially free from impurities and also having considerable flexibility, plus an ability to make *aqua* ammonia and derivatives. However, operating costs are high and effluent disposal problems may arise. In addition, ammonia losses may be appreciable, owing to incomplete reaction and absorption.

The semi-direct process offers a compromise between direct and indirect operation, whereby the gas is first cooled and washed to deposit tar and an aqueous condensate (3). The latter is "sprung" in a relatively small ammonia still, and the released NH_3 is combined with the main gas-stream, which is reheated to about 70° C and scrubbed with a solution containing nearly saturated ammonium sulphate and 5 to 6 per cent of sulphuric acid at about 50° to 70° C, in units either of the spray-absorber type or of the older saturator type incorporating a cracker pipe (18) (or bubbler-ring). As this process gives ammonia recoveries greater than those attainable by direct operation and also produces a salt largely free from tar, pyridine and other impurities, it has become the most popular for large installations. Figure 13 shows the basic flow diagram of a semi-direct gas scrubber/ammonium sulphate unit, as well as an illustration of an ammonium sulphate saturator.

Figure 13. Semi-direct process for ammonium sulphate production from coke-oven gas



Legend

A: Primary gas-cooler
B: Electrostatic tar-precipitator
C: Gas reheater
D: Main gas-blower
E: Tar separator
F: Crude ammonia liquor storage
G: Still feed-pump
H: Lime leg
I: Ammonia still
J: Dephlegmator
K: Sulphate saturator-crystallizer
L: Slurry concentrator
M: Slurry feed-pump
N: Batch or continuous centrifuge
O: Drier conveyer
P: Rotary drier
Q: Product conveyer

Several varieties and modifications of these systems are found throughout the world, principally developed by the Koppers, Otto and Wilputte organizations (3, 19). Scrubbers of the spray type, which were pioneered by the Otto Company, have become popular (20); the use of separate crystallizers (21) and the installation of compactor-granulators to increase product size are also gaining favour. In localities where furnace-grade phosphoric acid is available, an ability of the by-product unit to produce diammonium phosphate is another recently developed feature, and a method of using wet-process acid in conjunction with gas-works ammonia has also been developed (22, 23, 24).

Another recent development in this field is the adoption of ion-exchange units to remove ammonia from coke-oven liquors by means of cationic agents either of the conventional type or derived from by-products also obtained from coke-oven sources (25, 26). Mention should also be made of the direct synthesis of ammonia from raw coke-oven gas, as undertaken by the United States Steel Corporation at Provo, Utah, United States of America.

(c) *Ammonium carbonate-gypsum process*

This method, which is also known as the Merseburg Process, has long been used in Austria, India and the United Kingdom (27, 28, 29). It is based on combining ammonia and carbon dioxide (30, 31) to produce ammonium carbonate, which is then reacted with gypsum or anhydrite (of natural or by-product origin) to yield ammonium sulphate and calcium carbonate, as follows:

$$NH_3 + H_2O \rightarrow NH_4OH \quad 8{,}320 \text{ cal/g-mole}$$

$$2NH_4OH + CO_2 \rightarrow (NH_4)_2CO_3 + H_2O \quad 22{,}080 \text{ cal/g-mole}$$

$$CaSO_4 . 2H_2O + (NH_4)_2CO_3 \rightarrow CaCO_3 + (NH_4)_2SO_4 + H_2O - 3{,}900 \text{ cal/g-mole}$$

Under certain circumstances, this process has several advantages, for example, countries without indigenous sulphur supplies, but having natural or by-product sources of gypsum (32) (or anhydrite), can produce ammonium sulphate without purchasing sulphur from abroad. In addition, the by-product calcium carbonate can be used for cement production or other purposes, such as for agricultural lime or in calcium ammonium nitrate manufacture.

In one large Indian plant (Sindri), ammonia gas is absorbed in water and carbonated at about 30 psig in two series-connected aluminium towers, since this pressure allows a higher cooling-water temperature to be employed than if atmospheric pressure were used. Carbon dioxide is introduced at the base of the primary tower, which is packed with 2-inch stoneware rings wetted with a solution of ammonium hydroxide and recycling ammonium carbonate. Final absorption is undertaken in the secondary tower, and reaction heat is removed by recirculation liquor through water-cooled heat exchangers in closed circuit with each tower. The preferred liquor strength corresponds to approximately 170 grammes of ammonia and 225 grammes of carbon dioxide per litre. Stainless steel is used for the wetted parts of pumps and liquor piping is made of aluminium.

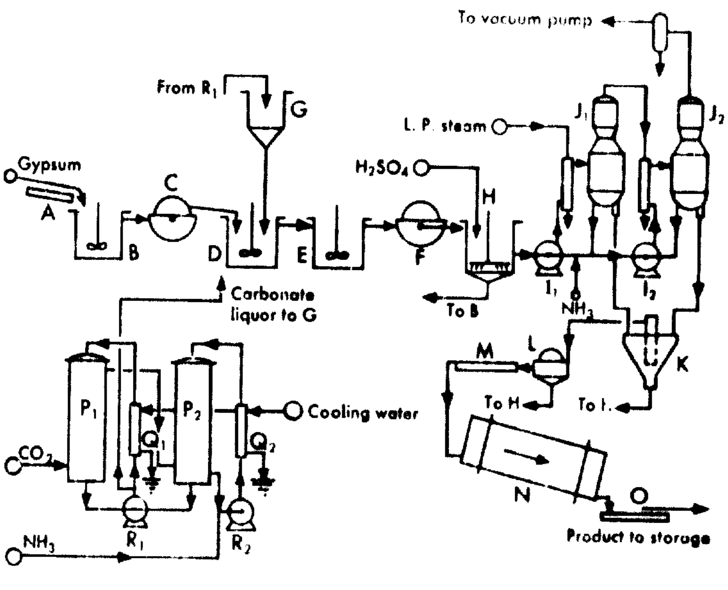
In a more recent Indian plant (Fertilizers and Chemicals Ltd., Travancore), jet absorbers are used to prepare both the ammonia solution and the ammonium carbonate liquor in conjunction with a carbonating tower. Cooling is undertaken by recycling liquor through water-cooled heat exchangers, and the heat of reaction thereby vaporizes the liquid anhydrous ammonia used in the process. When the desired strength has been reached, the solution is sent to storage and subsequent reaction. The relation between liquor strength, moisture in the gypsum and the resulting ammonium sulphate liquor concentration has been reported by George and Gopinath (33).

When natural gypsum or anhydrite is used, it is crushed and ground before reaction. In one case, the preferred final size is about 90 per cent through 120 mesh, although, under certain circumstances, there are indications that a coarser grade is permissible. When using by-product gypsum of phosphoric acid-plant origin, it may be preferable to remove impurities by repulping the filter cake in an agitated vessel (or, alternatively, by scalping in liquid cyclones) prior to washing and dewatering to the maximum extent on a drum or disc filter before reacting with ammonium carbonate. Final drying in a flash drier has also been proposed, in order to yield the highest ammonium sulphate concentration and to minimize subsequent evaporation needs if local steam-supplies are limited. A new, proprietary method of purifying by-product gypsum has recently been announced by the Onoda Cement Company of Japan.

Reaction can be undertaken either in a series of wooden vessels or mild-steel tanks fitted with steam coils and agitators, and the reaction train is usually designed to give a total retention time of four to six hours. The slurry produced is filtered and the calcium carbonate cake washed and dewatered on continuous vacuum machines of the travelling-belt type, or alternatively, on a two-stage drum-filter installation provided with intermediate repulping. (In some earlier plants, plate-and-frame filter presses were installed for this purpose.) Final clarification by pressure filtration or settling is sometimes employed to ensure maximum purity of product, followed by neutralization with sulphuric acid and heating to about 110° C to remove excess ammonia prior to concentration and crystallization. The evaporator feed-liquor usually contains about 500 to 520 grammes of ammonium sulphate and less than 0.1 grammes of ammonia per litre.

Evaporation is undertaken in continuous multiple-effect evaporator crystallizers, and production can be supplemented if desired by adding ammonia and sulphuric acid to the crystallizer recirculating line as previously described. Crystals of the required size range are separated and washed in a centrifuge, dried in a rotary drier at 120° C to 130° C and sent to storage. Alternatively, a vertical tray type of drier-cooler can be used, since this is said to give reduced crystal breakage and dust formation, compared with the use of a rotary drier and cooler. An interior view of a gypsum-process ammonium sulphate plant is given in figure 14.

Figure 14. Gypsum process for ammonium sulphate production



Legend

A: Gypsum conveyer
B: Gypsum washing tank
C: Gypsum dewatering filter
D: Primary reactor
E: Secondary reactor
F: Calcium carbonate filter
G: Ammonium carbonate storage tank
H: Sulphate-liquor clarifier
I_1, I_2: Evaporator feed-pumps
J_1, J_2: Vacuum evaporator-crystallizers
K: Slurry concentrator
L: Batch or continuous centrifuge
M: Drier conveyer
N: Rotary drier
O: Product conveyer
P_1, P_2: Ammonium carbonate towers
Q_1, Q_2: Heat exchanger-coolers
R_1, R_2: Carbonate liquor recirculating pumps

(d) *Recovery of by-product liquor*

In Japan and the United States of America several large by-product units have been installed for producing ammonium sulphate from the waste streams of caprolactam, acrilonitrile and certain other processes (34, 35, 36). In such cases, the waste liquor should normally contain at least 35 per cent of ammonium sulphate in solution (21). Otherwise, recovery may not be justified unless for the purpose of preventing stream pollution.

Occasionally, spent sulphuric acid from petroleum refineries, petrochemical plants and soap factories can be used for ammonium sulphate production, if impurities do not cause insurmountable frothing or corrosion problems, or render the product unacceptable. If the acid is too badly contaminated, it may be more expedient to burn off the impurities in a specially designed furnace and to produce fresh acid for ammoniation. Another alternative is to ammoniate the contaminated acid and granulate the slurry in a drum or pug-mill type of granulating system, similar to those used for producing granular fertilizers. In one process, it is claimed that acids containing up to 40 per cent of organic material can be ammoniated and granulated in this way, using recycle ratios between 1.5 and 4.0 based on the amount of feed (37).

(e) *Spray-tower ammoniation*

Substantial tonnages of ammonium sulphate have been made for many years in Japan in spray towers from the chamber or contact type of sulphuric acid and anhydrous ammonia. The acid is sprayed into ammonia vapour inside the tower, and the heat of reaction produces a dry, amorphous product, mostly below 300 mesh, which is continuously removed from the base of the tower by a screw conveyor. This form of ammonium sulphate is particularly suitable for dry-mixed and granulated-mixed fertilizers.

(f) *Double and mixed salt production*

By ammoniating mixtures of sulphuric and nitric acid, or by combining their ammonium salts in special ways, it is possible to produce compounds containing both ammoniacal and nitrate nitrogen in the form of true double salts, for example, ammonium sulphate nitrate $(NH_4)_2SO_4 . 2NH_4NO_3$ and, to a lesser extent, the trinitrate and mononitrate compounds.

One German process produces an ammonium sulphate nitrate corresponding approximately to $(NH_4)_2SO_4 . NH_4NO_3$, and containing 62 per cent ammonium sulphate and 38 per cent ammonium nitrate. Total nitrogen content is 26 per cent, about three-quarters being present in ammoniacal form and one-quarter as nitrate nitrogen. It is made by ammoniating the requisite mixture of sulphuric and nitric acids, evaporating to a moisture content of 3 per cent, adding about 1 per cent of ferrous sulphate (to reduce subsequent caking), cooling to 100° C, chilling and flaking. After further conditioning by spraying with dilute ammonia solution, the double salt is granulated (sometimes with additional ammonium sulphate), dried, cooled and bagged.

In a simpler process, also of German origin, ammonium nitrate solution is evaporated under vacuum to a 95 per cent concentration, cooled to about 130° C and reacted with solid ammonium sulphate in a pug-mill granulator system having a recycle ratio of 2 or 3 to 1 of product until a pH of 4.0 is attained, after which the product is dried, cooled and bagged.

Compared with ammonium sulphate, ammonium sulphate nitrate contains an additional 5 per cent nitrogen. Its storage properties are superior to ammonium nitrate or mixtures of solid ammonium sulphate and ammonium nitrate, since free ammonium nitrate is absent. However, the large-scale manufacture of urea, as well as of binary and ternary high-analysis fertilizers in recent years, has diminished the importance of ammonium sulphate nitrate in most countries.

When mixtures of sulphuric acid and phosphoric acid are ammoniated, a variety of mixed and double-salt products can be made. One of the most popular is "ammo-phos", containing 16 per cent nitrogen and 20 per cent P_2O_5. After ammoniation, the slurry formed is granulated in a pug-mill or drum unit, then dried and screened (and sometimes cooled) to give a water-soluble product containing about two-thirds of ammonium sulphate and one-third of ammonium phosphate by weight. This material has good storage properties under normal conditions.

More recently, in the United States of America, the Chemical Engineering Division of the Tennessee Valley Authority has developed a pan-granulation method for the large-scale production of high-analysis fertilizers, based on the ammoniation of mixed sulphuric, nitric and phosphoric acids. This process is described in a subsequent section.

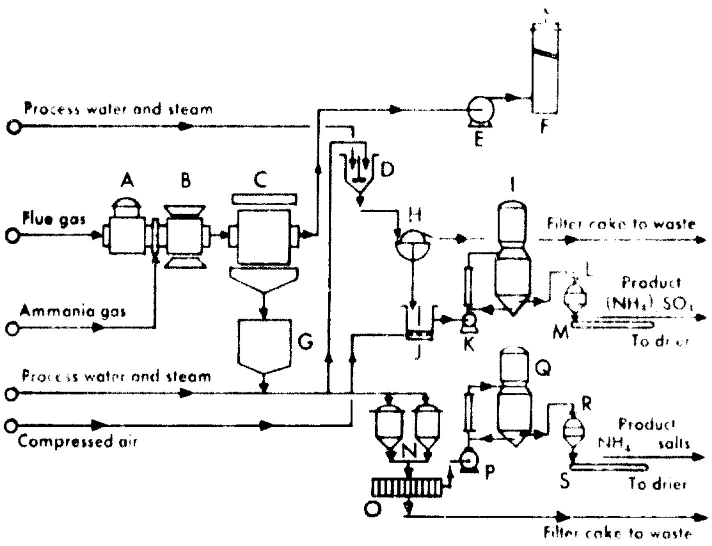
(g) *Miscellaneous processes*

An interesting Spanish method for producing ammonium sulphate by absorption of sulphurous gases in an organic solvent has been described (6, 38). After absorption, the sulphite-rich liquor is blown with air to form a basic sulphate, and ammonia is then added to produce ammonium sulphate, which separates from the organic base and is centrifuged, dried and sent to storage. The basic absorbent (e.g., xylindine or monomethylaniline) is recycled for further use. Since this process does not require a source of sulphuric acid and can operate on rich or lean gases from roasters, boiler flues and other sources, it may have useful applications in other countries where sulphur is costly and/or serious air-pollution problems exist.

Other proposals for recovering sulphur from flue gases have been developed (8), based on scrubbing with ammonia, to yield mixtures of such by-products as ammonium bisulphite and ammonium sulphate; one suggested method (7) is shown in figure 15. Successful application of such methods on a wide scale would greatly reduce air-pollution hazards and be most beneficial to mankind. At the same time, the complex compounds of ammonia and sulphur produced as by-products should be of use for fertilizer purposes in many areas of the world.

A process for the manufacture of a granular ammonium sulphate-urea complex fertilizer containing about 27 per cent nitrogen has been reported (39). This is based on adding 70 per cent sulphuric acid to a 40 per cent urea

Figure 15. Chemico process for recovery of ammonium salts from flue gases



Legend

A: Economizer
B: Combustion air pre-heater
C: Electrostatic precipitator
D: Ammoniated dust leach-tank
E: Stack fan
F: Stack
G: Ammoniated-dust hopper
H: Sulphate sludge filter
I: Ammonium sulphate evaporator-crystallizer
J: Oxidizing tank
K: Evaporator feed-pump
L: Ammonium sulphate centrifuge
M: Ammonium sulphate conveyer
N: Autoclaves
O: Filter
P: Evaporator feed-pump
Q: Ammonium salt evaporator
R: Ammonium salt centrifuge
S: Ammonium salt conveyer

solution followed by ammoniation and heating to complete the reaction.

7. *Ammonium sulphate storage and handling*

Several factors contribute to trouble-free storage of ammonium sulphate and other fertilizers (40). First, the product should be of uniform crystal size and should contain a low percentage of fines. Secondly, it should be dry and preferably have below 0.1 per cent free moisture. Thirdly, no free acidity should be present on the crystal surfaces. Fourthly, the product should be cooled with dry air under controlled conditions after drying, if the ambient temperature and humidity are sufficiently high to cause subsequent moisture condensation after cooling in a bulk storage pile or in sealed bags.

In some very humid parts of the world, caking troubles may arise even after the above-mentioned precautions have been taken, unless the product is coated, after cooling, with an inert material, for example, diatomaceous earth, kieselguhr or special clays. Certain fatty-acid derivatives and naphthalene sulphonate compounds applied by spray alone, or in conjunction with inert coating agents, have proved particularly effective. In some cases, soluble anti-caking agents can be added prior to crystallization or final washing and drying; however, this can only be undertaken when there is no danger of causing foaming problems in the evaporator-crystallizer, or of upsetting the crystal habit.

The importance of minimizing the presence of fines in the product emphasizes the need for careful design as regards the conveying and handling of wet and dried crystals. Transfer points and free-falls should be minimized; lengthy screw conveyors should be avoided; and attrition in driers, coolers and coating drums should be reduced as much as possible by careful design of flights and lifters, and the use of optimum drum-speeds. The gas velocities adopted (41) and the shape of internal lifters and flights should ensure that undesirable fines are swept out of the gently cascading material for subsequent reprocessing. These principles apply equally to other salts and also to granulated fertilizers.

C. AMMONIUM CHLORIDE

1. *General information*

Although ammonium chloride contains 26 per cent nitrogen, its use as a fertilizer is virtually unknown except in India, Japan, and other countries in the region, where it is applied to paddy on an appreciable scale in some areas. The annual consumption in India and Japan is currently about 70,000 tons and 400,000 tons, respectively. Tests have shown that it could also be used for wheat and maize on well-drained soils regularly treated with lime and gypsum. The major disadvantages of ammonium chloride as a fertilizer are the resulting high acidities and chloride content in most soils (unless well irrigated and limed), the poor storage properties (except when granulated and packed in moisture-proof bags) and a tendency to corrode handling and application equipment unless certain components are suitably modified and protected with acid-resistant materials.

Nevertheless, it is possible that ammonium chloride fertilizer could become a useful outlet for the surplus supplies of chlorine that arise from time to time in various countries, provided the above-mentioned precautions were observed. Another useful feature of ammonium chloride is that it can be applied to rice with safety in the presence of certain fungi which would reduce ammonium sulphate to toxic sulphides. The industrial uses of ammonium chloride are world-wide, although in relatively small tonnages. The major applications include dry-battery manufacture and use as a flux for soldering and brazing.

2. *Properties of ammonium chloride*

The properties of ammonium chloride are given in table 34:

TABLE 34. PROPERTIES OF AMMONIUM CHLORIDE

Colour	White
Molecular weight	53.50
Density 20°/4° C	1.526
Nitrogen content (percentage)	26
Solubility	
Temperature (°C)	*Grammes NH_4Cl in 100 grammes H_2O*
0	29.4
20	37.2
40	45.8
60	55.3
80	65.6
100	77.3
115.6 (boiling-point)	87.3
Effect of heat	
Ammonium chloride begins to dissociate at 350° C and sublimes at 520° C	
Critical relative humidity:	
At 20° C (68° F)	79.2
At 30° C (86° F)	77.5

3. *Production methods*

Several methods for producing ammonium chloride are used, the order of importance being:

(*a*) The dual-salt process, whereby ammonium chloride and sodium carbonate are produced simultaneously;

(*b*) Direct neutralization of ammonia with hydrochloric acid;

(*c*) Miscellaneous methods.

(a) *The dual-salt process*

Most ammonium chloride used in India and Japan for fertilizer purposes is produced by the dual-salt process (or in suitably modified Solvay plants). In this method, ammonium chloride is salted out by the addition of solid, washed sodium chloride instead of being decomposed by lime liquor to recover ammonia, as in the Solvay ammonia-soda process.

In conventional Solvay plants, an ammoniated solution of about 30 per cent sodium chloride is treated with carbon dioxide in large absorber towers to form ammonium carbonate:

$$2NH_3 + H_2O + CO_2 \rightleftharpoons (NH_4)_2CO_3$$

Additional carbonation produces ammonium bicarbonate:

$$(NH_4)_2CO_3 + CO_2 + H_2O \rightleftharpoons 2NH_4HCO_3$$

The addition of sodium chloride yields sodium bicarbonate and ammonium chloride:

$$NH_4HCO_3 + NaCl \rightleftharpoons NaHCO_3 + NH_4Cl$$

The sodium bicarbonate is separated by centrifuging or filtration and calcined to produce sodium carbonate and CO_2, the latter being recycled to the system. In the Solvay process, reaction reaches equilibrium at about 75 per cent completion, and the mother liquor is reacted with lime liquor to recover ammonia for re-use in the process, i.e.:

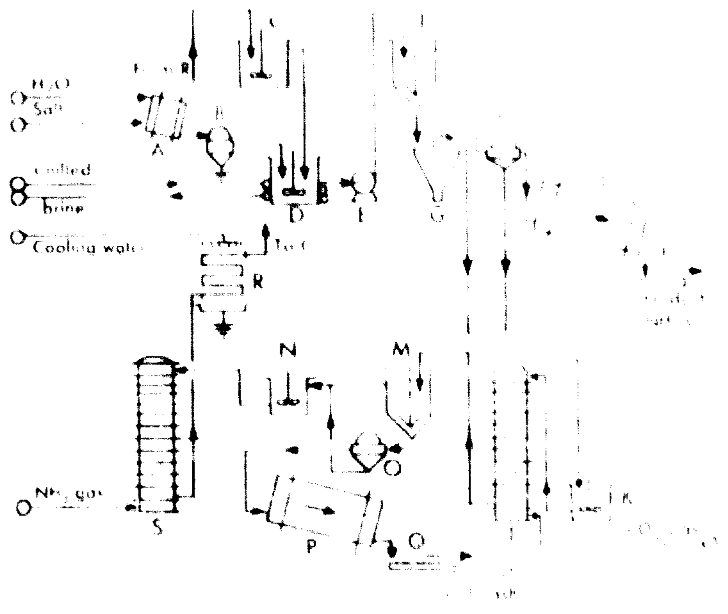
$$2NH_4Cl + Ca(OH)_2 \rightleftharpoons CaCl_2 + 2NH_3 + 2H_2O$$

The calcium chloride liquor can sometimes be sold, but may have to be discarded in the absence of suitable markets.

In the dual-salt process (or the modified Solvay process), the mother liquor remaining after separation of sodium bicarbonate is ammoniated, cooled below 15° C and salted out by adding washed, solid sodium chloride (42). The precipitated ammonium chloride is centrifuged, washed and dried. More recently, in Japan, a method of producing large ammonium chloride crystals of the rice type, 2 to 3 millimetres in size, has been developed by undertaking cooling, nucleation and crystallization of the ammonium chloride under closely controlled conditions in separate vessels of special design.

Slurry from the last crystallizer is centrifuged, washed and dried to about 0.25 per cent free moisture in a rotary drier at 105° C. After removal of ammonium chloride, the liquor is re-ammoniated and returned to the carbonating tower to produce further sodium bicarbonate and to commence a new cycle of operations. A basic flow diagram of this process is shown in figure 16.

Figure 16. Dual-salt process for ammonium chloride production



Legend

A: Salt washer
B: Salt centrifuge
C: Ammoniated-brine tank
D: Salt reactor
E: Slurry pump
F: Ammonium chloride slurry tank
G: Ammonium chloride concentrator
H: Ammonium chloride centrifuge
I: Ammonium chloride drier
J: Ammonium chloride product conveyer
K: Mother-liquor tank
L: Carbonating tower
M: Bicarbonate slurry tank
N: Bicarbonate mother-liquor tank
O: Bicarbonate centrifuge
P: Soda-ash calciner
Q: Soda-ash product conveyer
R: Ammoniated-brine cooler
S: Ammoniation tower

The ammonium chloride produced by this method, when packed in moisture-proof bags and used as soon as possible after the bags are opened, is normally not difficult to store and handle. A typical analysis is given in table 35:

TABLE 35. TYPICAL ANALYSIS OF DUAL-SALT PROCESS AMMONIUM CHLORIDE

	Per cent minimum
NH_4Cl	95.0
NaCl	1.5
Carbonates as CO_2	0.5
Sulphates as SO_4	0.3
Insoluble material	0.1

As previously mentioned, in a conventional Solvay process, precipitation of sodium bicarbonate is taken to about 75 per cent completion only. The modified Solvay process and the dual process permit the attainment of considerable reductions in sodium chloride requirements, perhaps to 1.25 to 1.5 tons per ton of soda ash, compared with approximately 2 tons for the orthodox Solvay process. This can represent appreciable savings in foreign exchange to countries compelled to import common salt.

(b) *The direct-neutralization method*

Ammonium chloride of high purity is made in several countries by the direct reaction between anhydrous ammonia vapour and hydrochloric acid gas, according to the reaction

$$NH_3(g) + HCl(g) \rightleftharpoons NH_4Cl(s) - 42{,}000\ cal/g\text{-}mole$$

In most cases, neutralization is undertaken at reduced pressures of 250 to 300 millimetres of mercury in one or more rubber-lined steel vacuum reaction vessels protected with an additional inner lining of inert brick. Concentrated hydrochloric acid gas is passed through an aspirator, wherein it is diluted with air to about 20 per cent concentration and enters the reactor *via* a vertical sparger tube. According to preference, ammonia gas is introduced either by a second sparger or by tangential nozzles in the base of the reaction vessel. Agitation is provided by the large volume of air entering the reactor with the hydrochloric acid vapour, thus avoiding the need for a mechanical agitator with its additional power requirements and maintenance problems.

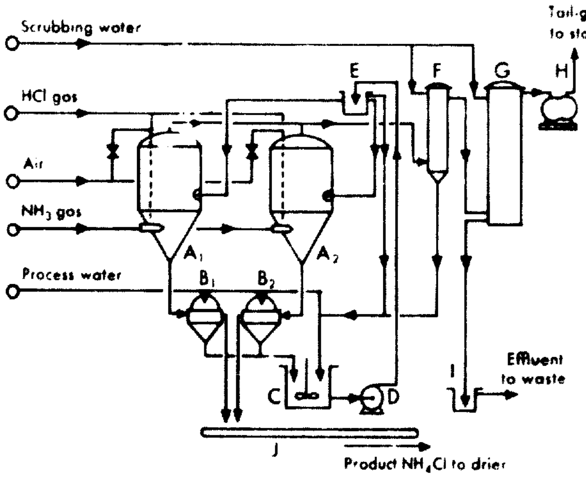
Similarly, operation under vacuum not only provides excellent cooling, but simultaneously prevents the escape of noxious vapours and eliminates the need for hydrochloric acid-vapour blowers, plus their attendant cost and maintenance charges. A reduced pressure of 25 to 30 centimetres of mercury and a corresponding slurry temperature of 75° to 80° C represent typical operating conditions.

In most cases, it is usual to maintain a uniform acid feed for the desired output level and to control the ammonia addition to achieve a steady pH of 8.0. The control system should include an audible alarm and provisions for shutting off the acid feed if the pH falls below 7.0; otherwise, those components in the system not protected by rubber or plastic linings (e.g., the centrifuge) would be quickly damaged by corrosion. Slurry is withdrawn from the saturator at about 80 per cent solids concentration, and the ammonium chloride crystals are separated and rinsed in stainless-steel centrifuges. In some cases, drying is also undertaken in the separator by blowing hot air through the crystal bed before discharge. Alternatively, a top-feed filter-drier can be used instead of centrifuges.

Mother liquor from the centrifuges is pumped back to the saturator (s) *via* a storage tank. Saturator off-gases must be well scrubbed before entering the vacuum pump or ejector unit to prevent corrosion and to eliminate air pollution. A two-stage scrubbing system is usually employed and may consist of a direct, barometric scrubber-condenser followed by a wetted, packed tower. Liquor from the scrubber-condenser is returned to the mother-liquor tank and is evaporated in the saturator, thus providing a means of temperature control, as well as of acid recovery. Figure 17 shows the basic flow diagram for a typical direct-neutralization unit.

As with other processes involving reactions between hydrochloric acid (or chlorides) and ammonia, traces of free chlorine in the acid feed can lead to disastrous explosions caused by the formation of nitrogen trichloride in the saturator. Hence, adequate safety precautions must be installed whereby the HCl gas feed is monitored and the flow shut off when chlorine is detected. This can be accomplished by such means as bypassing a small stream of gas through a photocell-colorimeter unit containing potassium iodide, or using a modern continuous gas-analyser of the absorption or chromatographic type.

Figure 17. Direct-neutralization process for ammonium chloride production



Legend

A_1,A_2: Neutralizer-crystallizers
B_1,B_2: Batch or continuous centrifuges
C: Mother-liquor tank
D: Neutralizer feed-pump
E: Splitter feed-box
F: Primary scrubber
G: Secondary scrubber
H: Vacuum pump
I: Seal-pot
J: Product conveyer

After separation and drying, the crystalline ammonium chloride is packed as quickly as possible in moisture-proof bags to minimize subsequent storage and application difficulties. Recent trials have shown that such anti-caking agents as certain fatty acid derivatives or inert powders, either applied to the crystals after drying or added to the saturator, can be helpful in reducing caking tendencies after manufacture. Certain polyacrylamides are also reported to be useful additives (43).

In accordance with the purity of the feed-materials (plus any reworked product) and provided the plant has been properly designed and maintained in good condition, the direct-neutralization method will produce ammonium chloride of high purity. For example, as shown in table 36, in one Indian plant a product of a quality well in excess of British Pharmacopoea specifications can be achieved (44).

TABLE 36. TYPICAL ANALYSIS OF DIRECT-NEUTRALIZATION PROCESS AMMONIUM CHLORIDE

	British Pharmacopoea specification	*Direct-neutralization product*
pH	—	5.00
Free moisture (percentage)	1.00	1.00
Water-insoluble material (ppm)	—	10
Non-volatile matter (ppm)	1,000	100
Iron (ppm)	5	2
SO_4 (ppm)	—	35
Heavy metals as Pb (ppm)	5	5
Arsenic (ppm)	5	0
Purity (percentage)	99.5	99.9

(c) *Miscellaneous processes*

Ammonium chloride can be made from ammonium sulphate and sodium chloride according to the reaction:

$$(NH_4)_2SO_4 + 2NaCl \rightleftharpoons Na_2SO_4 + 2NH_4Cl$$

In one method, the ammonium chloride and a 5 per cent excess of common salt are added to an ammonium chloride solution, followed by heating and stirring for several hours. The resulting slurry is filtered or centrifuged while hot, and is washed with hot water to separate the solid sodium sulphate from the ammonium chloride liquor. The latter is concentrated, cooled and crystallized in leadlined pans, and the crystals centrifuged, washed with water and dried. Normally, only ammonium chloride for chemical purposes would be made by this method and in relatively small quantities, since the ammonium sulphate used as a raw material could be considered a preferable fertilizer.

Another method is the use of SO_2 or sulphite liquor in conjunction with ammonia and sodium chloride, as shown below:

$$SO_2 + 2NH_3 + H_2O + 2NaCl \rightarrow 2NH_4Cl + Na_2SO_3$$

Ammonia, and sulphur dioxide or sulphite liquor, are added to a solution of common salt, and an excess of SO_2 equivalent to about 2 per cent bisulphite is initially maintained, which is reduced to about 1 per cent as the reaction reaches equilibrium. As the temperature approaches 60° C, the sodium sulphite precipitates and is centrifuged, washed and dried. The ammonium chloride mother-liquor is concentrated, crystallized and centrifuged to yield a product of high purity after washing and drying.

D. NITRIC ACID

1. *Historical development*

Nitric acid has an interesting history and was made in mediaeval times, if not earlier. About 1100, Geber described a method of preparing ***aqua fortis*** by distilling nitre with copper sulphate and alum. In the mid-seventeenth century, Glauber made fuming nitric acid by distilling nitre with strong sulphuric acid. Cavendish, in 1785, established that nitric acid was composed of nitrogen and oxygen, by passing electric sparks through a mixture of these gases. Milner of Cambridge obtained nitric acid in 1788, by passing ammonia over heated manganese dioxide and absorbing the vapours in water (45). In 1839, Kuhlman patented a method of nitric oxide formation using platinum to oxidize a mixture of ammonia and air, which has become the basis of virtually all nitric acid manufacture today.

In 1895, Rayleigh demonstrated that nitrogen and oxygen could be removed from air and combined to form oxides of nitrogen by means of an electric arc. This phenomenon was also investigated by Crookes, and a small pilot plant using this principle was operated in Manchester, England, in 1900. However, the yield of nitric oxide by this method was only 1.5 to 2.0 per cent, despite huge power requirements. A commercial plant was built by Birkeland and Eyde in Norway, in 1902, using 350,000 horsepower from hydro-sources, and was operated for several years. However, this process gave place to the ammonia-oxidation method using a platinum catalyst, developed by Ostwald and Brauer (46) and first operated in Germany about 1908. This method also rendered obsolete the nitre process (formerly the major source of nitric acid) whereby sodium nitrate, principally from Chile, was distilled with concentrated sulphuric acid and the vapours simultaneously oxidized and absorbed in water, using stoneware equipment.

It is also of interest to mention some recent developments in nitric acid technology which may be of future importance, yet are related to the early classical discoveries. In one proposed method—the Wisconsin Process (47)—a mixture of nitrogen and oxygen or air is heated to about 2,000° C and 150 to 200 pounds per square inch gauge (psig) and is exposed to radiation from uranium-235. Assuming a 50 per cent efficiency in the conversion of nuclear energy to chemical energy, one mole of 20 per cent enriched uranium costing about \$6,000 should, according to reports, provide some 70 tons of nitrogen oxides or nearly 260 tons of 100 per cent HNO_3 having a value of about \$10,000.

The joint production of electricity and nitrogen oxides in magneto-hydrodynamic generators has also been proposed (48). However, until the costs of energy from atomic and plasma sources are much lower than the current level, catalytic ammonia oxidation processes are likely to remain the principal manufacturing methods.

The current annual world production of nitric acid is of the order of 10 million tons, and about 75 per cent is used in fertilizer production. Some 15 per cent is used for explosive manufacture (nitrates and nitro-compounds), and approximately 10 per cent is consumed by the chemical industry for numerous purposes (49). Related strongly oxidizing materials, for example red, fuming acid and nitrogen tetroxide, may find extensive future use in rocket and missile applications.

2. *Properties of nitric acid*

Nitric acid is a strong acid and a powerful oxidizing agent. Anhydrous HNO_3 does not normally exist in liquid form. On distilling strong solutions under reduced pressure with concentrated sulphuric acid and ozone, one obtains almost pure nitric acid having a concentration of 99.7 per cent and a specific gravity of 1.52. On freezing a 98 per cent solution, colourless crystals having a melting point of −41.6° C separate. When heated at atmospheric pressure, concentrated nitric acid boils at 78.2° C, but begins to decompose and eventually yields a 68 per cent HNO_3 solution with a maximum boiling-point of 120.5° C. This corresponds approximately to $2HNO_3.3H_2O$, but is not a true hydrate since its composition and concentration are functions of pressure. The more important properties of nitric acid are summarized in table 37.

Two solid hydrates can be prepared; $HNO_3.H_2O$ and $HNO_3.3H_2O$, having melting-points of approximately −38° C and −18.5° C, respectively. Heat of dilution is at a maximum, corresponding to $3HNO_3.H_2O$, although no true hydrate having this analysis has been found. When dilute solutions of nitric acid are concentrated under atmospheric pressure, a maximum boiling-point solution again corresponding to 68 per cent HNO_3 results. The relation between specific gravity and percentage of nitric acid at 15° C is given in figure 18.

TABLE 37. PROPERTIES OF NITRIC ACID

Molecular weight	63.02
Colour	
In liquid state	Transparent to yellow
As gaseous oxides	Transparent to yellow or brown (colour darkens on prolonged exposure to light)
Odour	Sweet to pungent
Hazards	
In liquid state	Rapidly attacks flesh and most organic matter
As gaseous oxides	Anæsthetic to dangerously toxic
Melting-point	−41.6° C
Boiling-point of constant boiling-point mixture containing 68 per cent HNO_3, at 760 mm Hg	120.5° C
Density of 68 per cent HNO_3, 20°/4° C	1.41
Refractive index at 16.4° C	1.397
Solubility in water	Totally soluble at all concentrations
Acidity	A strong acid, having pronounced oxidizing characteristics. Will passivate some metals, such as iron and aluminium
Entropy	
Liquid at 16° C	37.19 cal/g-mole
Gas at 25° C	63.62 cal/g-mole
Heat of fusion	2,503 cal/g-mole
Heat of vaporization at 20° C	9,426 cal/g-mole
Heat of infinite dilution at 25° C	−7,971 cal/g-mole
Heat capacity at 27° C	26.24 cal/g-mole
Typical impurities in HNO_3 of ammonia origin	Cl_2 — less than 5 ppm HNO_2 — less than 5 ppm

3. *Chemical reactions of nitric acid manufacture*

(a) *From nitre and sulphuric acid*

The reaction from nitre and sulphuric acid is:

$$3NaNO_3 + 2H_2SO_4 \rightleftharpoons 3HNO_3 + Na_2SO_4 + NaHSO_4$$

(b) *From nitrogen and oxygen (or air)*

The reaction in high-temperature furnaces, followed by NO oxidation and absorption in water, is:

$$N_2 + O_2 \rightleftharpoons 2NO$$

$$2NO + O_2 \rightleftharpoons 2NO_2 \qquad \Delta H = -27{,}100 \text{ cal/g-mole}$$

$$2NO_2 + H_2O \rightleftharpoons HNO_3 + HNO_2$$

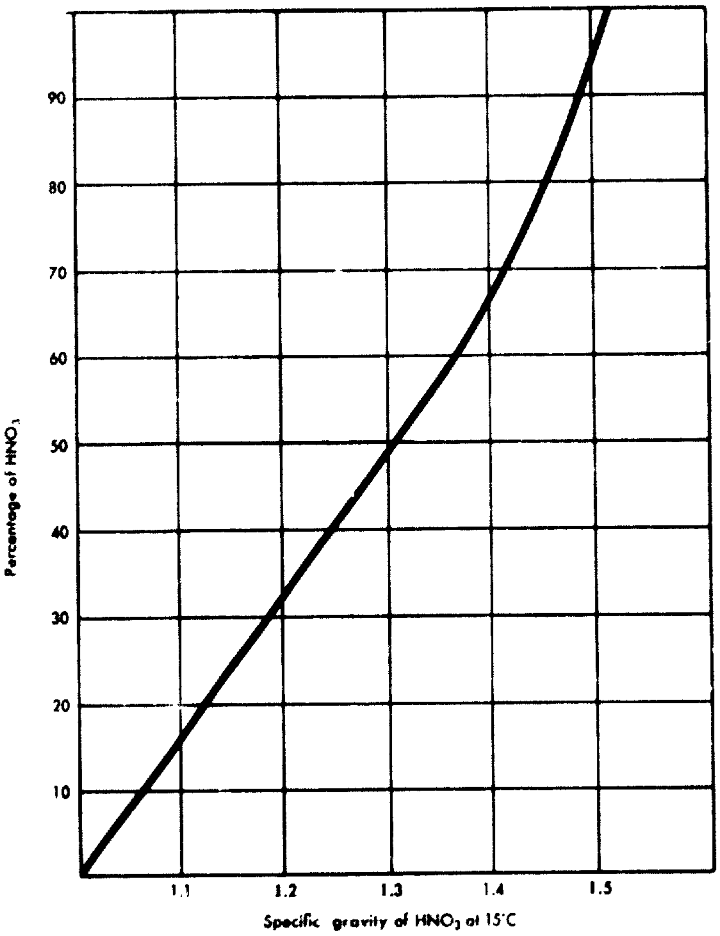
$$3HNO_2 \rightleftharpoons HNO_3 + 2NO + H_2O$$

The NO produced in the fourth reaction is oxidized by the excess air present and yields additional nitric acid.

(c) *By catalytic oxidation of ammonia*

The reactions by catalytic oxidation of ammonia followed by NO oxidation and absorption in water are given below.

Figure 18. Specific gravity at 15° C, nitric acid solutions



Ammonia oxidation

According to conditions, the following reactions can take place between ammonia and oxygen:

	ΔH per gramme-mole (calories)
(*a*) $4NH_3 + 3O_2 \rightleftharpoons 2N_2 + 6H_2O$	−302,948
(*b*) $4NH_3 + 4O_2 \rightleftharpoons 2N_2O + 6H_2O$	−263,848
(*c*) $4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_2O$	−216,548
(*d*) $4NH_3 + 7O_2 \rightleftharpoons 4NO_2 + 6H_2O$	−271,148
(*e*) $4NH_3 + 6NO \rightleftharpoons 5N_2 + 6H_2O$	−432,548

Oxygen is supplied in the form of air, which is pre-heated to promote the reaction and mixed with superheated ammonia vapour prior to oxidation. The stoichiometric requirement is 14.2 per cent NH_3, but to avoid risk of explosion (which may occur with ammonia-air combinations containing 12 to 14 per cent of NH_3), mixtures containing about 8 to 11.5 per cent of NH_3 by volume are used in commercial practice.

When a platinum type of catalyst is employed, oxidation is normally undertaken at pressures between atmospheric and 120 psig, and at temperatures between 800° C and 950° C, according to the type of process. The thermodynamic equilibria established under these conditions tend to promote the foregoing reactions and lead to the formation of unwanted nitrogen and nitrogen oxides. Hence, plant design, choice of catalyst and operating conditions must be in accordance with the circumstances favourable to the third reaction.

Various alloys and metallic oxides have been tried as catalysts, but universal preference is for platinum containing between 2 and 10 per cent rhodium. The addition of rhodium increases conversion efficiency and greatly prolongs catalyst life (50). Much research has been undertaken on this oxidation reaction (51), and it is believed by some that oxygen is first chemically absorbed by the platinum (52) and forms a series of intermediate complexes, e.g., hydroxylamine (NH_2OH), which are almost instantaneously transformed into nitric oxide and water.

It has also been established that nitric oxide yields are improved by increased temperatures, the optimum level being dependent on the rate of gas flow. The effect of pressure on the reaction has been investigated by many, with conflicting results, probably owing to the partly heterogeneous nature of the reaction. Although experimental data indicate that nitric oxide yields should not be adversely affected by increased pressures, this is not borne out in practice. However, increased pressures also increase the amount of ammonia brought into contact with the catalyst per unit of time, and careful burner design in plants of the pressure type has reduced the negative effect of pressure on conversion efficiency to very small proportions.

An extremely important variable is the rate of gas flowing past the catalyst. Increased flow rates not only increase the weight of ammonia available for oxidation (assuming a constant gas composition), but also probably lead to higher oxygen-transport rates on the catalyst surface and quicker removal of the newly formed intermediate products. Furthermore, at low velocities, nitric oxide can diffuse up-stream behind the catalyst to form nitrogen dioxide as in reaction (*e*), which will subsequently yield unwanted nitrogen, as shown below in reaction (*f*):

$$8NH_3 + 6NO_2 \rightleftharpoons 14N_2 + 12H_2O$$

Increased gas velocities, plus the provision of several layers of catalyst, also help to minimize undesirable down-stream reactions between unconverted ammonia and nitrogen oxides as in reactions (*e*) and (*f*), as well as the dissociation of nitric oxide into nitrogen and oxygen. Undesirable side reactions are thus minimized, and reaction (*c*) is favoured by providing high gas velocities and a short contact time, which is usually in the region of 0.001 seconds.

Nitric oxide oxidation

Nitric oxide produced in the ammonia burner must be oxidized to nitrogen dioxide by the excess air present before absorption in water. Some nitric oxide is formed during this absorption and must also be oxidized prior to re-absorption; i.e.:

Cal/g-mole

$2NO + O_2 \rightleftharpoons 2NO_2$ 27,100

This is an unusual, third-order, trimolecular reaction, as it has a negative temperature coefficient and is thus assisted by decreased temperatures and increased pressures. Conversion time has been shown to be a function of the square of the pressure. Although this reaction has been studied by several workers in great detail (53, 54, 55), it is still not fully understood and it is possible that such transient complexes as $(NO)_x$ and $(NO_3)_y$ are formed during oxidation. Some investigators believe the reaction rate is influenced by such factors as materials of construction and the vessel walls of the plant, since the reaction is probably partly heterogeneous (52, 56).

Nitrogen dioxide absorption

The principal absorption reactions of significance in nitric acid manufacture are:

(*a*) $2NO_2 + H_2O \rightleftharpoons HNO_3 + HNO_2$

(*b*) $2HNO_2 \rightleftharpoons H_2O + NO + NO_2$

(*c*) $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO$ . . . . $-32,200$ cal

(*d*) $2NO + O_2 \rightleftharpoons 2NO_2$

(*e*) $2NO_2 \rightleftharpoons N_2O_4$

The over-all equilibrium reaction between nitrogen dioxide and water is given in reaction (*c*).

The absorption of nitrogen dioxide in water has been studied extensively (51, 57) under widely different conditions (58, 59), but correlation has not always been obtained (60). This may be owing in part to the effect of such extraneous variables as materials of construction and equipment design, since this reaction (like the oxidation of NO) is probably partly heterogeneous and may also involve the brief formation of complex intermediates.

Nevertheless, several principal conclusions can be drawn from the mass of research data available (61). For example, when temperatures are reduced, the gas-phase equilibrium moves towards the formation of additional dinitrogen tetroxide and an increased solubility in HNO_3. As a result, in some cases a reduction of 5° C not only improves the absorption rate, but also increases acid concentration by about 2 per cent. In addition, the tendency for nitric acid to decompose according to reaction (*a*) is diminished. Reduced temperatures also reduce the activity of reactions (*a*) and (*b*) when in the liquid phase. Hence, the over-all absorber operation is greatly improved by lower temperatures.

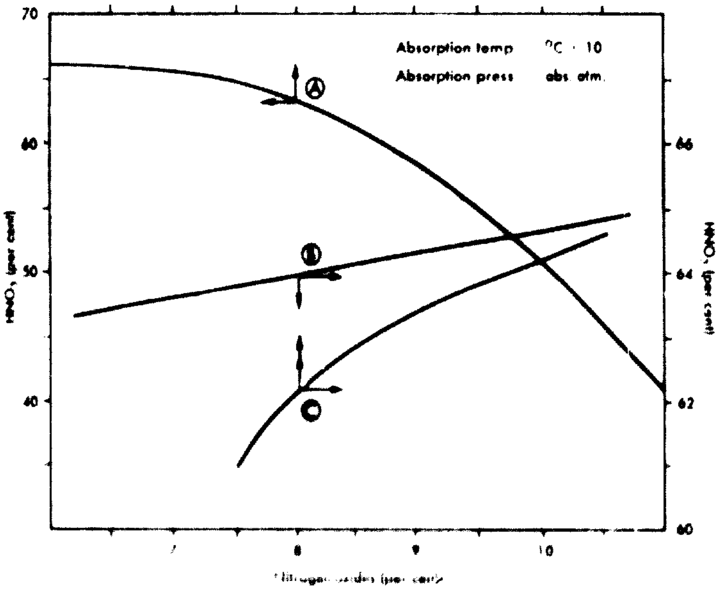
Absorber performance is also aided by increased pressure (62), not only because of the simultaneous beneficial effect on reaction (*d*), but because the absorption rate is also increased and the chemical equilibrium moves towards the formation of stronger nitric acid. At pressures of 50 atmospheres and with cooler/absorber residence times as long as fifteen seconds, acid concentrations as high as 72 per cent HNO_3 can be obtained, although absorption efficiency is low. In commercial operation, however, uneconomic increases in pressure are needed to obtain concentrations above 60 per cent HNO_3, except in absorber units of special design. Numerous studies of the absorption mechanism in most types of contacting equipment have been made, with conflicting results in some cases. Nevertheless, it seems apparent that gas-phase reactions between N_2O_4 and H_2O are not appreciable, and absorption rates are largely functions of chemical reaction rates and not diffusion rates from the gas phase to the liquid phase.

More recent work by Andrew and Hanson, using a sieve plate, showed the controlling factor to be the gas composition (57). When the NO_2 concentration is high, the rate of solution of N_2O_4 in the acid (followed by rapid hydrolysis) is the principal factor. When the NO_2 concentration is low, absorption rate is a function of the $NO:NO_2$ ratio in the gas phase. A ratio of NO to NO_2 greater than 5 to 1 will cause the absorption rate of nitrous acid (followed by rapid decomposition in the liquid phase) to assume control. At ratios less than 1:2, the absorption rate of NO_2 is of greater importance; and for intermediate ratios, a combination of both controlling influences can be anticipated, with results that may be difficult to predict.

The effects of major absorption variables on the strength of nitric acid produced during initial cooling are shown in figure 19.

The principal effects of major process variables on the three fundamental steps involved in nitric acid manufacture are summarized in table 38.

Figure 19. Effect of major process variables on equilibrium concentration of nitric acid produced during absorption



Source: United States of America, Tennessee Valley Authority

Legend

Curve A: Temperature in Centigrade degrees *versus* concentration (for 9.5 per cent nitrogen oxides at 6 absolute atmosphere and 0.9 oxidation)

Curve B: Percentage of nitric oxides in gas *versus* concentration (for a gas at 30° Centigrade, 6 absolute atmosphere and 0.9 oxidation)

Curve C: Pressure in absolute atmosphere *versus* concentration (for a gas containing 6.65 per cent nitrogen oxides at 30° Centigrade and 0.9 oxidation)

4. *Production considerations*

(a) *General information*

Numerous proprietary processes for nitric acid manufacture are now available, but they differ mostly in design details or selected operating conditions and not in fundamental principles. The major features usually found in modern nitric acid plants include:

(*a*) Vaporization, superheating and, perhaps, filtration of anhydrous ammonia;

(*b*) Pre-heating, filtration and compression of process air;

(*c*) Catalytic oxidation of ammonia;

(*d*) Cooling of nitric oxide by heat exchange with various media, e.g., process air, boiler-water, tail-gas etc.;

(*e*) Oxidation of nitric oxide to higher oxides;

(*f*) Absorption of nitrogen oxides in water to form nitric acid;

(*g*) Bleaching of acid by additional air or other means;

(*h*) Treatment of tail-gas to improve total plant efficiency and to reduce air pollution (in some cases);

(*i*) Recovery of energy in compressed process-gases;

(*j*) Recovery of catalyst for resale.

Ammonia-gas preparation

The anhydrous ammonia used must be free from the catalyst poisons mentioned below; and the oil content must be limited to a few parts per million to avoid fouling the vaporizer and catalyst screens. Liquid, anhydrous ammonia produced to the required specifications is vaporized, filtered and superheated to eliminate any possibility of liquid droplets entering the catalyst chamber and burning holes in the screens. The superheated vapour is thoroughly mixed with process air in various ways, e.g., by venturis, spargers, diffusers etc., according to the type of process. Some plants also use specially designed ducts, baffles and even packed columns to ensure complete mixing.

Process-air preparation

Process air must also be free from catalyst poisons, dust and oil. In some plants, ambient air is given a preliminary wash with water in a spray tower or packed column before being compressed, filtered, pre-heated and

TABLE 38. EFFECT OF MAJOR PROCESS VARIABLES ON NITRIC ACID MANUFACTURE

Process change	*Effect of change*		
	NH_3 oxidation	*NO oxidation*	*NO_2 absorption*
Increased temperature	Greater yield	Lower yield	Reduced absorption, lower HNO_3 strength
Increased pressure	Oxidation rate slightly reduced. Weight of NH_3 oxidized increased per unit time	Increased yield	Improved absorption, greater HNO_3 strength
Increased flow rate	Optimum operating temperature increased. Weight of NH_3 oxidized increased. NO yield improved	Reduced secondary reactions More turbulence and increased yield	Minor improvements only, as absorption mostly controlled by gas composition and reaction rates

mixed with superheated ammonia vapour for subsequent combustion.

In certain plants employing atmospheric or low-pressure oxidation, the process air can be raised to the required pressure by suitably designed fans. For medium- and high-pressure oxidation, rotary machines of the lobe, vane, centrifugal or axial flow design can be used, with an increasing preference for the two latter types, since these units can be combined with various turbine drives and expanders in the form of one large single-shaft installation.

The ratio of ammonia to air, as well as the flow rate of each component, must be carefully controlled to ensure maximum conversion efficiency, freedom from explosion and maximum plant output. Hence, reliable instrumentation in this section, as well as in other parts of the plant, is of the utmost importance.

Catalytic ammonia oxidation

Catalyst considerations. Although other catalysts, such as special oxides, have been investigated or used to a limited extent (46, 50, 63), the customary choice is a platinum-rhodium gauze, as this alloy promotes reaction and also meets other operating criteria, as well as the severe conditions of service. According to the type of process used, a rhodium content of 2 to 10 per cent offers an optimum economic balance between oxidation efficiency and operating costs, although higher percentages tend to give slightly greater conversions and longer life. In many plants, a 10 per cent rhodium content has become standard.

The need to minimize and control contact time in order to suppress unwanted reactions and to minimize catalyst requirements led to the early adoption of fine screens as a suitable catalyst form. These are usually circular in shape and are stacked in multiple array, as the use of several screens permits variations in residence times and contact times to be easily made, in order to obtain the maximum yield of nitric oxide. The use of multiple platinum gauzes in conjunction with pre-heated air was patented in 1909 by Kaiser in Germany, and these principles are still standard practice today. High-pressure burners are frequently fitted with 80 × 80 inch mesh gauzes having wires 0.003 inches in diameter. Finer gauzes with wires in the range of 0.002 to 0.00225 inches are preferred by some for installation in low-pressure units (64, 65). Chromenickel alloy grids are used to support these fine screens because they have a very low mechanical strength when they are operating in the 900° C range and, simultaneously, are being subjected to appreciable differential pressures caused by the high gas velocities in the burner chamber.

When first installed, a new gauze exhibits a relatively low activity, but after several days of operation under proper conditions, catalytic efficiency rises to a satisfactory level and remains constant during the useful life of the screen, which should be several weeks, or even months, for high- and low-pressure burners, respectively. During operation, the crystalline structure of the platinum alloy is modified by the severity of service, and distortion takes place. Erosion also occurs if vibration is present, especially at high temperatures and pressures, which also results in diminished activity. Eventually, the screen wears out and has to be replaced.

As is well known, platinum catalysts for most processes can be poisoned by such elements as As, Bi, P, Pb, S, Si and Sn, and ammonia-oxidation gauzes are no exception. Fortunately, synthetic ammonia is normally of high purity, unless accidently contaminated. If poisoning by impure ammonia or air should arise, deep penetration may occur, leading to the formation of inactive compounds in the wires and, perhaps, to ruination of the catalyst. In other instances, contamination by traces of Cr, Fe or Ni may temporarily reduce conversion efficiency, which can often be restored by treatment with hydrochloric acid or certain salts. Frequently, activity can also be assisted by dismantling the catalyst screen-assembly from time to time and removing accumulated solids by gently brushing the gauzes, which also helps to reduce the pressure-drop across the burner. However, catalyst screens should be handled to the minimum extent because they become brittle during service.

Burner operation. Ammonia burners are classified into low-, medium- and high-pressure types in accordance with conditions of operation, although medium-pressure burners tend to resemble low-pressure units in size and design. Burners for atmospheric and low to medium pressures are often 10 to 12 feet in diameter and perhaps may incorporate up to five or so catalyst screens, whereas high-pressure burners are much smaller in diameter — perhaps 4 to 5 feet and may contain about twenty-five gauzes. Surprisingly enough, high-pressure units of this size can produce 250 tons of HNO_3, or even more, per twenty-four hour day. Gas velocities are much greater in such high-pressure burners and efficiencies are usually less, say, in the 94 per cent range, compared with 97 per cent or so for low-pressure and atmospheric units.

However, the most recent designs of high-pressure burners, in which diameters are increased to reduce gas velocities, are said to approach efficiencies formerly only attainable in low-pressure atmospheric units. Most low-pressure burners operate in the region of 800° C and high-pressure units at about 900° C. The higher temperatures, pressures and gas velocities associated with high-pressure burners reflect much greater catalyst losses. Mukherjee *et al.* gave the following relative losses before recovery as a typical guide (66).

TABLE 39. RELATIVE CATALYST LOSSES OF DIFFERENT TYPES OF NITRIC ACID PROCESSES

Ammonia-burner pressure	*Absorption pressure*	*Relative platinum losses*
Atmospheric	Atmospheric	1
Atmospheric	3.2 × atmospheric	1
3.2 × atmospheric	3.2 × atmospheric	3
8.0 × atmospheric	8.0 atmospheric	5

Sagoeschen similarly indicates low-pressure burner platinum losses to be of the order of 0.03 to 0.06 grammes per ton of HNO_3, compared with 0.22 to 0.44 grammes on the same basis for some high-pressure units (67). Hence, the down-time for catalyst renewal is relatively much greater in high-pressure burners for a given weight of installed catalyst. None the less, in some high-pressure plants, an average screen-life approaching 1,000 hours of continuous operation is obtained.

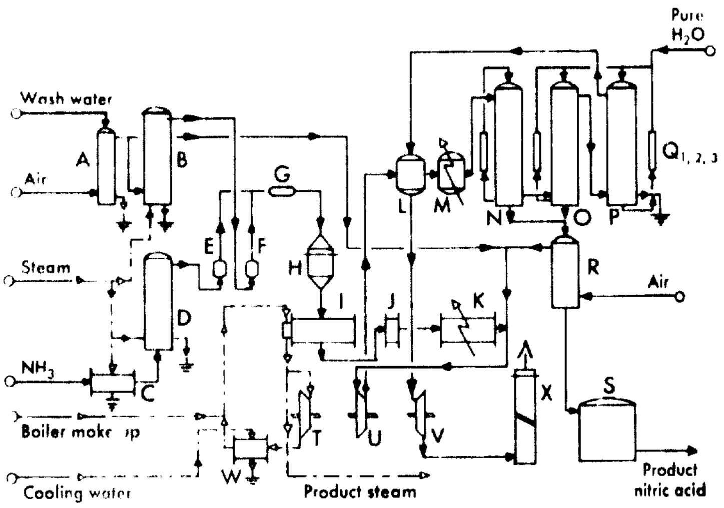
Cooling of reaction products. Hot gases leaving the burner are cooled in order to increase the formation of nitrogen dioxide and to recover heat for use elsewhere in the plant, thereby contributing to the self-sufficiency of the process. In some atmospheric and low-pressure installations, the gases pass in turn through an air pre-heater, a waste-heat boiler, an economizer and a cooler before absorption. In most medium- and high-pressure plants, different sequences are used, perhaps with the addition of tail-gas heaters, intermediate compressors and expander. In one process used in the United States of America, all major heat exchangers are mounted horizontally end-to-end to simplify plant design and to reduce capital costs (68). In several European processes, some of the heat exchangers are built as an integral part of other equipment, for example, the burner or the waste-heat boilers. Heat recoveries of the order of 82 to 85 per cent are attained in some plants, higher figures being limited by dew-point (69) and corrosion considerations. In certain cases, about 1.1 tons of steam per ton of 100 per cent HNO_3 can be produced, but most of this is normally used for power purposes within the nitric acid plant.

The optimum gas-cooling sequence is closely associated with the number and types of energy recovery units, and also the operating temperatures and pressures selected for each stage of the process. Plant capacities, ammonia costs, capital and operating costs must also be taken into consideration when selecting the best cooling sequence for a specific installation.

Nitric oxide oxidation. In atmospheric, and some low-to medium-pressure processes, one or more separate oxidation-cooling units are often included prior to gas absorption. These are built in the form of vertical towers cooled with external water curtains, shell and tube units, and also drum and cascade coolers. Excess air in the gas promotes initial oxidation and some of the water vapour also present condenses to form weak nitric acid, which is later concentrated in the absorption section. In some plants, the gas is rapidly cooled in specially designed units to condense the water vapour without forming much weak acid, thereby helping to increase final acid concentration. A combined multistage condenser-cyclone separator unit, designed to remove water from the system and capable of yielding an acid concentration of about 63 per cent HNO_3, has recently been described (70). A basic flow diagram for a typical low-pressure nitric acid process is given in figure 20.

When high-pressure absorption is employed, nitric oxide cooling and oxidation are often undertaken in a combined oxidation-absorption column. However, the additional flexibility provided by a separate oxidation-cooling unit and the ability to minimize the amount of weak acid formed prior to absorption is considered advantageous by some producers.

Figure 20. Basic flow diagram for a typical low-pressure nitric acid process



Legend

A: Air washer
B: Air heater
C: Ammonia vaporizer
D: Ammonia superheater
E: Ammonia filter
F: Air filter
G: Ammonia-air mixer
H: Ammonia burner
I: Waste-heat boiler
J: Platinum filter
K: Nitrogen oxides cooler No. 1
L: Tail-gas heater
M: Nitrogen oxides cooler No. 2
N: Oxidation tower
O: Absorption tower
P: Scrubber tower
$Q_{1,2,3}$: Tower liquor-coolers
R: Bleacher column
S: Product acid tank
T: Steam turbine
U: Nitrogen oxides compressor
V: Tail-gas expander
W: Turbine condenser
X: Stack

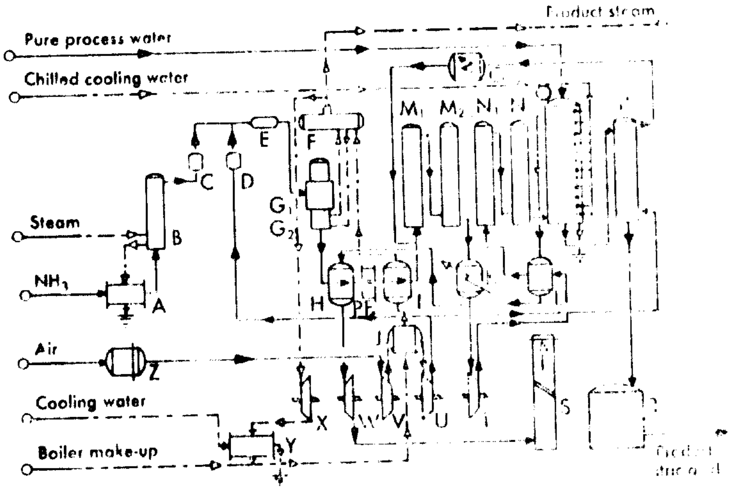
Nitrogen dioxide absorption. At near atmospheric pressures, the absorption rate is slow, and some earlier atmospheric and low-pressure plants used between five and ten large, packed stoneware towers in which the partially oxidized gases were absorbed in a counter-current stream of nitric acid of increasing concentration. Maximum strengths attainable were in the range of 47 to 52 per cent HNO_3.

In order to reduce capital investment and to obtain increased operating efficiencies, absorption under pressure was developed, using various types of equipment (51, p. 116), e.g., cascade coolers, packed columns, spray towers and columns incorporating bubble-plates, sieves and such special devices as the Kuhlman tray (71, 72).

Since acid concentrations are favoured by low-temperature absorption, several different cooling methods have also been developed, e.g., by external units of the plate, drum or cascade type, by water curtains outside the tower and also by cooling coils strategically located inside the absorption column. In some plants using low-pressure ammonia oxidation, vaporization of the ammonia is used to pre-cool the absorber feed-water.

Modern pressure-absorption systems permit efficiencies of about 99 per cent to be obtained, together with acid concentrations in ranges of 55-57 per cent and 60-61 per cent for medium- and high-pressure systems, respectively (73). In some European processes, concentrations of up to 70 per cent HNO_3 are achieved by using pressures in the range of 90 to 100 psig and cooled water in conjunction with specially designed absorption columns. Process water for absorption systems must be very pure, to reduce corrosion effects in the nitric acid plant and also in applications involving subsequent use of the acid. In particular, the chloride content must be particularly low. Hence, water from condensate sources of ion-exchange purification units is often used. A basic flow diagram for a mixed, medium-pressure nitric acid process is shown in figure 21.

Figure 21. Basic flow diagram for a typical medium-pressure nitric acid process



Legend

- **A: Ammonia vaporizer**
- **B: Ammonia superheater**
- **C: Ammonia filter**
- **D: Air filter**
- **E: Ammonia-air mixer**
- **F: Steam drum**
- **G_1: Ammonia burner**
- **G_2: Waste-heat boiler**
- **H: Tail-gas heater No. 2**
- **I: Nitrogen oxides cooler No. 1**
- **J: Compressor intercooler exchanger**
- **K: Nitrogen oxides cooler No. 2**
- **L: Tail-gas heater No. 1**
- **M_1, M_2: Primary oxidation towers**
- **N_1, N_2: Secondary oxidation towers**
- **O: Absorption tower**
- **P: Bleacher column**
- **Q: Bleacher-gas cooler**
- **R: Product acid tank**
- **S: Stack**
- **T: Nitrogen oxides compressor**
- **U: Air compressor, stage No. 2**
- **V: Air compressor, stage No. 1**
- **W: Tail-gas expander**
- **X: Steam turbine**
- **Y: Turbine condenser**
- **Z: Intake air cleaner**
- **PF: Platinum filter**

Acid bleaching. Acid produced in most absorber units is invariably yellow or brown in colour, owing to unabsorbed nitrogen dioxide. This is removed either in a separate small bleaching tower or in an additional, lower section of the main absorber column, by means of compressed-air injection.

Tail-gas treatment. Except for atmospheric units, exit gas from the absorber is normally pre-heated and expanded in a turbine to recover an appreciable amount of the energy used for compression purposes. This gas contains some water vapour, oxygen and mixed nitric oxides, typical concentrations of the latter being about 1,000 and 2,000 parts per million of NO_2 and NO, respectively.

In recent years, air-pollution research has demonstrated that nitrogen oxides are major contributors to smog formation and corrosive atmospheres. Nitric oxide appears to catalyze the partial oxidation of hydrocarbons emitted from industrial plants and automobiles, and nitrogen dioxide leads to the formation of nitric acid, as well as sulphuric acid, if sulphur dioxide is also present in the atmosphere (74). In addition, concentrations of nitrogen oxides greater than 10 parts per million may be cumulatively harmful if regularly inhaled. Furthermore, nitrogen dioxide will impart a yellow colour to the tail-gas in concentrations as low as 500 ppm and when present in amounts several times greater than this figure, the persistent brown plume may cause great concern in the neighbourhood. For these reasons, various measures are frequently taken to minimize these undesirable features; and, in some countries, local regulations insist on the installation of tall stacks to reduce nitrogen oxide concentrations to below 0.5 ppm in the plant vicinity, by means of atmospheric dilution (75). The aspiration of secondary air into the stack gases is also undertaken to increase oxidation and dilution of the nitrogen oxides.

The reduction of pollution by dilution, however, is more apparent than real, for the harmful nitrogen oxides are not decomposed. If, however, circumstances necessitate their conversion to innocuous products, several methods are available. For example, the tail-gas can be scrubbed with caustic soda to yield by-product sodium nitrate and sodium nitrite. Waste alkali liquors can sometimes be used, and scrubbing with lime slurry is also undertaken (76).

An alternative method is to reduce the nitrogen oxides by combustion with a hydrocarbon fuel or hydrogen over a platinum or palladium (77) catalyst after pre-heating by heat-exchange with gas from the ammonia burner, or even by the hot gases from the reduction unit (78, 65). In some cases, the tail-gas burner can be interposed between the reheater and the waste-heat boiler, prior to the expander, thus recovering the heat of combustion of the fuel used to burn the tail-gas residuals. If the oxygen content of the tail-gas from the absorber is greater than about 3 per cent, a two-stage combustion unit with inter-cooling may be needed to permit both the oxygen and the nitrogen oxides to be reduced under controlled conditions and to avoid burning out the reduction unit.

It is also possible to reduce most of the offensive NO_2 without simultaneously removing most or all of the oxygen and NO also present in the tail-gas, provided the NO and total acidity are already within acceptable limits (79). This is accomplished by selective combustion under controlled conditions and leads to useful savings in fuel. In a similar alternative method of recent development, ammonia is used to reduce catalytically only the nitrogen oxides under low-temperature conditions. In one instance, the use of a selective reduction unit together with chemical scrubbers permits nitrogen from tail-gas sources to be reused for ammonia-synthesis prupose (80).

Energy recovery. Except in older plants operating at atmospheric pressure throughout, and in very small medium- and high-pressure installations, most or all of the energy needed to drive the air compressor can be recovered in the form of steam and hot tail-gas (57). In some instances, a small amount of surplus steam may even be generated.

This is made possible by the availability of highly efficient machines, which comprise a compressor, steam turbine and tail-gas expander built in the form of a single, in-line unit (81). In one European process, a compressor for raising the pressure of nitrogen oxides, prior to absorption, is also included (82). Occasionally, an electric motor is also added to the power unit for start-up or emergency purposes, if sufficient steam is not always available (68). Electrical requirements for pumps and ancillary purposes are usually drawn from the main factory power-supply.

Platinum recovery. Platinum passes into the gas stream in the form of very fine particles, and its loss can represent an increase of several per cent in production costs. Therefore, recovery units are installed in many plants, and the fine dust reclaimed is returned with spent gauzes to the precious-metal refinery. Several types of recovery units are in use, the more common incorporating filters of glass wool or silica fibres (65, 68). One device uses calcium oxide as a filter medium, and the retained platinum dust is recovered by slurrying with water and dissolving in nitric acid, followed by filtration. In another recovery method, the platinum dust forms an alloy with gold previously deposited on ceramic rings, which are eventually stripped and reprocessed (64). Recoveries should be of the order of at least 50 per cent for dry filters and may be as high as 80 per cent for the lime type of unit, according to the permeability of the filter media used and the type of process. Attempts to increase platinum recovery by using finer filter media may result in greater operating costs; hence, an optimum balance between these two factors must be adopted.

5. *Technical and economic comparisons*

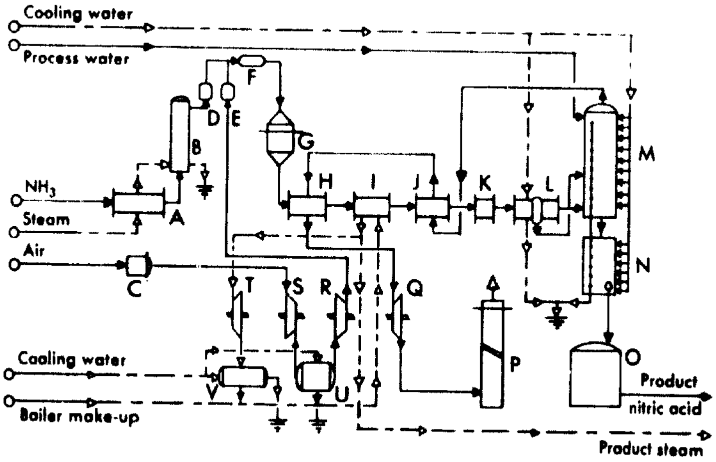
The availability of low-, medium- and high-pressure techniques for oxidation and absorption offers a variety of alternative combinations by which nitric acid can be manufactured, and this has led to the development of numerous commercial processes differing largely in accordance with the combination selected (83). In general, high-pressure operation permits smaller plant units to be used for a given output and helps to reduce capital cost. High pressures also favour NO_2 absorption (61). However, high-pressure ammonia oxidation induces greater catalyst losses and also increases power requirements unless additional equipment is installed for power recovery. In terms of percentages, capital costs for a high-pressure plant could be at least 10 per cent lower than those for a low- or medium-pressure plant of the same capacity, and the steam produced might be 20 per cent greater. At the same time, the total nitrogen conversion efficiency might be 1.0 to 1.5 per cent lower and the platinum consumption two to three times greater. In addition, the energy consumption and maintenance changes are likely to be higher for a high-pressure plant.

Plant investment and production costs are charted in chapter XXI, figures 90, 91 and 92.

Figure 22 shows the basic flow diagram of a typical high-pressure nitric acid process.

In order to obtain an optimum compromise between capital investment and production cost, several European proprietary processes incorporating low- or medium-pressure oxidation and high-pressure absorption, together with maximum steam and power recovery, have been devised. Combinations of low and medium pressures are also used in other processes. Hence, there appears to be no one best method (84), but rather an optimum combination of techniques for each set of conditions (85). This can be determined only on the basis of a detailed technical and economic analysis of several alternatives.

Figure 22. Basic flow diagram for a typical high-pressure nitric acid process



Legend

A: Ammonia vaporizer
B: Ammonia superheater
C: Air cleaner
D: Ammonia filter
E: Air filter
F: Ammonia-air mixer
G: Ammonia burner
H: Tail-gas heater No. 2
I: Waste-heat boiler
J: Tail-gas heater No. 1
K: Platinum filter
L: Cooler-condenser
M: Oxidation-absorption tower
N: Bleacher column
O: Product acid tank
P: Stack
Q: Tail-gas expander
R: Air compressor, stage No. 2
S: Air compressor, stage No. 1
T: Steam turbine
U: Compressor intercooler/exchanger
V: Turbine condenser

For example, where the costs of ammonia and power are high, a plant giving maximum over-all efficiency would be advocated, perhaps based on low-pressure oxidation and medium- or high-pressure absorption. In cases where available funds were limited and high-rates of return and/or a rapid write-off of capital were essential, but ammonia and power costs were not the critical factors, a completely high-pressure process might be the best choice. As with many other chemical processes, therefore, the optimum choice becomes a function of financial policy and accounting procedures, in addition to technological considerations. Alternatively, an emphasis on high acid-concentration might dictate the selection of a process incorporating high-pressure absorption and chilled process-water. One general comparison between the requirements per ton of 100 per cent HNO_3, for the low-medium combination-pressure plants of European design and high-pressure plants of the type used in the United States of America, was given as:

TABLE 40. GENERAL COMPARISON OF NITRIC ACID PROCESSES USED IN EUROPE AND THE UNITED STATES OF AMERICA

	Process used in Europe	*Process used in United States of America*
Ammonia (tons)	0.28 to 0.29	0.29 to 0.294
Platinum (troy ounces)	0.002	0.004 to 0.005
Steam credit (tons)	1.0 to 1.5	1.0 to 1.25
Cooling water (gallons)	25,000	25,000

SOURCE: *Chemical Week* (New York), vol. 54 (8 Dec. 1962).

As a guide, the principal features of some typical commercial nitric acid processes are given in table 41.

TABLE 41. PRINCIPAL FEATURES OF TYPICAL COMMERCIAL NITRIC ACID PROCESSES

Ref. No.	Name	*Operating pressures atmospheres (absolute) (approximate)* Combustion	Oxidation	Absorption	Product acid (percentage HNO_3)	Typical requirements per ton of 100 per cent HNO_3	Distinctive features
1*a*	Bamag (monopressure) .	1, 4 or 8	As for combustion	As for combustion	55 to 70	Dependent on pressures used	Uses perforated-plate towers with cooling-water coils on the plates
1*b*	Bamag (combination) .	1, 4 or 8	4 or 8	4 or 8	55 to 70	*(1, 4,4 atm. pressures)* NH_3 . . . . . . 280 kg Pt . . . . 45 mg Cooling H_2O . . 170 m^3 Pure H_2O . . . . 100 kg L.V. power . . . 20 kWh (Product steam) . 200 kg	Similar to above
2	Chem co	8 to 9	8 to 9	8 to 9	55 to 65	*(Steam turbine and 510° C Expdr.)* NH_3 . . . . . . 287 kg Pt . . . . 128 mg Cooling H_2O . . 135 m^3 Pure H_2O . . . . 500 kg L.V. power . . . 3.9 kWh (Product steam) . 200 to 350 kg	*(With steam turbine and 650° C Expdr.)* NH_3 . . . . . . 287 kg Pt . . . . 128 mg Cooling H_2O . . 100 m^3 Pure H_2O . . . . 540 kg L.V. power . . . 3.9 kWh (Product steam) . 970 kg
3	C & I	8	8	8	55 to 67+	NH_3 . . . . . . 292 kg Pt . . . . 170 mg Cooling H_2O . . 117 m^3 Pure H_2O . . . . 400 kg L.V. power . . . 93 kWh (Product steam) . 880 kg	Uses cascade cooling and a single tower for oxidation/absorption/bleaching
4	Fauser Montecatini . .	4 to 5	4 to 5	4 to 5	53 to 62	NH_3 . . . . . . 286 kg Pt . . . . 85 to 100 mg Cooling H_2O . . 100 to 230 m^3 Power . . . . . 50 kWh (Product steam) . 100 to 300 kg	Uses separate oxidation and absorption towers fitted with refrigerated trays. The figures shown refer to a steam-turbine drive
5	Grand Paroisse	3 to 4	7 to 8	7 to 8	56 to 70	NH_3 . . . . . . 282 kg Pt . . . . 100 mg Cooling H_2O . . 200 m^3 Pure H_2O . . . . 710 kg L.V. power . . . 10 kWh (Product steam) . 135 kg	Oxidation towers cooled by external water curtains. Absorption tower cooled by internal water-coils, 5-unit, single-shaft turbo-compressor used
6	Hercules	8	8	8	57 to 60	NH_3 . . . . . . 285 kg Pt . . . . 174 mg Cooling H_2O . . 85 to 95 m^3 Pure H_2O . . . . 500 kg L.V. power . . . 5 kWh (Product steam) . 80 kg	Uses high gas superheat to obtain maximum power recovery. Specially designed water-cooled trays ensure a minimum 99 per cent efficiency of absorption
7	Kuhlman	1	4	5	55 to 70	NH_3 . . . . . . 280 kg Pt . . . . 45 mg Cooling H_2O . . 150 m^3 L.V. power . . . 10 kWh (Product steam) . 110 kg	Uses a specially designed tray to induce oxidation and absorption in the liquid phase
8	Pechiney-St. Gobain . .	4 to 5	4 to 5	4 to 5	Normally up to 60	NH_3 . . . . . . 286 kg Pt . . . . 100 mg L.V. power . . . 50 kWh (Product steam) . 300 kg	Uses specially designed water-cooled trays in oxidation-absorption columns

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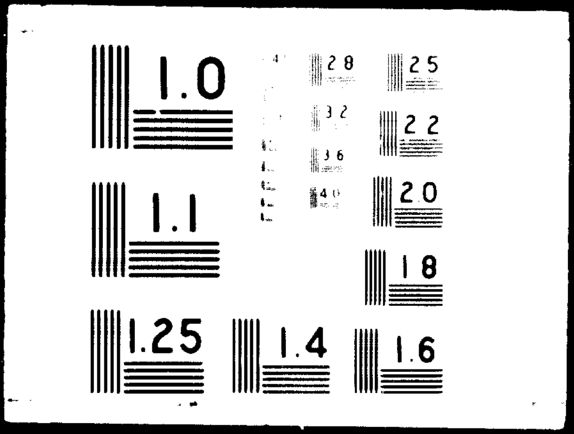


TABLE 41 *(continued)*

Ref. No.	Name	Operating pressures atmospheres (absolute) (approximate) Combustion	Oxidation	Absorption	Product acid (percentage HNO_3)	Typical requirements per ton of 100 per cent HNO_3	Distinctive features
9*a*	Société Belge de l'Azote (SBA)	1	3 to 5	3 to 5	58 to 70	*(For 55 per cent HNO_3)* NH_3 281 kg Pt 45 mg Cooling H_2O 150 m^3 Pure H_2O 650 kg L.V. power 10 kWh (Product steam) 0 to 950 kg	Packed columns for 58 per cent acid. Additional plate-type columns used for 70 per cent acid
9*b*	SBA	3.3	3 to 5	8	50 to 70	Similar to above	Similar to above. Uses catalytic tail-gas combustion for maximum energy recovery
10	Stami-Carbon	(*a*) 1 (*b*) to 5	5 to 6	5 to 6	50 to 65	NH_3 285 kg Pt 45 mg Cooling H_2O 250 m^3 Pure H_2O 730 kg L.V. power 20 kWh (Product steam) 0 to 100 kg	Specially designed plate coolers used in conjunction with packed columns. Figures shown refer to process (*a*)
11*a*	Uhde (normal-strength)	7 to 8	7 to 8	7 to 8	55 to 60	NH_3 285 kg Pt (before recovery) 200 mg Cooling H_2O 150 m^3 L.V. power 10 kWh (Product steam) 130 kg	79 per cent of steam produced used for driving air compressor, 11 per cent for heating tail-gas, 10 per cent as product steam. Bubble-tray absorbers used
11*b*	Uhde (high-strength)	(*a*) 4.5 (*b*) 1	4 to 5	4 to 5	68 minimum	*(Gas and steam turbines)* NH_3 283 kg Pt (before recovery) 60 mg Cooling H_2O 165 m^3 Pure H_2O 250 kg L.V. power 40 kWh (Product steam) 210 kg	Uses multistage, packed oxidation and absorption columns; each stage fitted with own cooler and pump. Figures shown refer to process 11*b* (*a*)
12	Weatherly	9.5	9.0	9.0	55 to 60 (or higher)	*(Steam turbine)* NH_3 284 kg Pt 165 mg Cooling H_2O 142 m^3 Pure H_2O 750 kg L.V. power 6 kWh (Product steam and condensate) 400 kg	Uses butted heat-exchanger assembly and single oxidation-absorption column fitted with bubble trays

Notes:

(1) Product steam refers to excess steam produced by the plant and available for use elsewhere.

(2) Table 41 is intended as a general comparative guide only. Actual plant performances depend in each case on such specific features as daily design capacities, water temperature, type of drive and other associated items, selected in accordance with local conditions.

6. *Nitric acid concentration*

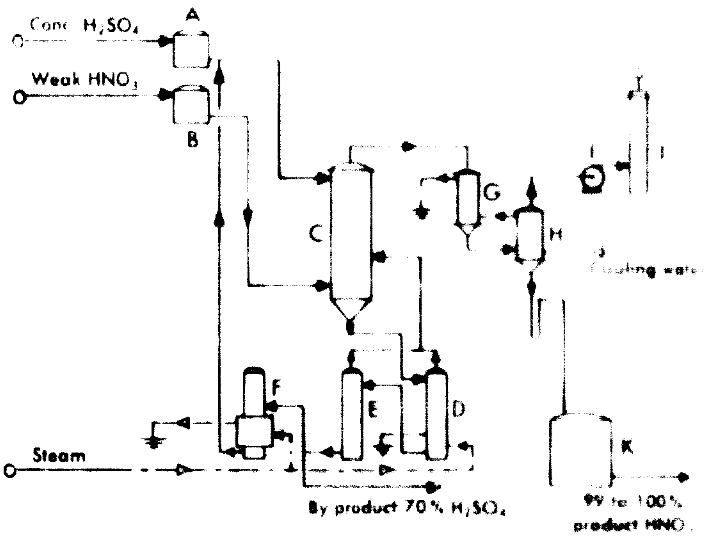
(a) *By sulphuric acid dehydration*

Although nitric acid concentrations of the order of 60 per cent HNO_3 suffice for most fertilizer purposes, higher strengths can sometimes yield financial savings in subsequent processing and/or transportation, and concentrations of 99 per cent or even 100 per cent are required for certain chemical processes (86). The usual method of concentration is to distil "weak" nitric acid (say, 55 to 60 per cent HNO_3) with strong sulphuric acid, which splits the 68 per cent azeotrope to yield concentrated nitric acid and dilute sulphuric acid.

In this process, distillation is undertaken continuously by feeding "weak" nitric acid and concentrated sulphuric acid into the bottom and top, respectively, of a packed dehydrating tower. Concentrated nitric acid is evolved from the top of the tower at about 110° C and is condensed in a water-cooled condenser as a "strong" 96 to 98 per cent HNO_3. The mixed acids leaving the base of the tower pass to a concentrator of special design in which the acid is heated by high-pressure steam (say, 180 to 200 psig) in jacketed, silicon-iron tubes. On leaving the concentrator, the diluted 70 to 73 per cent sulphuric acid enters a denitrating tower before being cooled and stored for re-concentration or for such by-product purposes as ammonium sulphate manufacture.

Nitric acid and nitric oxides released in the concentrator and denitrator also pass through the dehydrating tower and are condensed as "strong" HNO_3. The product acid is usually bleached before storage and subsequent use. A basic flow diagram of this process is shown in figure 23.

Figure 23. Sulphuric acid type of concentration process for strong nitric acid



Legend

A: Concentrated H_2SO_4 storage tank
B: Weak HNO_3 storage tank
C: Dehydrating column
D: Concentrator-separator column
E: Denitrator-separator column
F: Sulphuric acid evaporator
G: Nitrogen oxides condenser
H: Fume separator
I: Exhaust-fan
J: Stack
K: 99 to 100 per cent product acid tank

(b) *By magnesium nitrate dehydration*

In a novel process developed originally in recent years by the Hercules Powder Company of the United States of America, magnesium nitrate is employed as the dehydrating medium and is initially made by dissolving magnesium carbonate in 60 per cent HNO_3 (84, 87). This solution is concentrated to about 72 per cent in an evaporator and is then combined with "weak" nitric acid (55 to 60 per cent HNO_3) in a tray type of distillation column at approximately 100° C. The salt solution picks up water in the column and splits the azeotrope to yield "strong" nitric acid, which leaves the top of the column and is condensed to form a product containing at least 99 per cent HNO_3.

Part of this acid is returned to the column as a reflux acid, and magnesium nitrate is withdrawn from the base of the column as a 55 to 70 per cent solution at 115° C to 125° C, for cyclic concentration to a 72 per cent solution. It is claimed that a sulphate-free acid in the range of 99 to 100 per cent HNO_3 is readily produced by this process, and operating costs are about one-half of those incurred by dehydration with sulphuric acid. In addition, capital requirements are about two-thirds of the cost of a corresponding concentration unit of the sulphuric acid type. A basic flow diagram is shown in figure 24.

Figure 24. [illegible]

Legend

A Magnesium [illegible]
B [illegible]
C Stripping column
D Nitric acid rectifying column
E Magnesium nitrate make-up tank
F Weak magnesium nitrate liquor tank
G Strong magnesium nitrate liquor tank
H Recycle acid tank
I Recycle acid cooler
J Concentrated nitric acid cooler
K Concentrated acid storage tank
L Concentrated nitric acid condenser
M Weak acid absorber
N Reflux splitter

(c) *Other processes*

Several other methods for producing concentrated nitric acid have been developed or proposed. In the Fauser process, nitric oxides from an ammonia burner are quickly cooled to remove water vapour and are then further oxidized in a tower (88). The gases are compressed to at least 8 atmospheres and are cooled to 14° F to separate liquid N_2O_4. This is heated at 50 atmospheres and 70° C for about four hours with air and diluted nitric acid to yield HNO_3 of 98 to 99 per cent concentration. Modified versions of this method, using air or oxygen, have been developed by Bamag Meguin (89) and a similar process has been described by Atroshchenko and Kargin (62).

The Wisconsin Thermal Process for the manufacture of strong nitric acid has also been proposed as a possible future source of concentrated HNO_3 (90). In this case, the NO_2 produced in the furnace would be absorbed on silica gel and, subsequently, would be stripped and condensed to form liquid N_2O_4, which would finally be converted to concentrated nitric acid by further oxidation and combination with the theoretical amount of water under pressure. A concentrated nitric acid method involving agitation under pressure with liquid nitrogen peroxide has also been reported by Morris (91).

As previously mentioned, it is possible to obtain higher strengths of "weak" nitric acid by raising absorption pressures and using lower temperatures in conjunction with such special devices as the Kuhlman Tray, which permits the production of HNO_3 concentrations of about 70 per cent (82, 92). Meanwhile, the attainment of still higher concentrations without the use of chemical dehydrants (for example, sulphuric acid or corresponding salts) or recourse to batch autoclaves still remains a desirable goal.

7. *Materials of construction*

The strongly oxidizing properties of nitric acid produce a passivating effect on certain metals, e.g., iron, steel and aluminium, via the formation of complex oxides and nitrid film. Hence, these metals can be used also for the construction of certain equipment items and storage vessels, which come in contact with acid containing [illegible] per cent HNO_3 under mildly agitated or static conditions and not at elevated temperature. For severe service, silicon iron and some of the highly corrosion-resistant stainless steels are needed. Dilute HNO_3 solutions, especially if agitated and heated, may also require the use of alloy steels, e.g. for the wetted parts of pumps, impellers and distillation columns (69). Increased passivation of welded steel by anodic protection is another possibility (93). For equipment used in handling hot, dry gases, mild steel is usually adequate. In some instances, plants built almost entirely of stainless steel are preferred, as the savings in maintenance costs and the improved operating performance are said to justify the additional investment costs (68).

As regards non-metallic materials, earlier plants used stoneware extensively for equipment construction. Industrial glass-ware has also been employed. Various fluorcarbon plastics in the form of lined and unlined piping, sheet and coatings, as well as gaskets and seals, are used to an increasing degree in nitric acid plants because of their inertness, flexibility and convenience (84), even though initial costs may be relatively greater than for steel or some ferrous alloys. Some of the latest proprietary fluorcarbon materials are said to be inert even to hot, fuming nitric acid.

E. AMMONIUM NITRATE

1. *General information*

Although the nitrogen content of ammonium nitrate is 35 per cent, one-half of this is in the nitrate form, which is reported by some growers (especially paddy farmers) (86) to be inferior to ammoniacal nitrogen and also prone to leaching (94). In addition, ammonium nitrate is quite hygroscopic and, moreover, may involve some risk of fire or even explosion unless suitable precautions are undertaken (40). For these reasons, its popularity as a fertilizer has tended to be greater in the western hemisphere, particularly in the United States of America, where large tonnages are incorporated in fertilizer solutions (83, 95). More recently, improved production (96) coating (97, 98) and bagging (99, 100) techniques have greatly aided the storage properties of ammonium nitrate and may lead to a greater demand for the solid material in humid and tropical areas.

In continental Europe and in the United Kingdom of Great Britain and Northern Ireland, where the climate is usually much less humid than in tropical areas, substantial amounts of ammonium nitrate are prepared *in situ* and incorporated into multinutrient binary and ternary fertilizers. In the United Kingdom, ammonium nitrate is said to be replacing ammonium sulphate and even ammonium phosphate to some extent (101, 102). The Organisation for Economic Co-operation and Development (OECD) recently showed that in Europe, ammonium nitrate represented over 40 per cent of the total nitrogen production, compared with 27 per cent, 16 per cent and 5 per cent for ammonium sulphate, multinutrient fertilizers and urea respectively (103).

Increasing quantities of ammonium nitrate are used for blasting purposes in conjunction with fuel oil, and relatively small amounts are consumed by the brewing and chemical industries. The earlier "grained" type (104) of ammonium nitrate, made by rolling the semi-molten salt in an open pan together with resins or waxes, has been largely superseded by prilled, granular and crystalline end-products.

2. *Properties of ammonium nitrate*

The more important properties of ammonium nitrate are given below.

TABLE 42. PROPERTIES OF AMMONIUM NITRATE (CRYSTALLINE)

Colour	White
Molecular weight	80.05
Nitrogen content	35 per cent
Density 20°/4° C	1.725
Melting-point	170.4° C
Solubility	

Temperature (°C)	*Grammes NH_4NO_3 per 100 grammes H_2O*
0	118
20	187
40	297
60	410
80	576
100	843

Crystal states

Temperature (°C)	*State*	*System*
169.6	Liquid	—
169.6 to 125.2	Cubic	1
125.2 to 84.2	Tetragonal	2
84.2 to 32.1	Rhombic	3
32.1 to −18	Rhombic	4
Below −18	Tetragonal	5

Critical relative humidities

20° C (68° F)	63.3
30° C (86° F)	59.4

The changes in crystal state at 84.2° C and 32.1° C result in sudden expansion, which may cause particle degradation during processing and storage, leading to eventual caking problems unless special cooling provisions are undertaken. Another characteristic of ammonium nitrate is its negative heat of reaction: 60 parts of salt will give a reduction in temperature from 13.6° C to −13.6° C when dissolved in 100 parts of water. Schultz and Elmore (105) and others (106, 107) have investigated the system NH_4NO_3-NH_3-H_2O in considerable detail. From the solubility data shown above, it can be inferred that ammonium nitrate is quite hygroscopic under most conditions.

3. *Chemical reactions*

Ammonium nitrate is produced commercially from ammonia and nitric acid, according to the following equation:

$$NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq) - 26{,}000 \text{ cal/g-mole}$$

When heated, ammonium nitrate decomposes between 200° to 250° C and may continue to burn, giving off toxic fumes, e.g.

$$NH_4NO_3(s) \rightarrow N_2O(g) + 2H_2O(g) \quad 6.720\ \text{cal/g-mole}$$

When subjected to physical shock, especially if organic material is present, detonation can occur (as in the case of ammonium nitrate/fuel oil mixtures) on the following lines:

$$NH_4NO_3(s) \rightarrow N_2(g) + H_2O(g) + 1/2\,O_2(g) \quad 26,700\ \text{cal/g-mole}$$

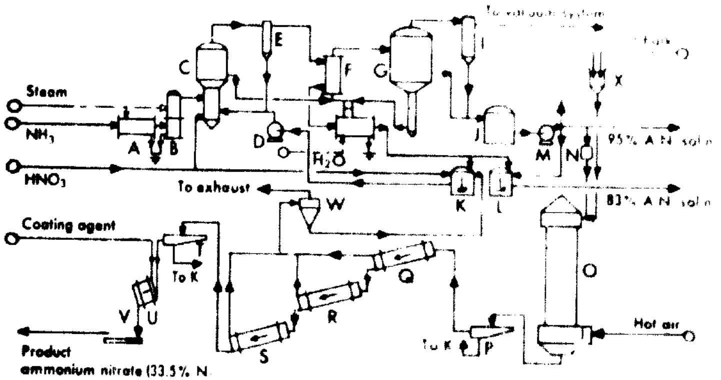
4 *Production methods*

Several proprietary processes for ammonium nitrate manufacture are available, using various combinations of different neutralization, evaporation, drying and finishing methods (19, pp. 232-236; 96, 108, 109). Solid ammonium nitrate is produced in the form of prills, crystals, and granules, either alone or in combination with other materials. Large tonnages of ammonium nitrate are also made (principally in the United States of America) in the form of solutions having concentrations in the range of 80 to 90 per cent, for use in liquid fertilizers. The major unit operations used in ammonium nitrate manufacture are described below.

(a) *Neutralization*

When sufficient steam to operate the plant is readily available from by-product or other low-cost sources, the use of an atmospheric type of neutralizer may be preferable, since such units are relatively low in capital costs and simple to operate. Alternatively, most or all of the steam needed to pre-heat the feeds and to concentrate the ammonium nitrate solution can be generated by neutralizing acids containing more than 50 per cent HNO_3 in a unit of the pressure type. (By using a 64 per cent acid, about 1 ton of steam can be produced for each ton of ammonia neutralized.) In some plants [illegible] designed to make a crystalline product, [illegible] performed under vacuum in equipment similar to that used for ammonium sulphate manufacture [illegible]. A flow diagram for a plant of the pressure type, to produce ammonium nitrate in the form of prills and also solutions, is shown in figure 25.

Figure 25. Pressure-neutralizer process for ammonium nitrate



Legend

A: Ammonia vaporizer
B: Ammonia superheater
C: Pressure neutralizer
D: Reclaim feed-pump
E: Separator No. 1
F: Evaporator heater
G: Vacuum evaporator
H: Ammonia flash condenser
I: Separator No. 2
J: 95 per cent ammonium nitrate solution tank
K: Reclaim tank
L: 83 per cent ammonium nitrate mix tank
M: 95 per cent solution pump
N: 95 per cent solution filter
O: Prill tower
P: Primary prill screen
Q: Prill pre-drier
R: Prill drier
S: Prill cooler
T: Secondary screen
U: Coating drum
V: Product conveyer
W: Dust cyclone
X: Nitro-chalk slurry mixer

(b) *Finishing*

Prilling

A popular method of producing solid ammonium nitrate is prilling, whereby the solution from the neutralizer is concentrated to about 95 per cent and sprayed under pressure or centrifugal force from the top of a tower into a rising stream of warm air (96, 111). (This is analogous to the use of shot-towers in the lead industry.) The solution solidifies in the form of small spheres or prills, which are recovered from the base of the tower and are subsequently dried, cooled, coated and bagged. To minimize particle degradation arising from changes in crystal structure during drying and cooling, these operations are usually undertaken in a special rotary drier-cooler sequence under carefully controlled conditions.

In some plants, concentration of the nitrate solution before prilling is raised to about 99.5 per cent in a wiped-film or other type of evaporator. To minimize variations in feed and particle size during prilling, various proprietary methods of spraying have been developed (96). Similarly, numerous designs of tower are used, ranging from converted chimneys to large structures about 200 feet in height and constructed in aluminium (112) or alloy steel. More recently, relatively short towers, 70 to 100 feet high, have also been installed in some plants for ammonium nitrate or urea prill production. Another development is the use of special clays in conjunction with naphthene sulphonate derivatives for coating the cooled prills, in order to minimize storage problems. Coatings of resin-paraffin mixtures are also used by some producers. The final product, containing about 33.5 per cent nitrogen, is packed in plastic moisture-proof bags or in plastic-lined paper of jute construction.

Plant investment and production costs for prilled ammonium nitrate are given in chapter XXI, figures 74 and 75. Additional data are given in figure 93.

Granulation

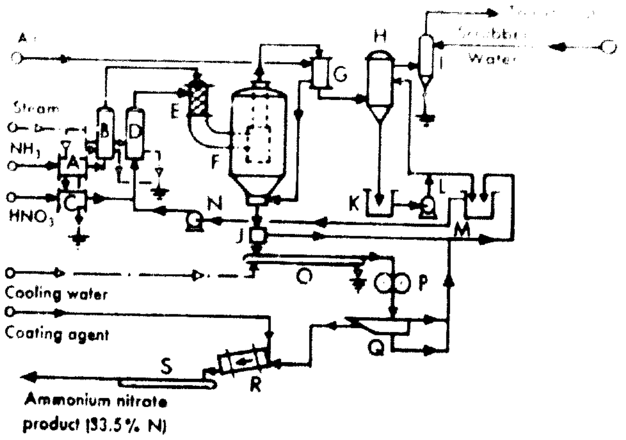
Ammonium nitrate is also produced in granular form using rotary drums, pug-mills or combinations of these machines (113). Latent heat of crystallization is used to effect most or all of the drying, following granulation of the concentrated solution. Final drying, cooling and hardening is usually undertaken in air-swept rotary drums, followed by coating and bagging in moisture-proof bags.

Melt processes

Ammonium nitrate can be produced readily in molten form also, and several processes of this nature have been developed or proposed. In the well-known Stengel process, 60 per cent nitric acid is heated to about 170° C, or combined with ammonia vapour superheated to about 150° C, in a packed, stainless-steel reactor operating at approximately 240° C and 50 psig (109, 114, 115). The resulting molten ammonium nitrate, steam and traces of ammonia are separated in a cyclone, and air, preheated to about 200° C, is blown through the molten salt, to reduce further the moisture content from about 2 per cent to nearly 0.2 per cent. Air leaving the separator is reheated, stripped of residual ammonium nitrate in a condenser and recycled through the melt.

The molten salt flows *via* a weir box onto a water-cooled stainless-steel belt and the chilled nitrate is fractured, coarse-ground, screened, coated and bagged as a 33.5 per cent nitrogen, semi-granular product. This process, which is illustrated diagrammatically in figure 26, can readily be adapted to produce nitro-chalk (ammonium nitrate-limestone) containing 20.5 per cent nitrogen and also ammonium nitrate-sulphate containing 26.0 per cent nitrogen if desired.

Figure 26. Stengel process for ammonium nitrate



Legend

A: Ammonia heater
B: Ammonia superheater
C: Nitric acid primary heater
D: Nitric acid secondary heater
E: Packed reactor
F: Separator
G: Air heater-exchanger
H: Primary scrubber
I: Secondary scrubber
J: Splitter box
K: Sump tank
L: Recycle pump
M: Reclaim tank
N: Reclaim pump
O: Water-cooled belt chiller
P: Cake crusher
Q: Screens
R: Coating drum
S: Product conveyor

In the Bamag process, gaseous ammonia and concentrated nitric acid are pumped into molten ammonium nitrate at about 150° C; after separation of the water vapour formed, the virtually anhydrous molten salt can be used to produce granules, prills or other forms of nitrate, according to need.

Crystallization

As previously mentioned, crystalline ammonium nitrate can be produced by the direct reaction of anhydrous ammonia and nitric acid in conventional, continuous crystallizers operating under vacuum, atmospheric or higher pressures. Either separate units or combined neutralizer-crystallizers may be used. In the former, ammonia and nitric acid are first reacted in a stainless-steel vessel to give a pH of about 0.7 and are trimmed by additional ammonia to a pH of nearly 6.5. The solution containing 56 to 60 per cent ammonium nitrate is concentrated to approximately 83 per cent in a forced circulation evaporator heated partly by steam produced in the neutralizer. Concentrated liquor leaves the evaporator at about 66° C and is sent to a vacuum crystallizer operating at 43° to 45° C. The crystals produced are removed by air lift (or other means) from the [illegible] of the crystallizer, centrifuged, dried to about 0.1 per cent free moisture and coated, prior to bagging in moisture-proof bags.

Graining

Grained ammonium nitrate is produced by evaporating a concentrated solution in a steam-heated, open pan to about 98 per cent and discharging the molten salt into a steam-heated kettle equipped with ploughs and scrapers. After removal of virtually all the moisture present, aided by careful temperature control, the pasty salt changes into small grains or pellets, which are cooled, coated and bagged.

Nitro-chalk

The addition of 40 per cent of powdered limestone or calcium carbonate to ammonium nitrate is widely undertaken as a means of improving storage properties (116) and minimizing the risk of fire or explosion. The addition is usually made to the concentrated solution before prilling or granulating, and the product (also called calcium ammonium nitrate or "Calnitro") contains about 20 to 21 per cent of nitrogen.

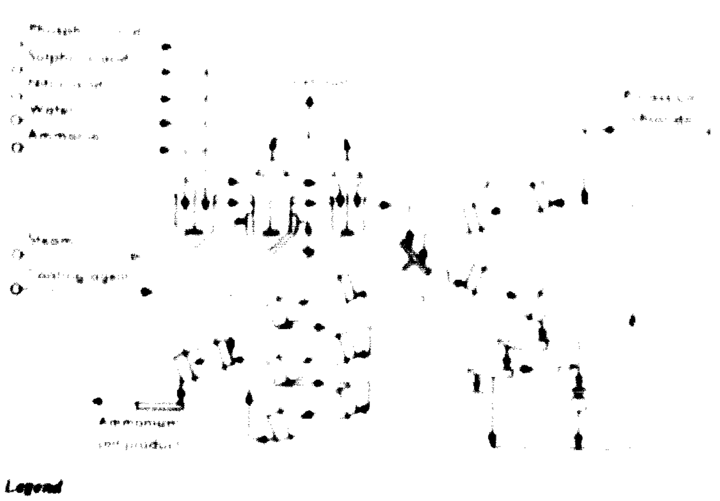
(c) *Granulated nitrogen salts*

In a process developed more recently in the United State of America, by the Tennessee Valley Authority, granulated ammonium salts and mixtures are made in a relatively simple way (117). The desired quantities of nitric acid, plus sulphuric and/or phosphoric acid are first ammoniated in a pre-neutralizer and then concentrated and neutralized with additional ammonia to yield a 94 to 98 per cent solution. This is sprayed over a rolling bed of recycled fines in a pan granulator and the discharged material is screened to remove on-size granules (in the 6 to 10-mesh range). Over-size material is crushed, combined with under-size material and returned to the pan granulator. Potash can be added to the last neutralizer or to the solid recycle stream to produce complete nitrogen-phosphate-potash compounds. For many formulations, recycle ratios are of the order of 1 to 1 of product, or even less. Typical products include ammonium nitrate (33 per cent nitrogen), ammonium sulphate nitrate (21 to 34 per cent nitrogen), ammonium phosphate nitrate (30-10-0) and such ternary grades as 24-6-12 and 17-17-17.

A flow diagram of this process is shown in figure 27 and pans up to 14 feet in diameter, with capacities of about 1 ton per hour per 15 square feet are used. The employment of a pre-cooler to reduce the on-size material to below the transition point of 32.1° C, prior to final drying, should be noted, as well as the cooling of the recycled material prior to regranulation.

Caution must be used when incorporating ammonium nitrate with other salts in mixed fertilizer formulations because of a possible increase in hygroscopicity. For instance, some mixtures of ammonium nitrate and monocalcium phosphate or urea may result in critical relative humidities as low as 36.4 per cent and 18.1 per cent, respectively.

Figure 2[illegible]. Process for granular ammonium nitrate used by Tennessee Valley Authority



Legend

A No 1 neutraliser
B Evaporator
C No 2 neutraliser
D Pan granulator
E Recycle cooler
F Pre-drier
G No 1 screens
H No 2 screens
I Recycle crusher
J Pre-cooler
K Product drier
L Product cooler
M Coating drum
N Product conveyor

(d) *Ammonium nitrate solutions*

In Canada and United States of America (and, to an increasing degree, in Europe and South Africa), substantial quantities of ammonium nitrate are produced in solution form and used either alone or in conjunction with other materials, such as solutions of urea and superphosphoric acid (83, p. 35; 95). In one integrated process used in the United States of America, part of the ammonia from the once-through urea is used to make nitric acid and part is reacted with tail-gas from the nitric acid unit to yield ammonium nitrate, which is used either alone or in combination with the urea, in the form of a fertilizer solution containing 32 per cent of nitrogen (UAL 32).

5. *Storage of ammonium nitrate*

(a) *Solid ammonium nitrate*

A major consideration when storing solid ammonium nitrate (and fertilizers containing more than about 60 per cent of ammonium nitrate) is the need for precautions against fire and possible explosion (118). Hence, in many countries, it is usual to find regulations controlling details such as maximum bulk-storage capacities, proximity to and admixture with other materials, bagging, labelling and handling procedures, etc. (40, 121). Another consideration is the avoidance of subsequent caking in both bulk and bagged storage by limiting free moisture to 0.3 per cent (or less), preventing the formation of fines, and minimizing wide fluctuations of temperature and humidity by sealing the storage building or by using some form of air-conditioning in extreme cases. The more recent availability of uniformly granulated and prilled products, plus effective coating agents and impervious plastic bags has greatly assisted the storage, handling and application of ammonium nitrate and related solid fertilizers.

(b) *Ammonium nitrate solutions*

Nitrogen solutions containing ammonium nitrate alone, or in conjunction with other materials, are used on a large scale in the United States of America and to an increasing degree in some European countries. Aluminium plate is widely used as a construction material for storage of ammonium nitrate solutions, and tanks having capacities of the order of 2 million gallons have been built (112). However, combination with other fertilizer materials may necessitate the use of corrosion-resistant steels or plastic linings. Insulation of storage and transportation vessels may also be required to prevent salting-out of ammonium nitrate and related solutions at reduced temperatures. Precautions against the accidental combustion of timber, bags or other items previously in contact with ammonium nitrate solutions are also necessary.

F. SODIUM NITRATE

1. *General information*

Before the availability of synthetic ammonia and its derivatives, sodium nitrate of natural origin was the major source of nitric acid and chemical nitrogen for fertilizer purposes in many countries. Most of this nitrate originated in Chile, where it is principally found in a large ore body nearly 500 miles long and 10 to 50 miles wide, on the eastern part of the Chilean coastal range. Nitrate production is still a major industry in Chile and currently approaches 760,000 tons annually. Small deposits occur in other areas, e.g., Africa, Australia, Mexico, the United Arab Republic and the United States of America. Substantial amounts of synthetic sodium nitrate were formerly made in Europe and the United States, but production has declined appreciably since the Second World War, from some 800,000 tons to about 150,000 tons per annum, owing to the availability of other nitrogen fertilizers which have lower costs per unit of nitrogen.

2. *Principal uses*

As a fertilizer, sodium nitrate has for long been applied as a surface-dressing in such countries as the United Arab Republic and the United States of America, for cotton, tobacco and some vegetable crops. However, its use as a "straight" nitrogen fertilizer has declined considerably during the last century (119). For example, in the United Kingdom, some 20,000 tons of nitrogen were used in the form of sodium nitrate in 1899, whereas relatively none is used today (94, p. 11). As with other nitrates (86), sodium nitrate is prone to leaching in the soil, but it has the advantage of possessing a metallic cation, and, unlike ammonia and derivatives, including urea, it will not promote cation losses in the soil and lead to unsuspected soil acidity.

Industrial applications include meat preservation, heat treatment of metals and use as a flux in the ceramic and metallurgical industries. Associated derivatives include potassium nitrate and other nitrates, for example, in the period 1962/1963, about 80,000 tons of potassium nitrate were produced and exported from Chile, lesser amounts being made in Europe and the United States, from sodium nitrate and other sources.

3. *Properties of sodium nitrate (synthetic)*

The properties of sodium nitrate are given in table 43.

TABLE 43. PROPERTIES OF SODIUM NITRATE (SYNTHETIC)

Formula	$NaNO_3$
Guaranteed analysis (typical)	
Nitrogen	16.0 per cent
Sodium	26.0 per cent
Appearance	White crystalline rhombohedra
Molecular weight	85.01
Melting-point	308.3° C
Effect of heat	Decomposes to sodium nitrate and oxygen above 450° C
Density 20°/4° C	2.257
Solubility in water	
Temperature (°C)	*Grammes per 100 grammes H_2O*
0	73
10	96
30	176
100	180
Bulk density	
Pellets	75 pounds per cubic foot
Coarse material	80 pounds per cubic foot
Fine powder	85 pounds per cubic foot
Critical relative humidities	
20° C (68° F)	74.7
30° C (86° F)	73.7

4. *Production methods*

(a) *From natural deposits*

In Chile, the nitrate ore or caliche is widely varying in composition and may range from 80 per cent to virtually zero nitrate content, although little high-grade material is available today. A typical analysis of run-of-mine ore might be the following (in percentages):

$NaNO_3$	7-10
NaCl	4-10
Na_2SO_4	10-30
Mg, Ca, K, Br, I_2	2-7
H_2O	1-2
Remainder	Gangue

These components are present in the form of complex, mixed sulphates, e.g., Darapskite, $NaNO_3.Na_2SO_4.H_2O$.

Early production methods were based on hand-picking the higher grade ore containing about 13 per cent sodium nitrate and leaching it in directly heated open pans until saturation was reached (119). The solution was then piped to settling-pans and cooled to produce sodium nitrate crystals, which were drained, dried in the sun and bagged or shipped in bulk overseas. An improved version of this method known as the Shanks process, which was first used about 1890, and remained popular for about fifty years, is now virtually obsolete. Most current production is undertaken by the Guggenheim process, which permits ores containing under 10 per cent nitrate to be profitably worked, thus extending the life of the Chilean nitrate industry by several decades.

In the Guggenheim method, caliche is mined by open-pit operations, using drag-lines and power-shovels, and is crushed to about 80 per cent between 3/4 and 3/8 inch (2). This product is leached at about 40° C with water in a series of vats, each having a capacity of some 10,000 tons of crushed ore. The underflow from each vat is heated before passing to the next, as sodium nitrate has a negative heat of solution. After extraction and washing are complete, the residue is removed from the vats by grabs and is hauled to a waste dump.

Fine material from the crushers is pulped in a separate system, and the gangue removed by means of Moore filters. The filtrates are combined with liquor from the leach tanks and are chilled in shell-and-tube units to precipitate crystalline sodium nitrate. Initial cooling is undertaken by heat-exchange with in-process leach liquor and final chilling by ammonia. The sodium nitrate slurry is dewatered and washed in batch centrifuges to yield a crystalline product of about 25 per cent pure sodium nitrate, substantially 48 mesh in size and containing approximately 3.5 per cent free-moisture. When a grained or prill type product is required, the centrifuged salt is melted at about 400° C in reverberatory furnaces, spray-dried in large towers, cooled by heat-exchange with mother-liquor in shell-and-tube units and screened to yield pellets in the 10- to 20-mesh range containing about 98 per cent sodium nitrate and 0.2 to 0.3 per cent free-moisture.

Iodine salts present in the caliche accumulate in the recycling mother-liquor and are reduced to iodine in a separate process, to the extent of some 2,000 tons annually. In addition, it has been found that salts which are insoluble in reclycling leach solutions can be extracted from the caliche by fresh water and recovered by solar evaporation, plus selective crystallization, to yield substantial tonnages of additional sodium nitrate, as well as potassium nitrate, plus various iodates, borates and sulphates. These associated salts are likely to be of great future significance to the Chilean nitrate industry.

(b) *Synthetic sodium nitrate*

The dependence of the United States of America and other countries on natural Chilean sodium nitrate during the early part of the twentieth century led to the development of several chemical processes for its manufacture. All these methods produce a sodium nitrate solution which is concentrated, crystallized and centrifuged. In some cases, the dewatered and washed salt is dried in a rotary drier prior to screening, storage and bagging; alternatively, it may be melted and grained or prilled.

A major source of synthetic sodium nitrate has been the nitrogen oxides process (120), whereby oxidized ammonia vapour is reacted with an alkali solution, such as sodium carbonate, to yield sodium nitrate, nitric oxide, carbon dioxide and water, e.g.:

$$6NH_3 + 2Na_2CO_3 + 10.5O_2 \rightarrow 4NaNO_3 + 9H_2O + 2NO + 2CO_2$$

Unconverted nitric oxide is recycled for further processing. On similar lines, the absorption of oxides of nitrogen by alkali solutions as a method of treating tail-gases from nitric acid plants and various nitrating processes is undertaken in several places throughout the world. Such scrubbing units constitute additional minor sources of sodium nitrate (and nitrite) when the effluent liquors are treated for recovery of nitrogen salts and not pumped to waste.

Appreciable quantities of sodium nitrate have also been made in the United States of America by the salt process developed by the Allied Chemical Corporation (120). In this method (which is believed not to be currently in operation), nitric acid and sodium chloride are reacted to yield sodium nitrate chlorine, nitrosyl chloride and water, e.g.:

$$4HNO_3 + 3NaCl \rightarrow 3NaNO_3 + Cl_2 + 2H_2O + NOCl$$

The nitrosyl chloride can be used as an intermediate for other derivatives, or it can be reacted with sodium carbonate to yield additional sodium nitrate plus sodium chloride, nitric oxide and carbon dioxide:

$$3NOCl + 2Na_2CO_3 \rightarrow NaNO_3 + 3NaCl + 2NO + 2CO_2$$

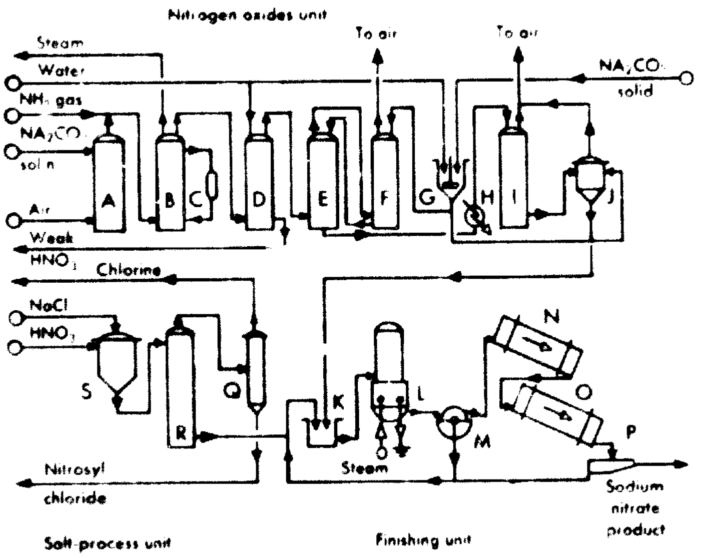
The salts produced can be redigested and the nitric oxide used to make additional sodium nitrate (or nitric acid). Alternatively, the nitrosyl chloride can be oxidized to yield dinitrogen tetroxide and chlorine for further use, e.g.:

$$2NOCl + O_2 \rightarrow N_2O_4 + Cl_2$$

Figure 28 illustrates diagrammatically the nitrogen oxides process and the salt process for the production of sodium (or potassium) nitrates.

Other methods used to produce sodium nitrate in minor quantities (sometimes as a by-product) include reacting nitric acid with soda ash or caustic soda, and using ion-exchange between calcium nitrate and a sodium zeolite. Several double-decomposition reactions between various nitrates and alkali salts, for example, ammonium nitrate and caustic soda or common salt, have either been proposed or operated on a small scale.

Figure 28. Nitrogen oxides and salt processes for sodium nitrate production



Legend

A: Air scrubber	**K: Nitrate solution storage tank**
B: Heat-exchanger tower	**L: Evaporator**
C: Oxidizing unit	**M: Filter or centrifuge**
D: Oxidation and cooling tower	**N: Rotary drier**
E: Acidulating tower	**O: Rotary cooler**
F: Alkalizing tower	**P: Screens**
G: Soda-ash solution tank	**Q: Chlorine-separating column**
H: Soda-ash solution heater	**R: Salt digester**
I: De-aerating tower	**S: Salt reactor**
J: Neutralizing vessel	

5. *Storage*

Sodium nitrate can be stored and shipped in bulk under conditions of low humidity, but should be packed in moisture-resistant bags when intended for use in damp or tropical climates. In some countries, it is regarded as a potential fire hazard and may necessitate special labelling, insurance and other precautions, as for ammonium nitrate and potassium nitrate (40, 121). Such materials as bags or timber, subsequently allowed to dry after impregnation with sodium nitrate, may quickly ignite if exposed to elevated temperatures and should be destroyed or thoroughly washed and fire-proofed.

G. POTASSIUM NITRATE

1. *General information*

When nitrate nitrogen and potassium, without the presence of chloride ions, are required for special agricultural purposes (122) (e.g., where a non-burning material is desired), potassium nitrate can be used as a component of the solid or solution types of fertilizers, although its relatively high cost in terms of plant-food units and its rather high temperature-solubility coefficient in water have limited such applications. The more recent availability of larger supplies of the synthetic material in the United States of America may lead to a much greater demand, especially for special-purpose solid and liquid formulations. The principal non-fertilizer uses include explosives, pyrotechnics and chemical manufacture, as well as others akin to those previously indicated for sodium nitrate. Alternative names for potassium nitrate are saltpetre and nitre, which appear in numerous medical, chemical and industrial formulations.

2. *Properties of potassium nitrate*

The properties of potassium nitrate are given in table 44.

TABLE 44. PROPERTIES OF POTASSIUM NITRATE

Formula	KNO_3
Appearance	White, crystalline
Molecular weight	101.103
Melting-point	308° C
Effect of heat	Decomposes, after melting, into potassium nitrite and oxygen
Density 20°/4° C	2.11
Solubility in water	
Temperature (°C)	*Grammes per 100 grammes H_2O*
0	13.3
10	20.9
30	45.8
60	110.0
100	246.0
Analysis (pure salt)	
Nitrogen	13.85 per cent
K_2O	46.6 per cent
Critical relative humidities	
20° C (68° F)	94.5
30° C (86° F)	93.3

Various grades are available, for example, technical quality (99 per cent purity) and fertilizer quality (95 per cent purity), the latter containing about 13 per cent N and 44 per cent K_2O. A mixed sodium-potassium salt is also made, containing about 15 per cent N and 14 per cent K_2O.

3. *Production methods*

The occurrence and recovery of potassium nitrate in conjunction with Chilean sodium nitrate has been previously mentioned. Other natural deposits which have been reported on a small scale in various parts of the world, for example, Australia and Mexico, are usually in remote and arid locations and are not commercially exploitable.

Some methods of producing potassium nitrate by chemical means (123) are similar to those described for sodium nitrate manufacture and include a recently developed process based on reacting potash with nitric acid, as in the salt process; this process is illustrated in figure 28. In another method, solid potash is added to a hot aqueous solution of sodium nitrate; the sodium chloride formed crystallizes in the hot mother-liquor, owing to its relatively low solubility (124), and is separated by filtration or centrifuging. The potassium nitrate liquor is concentrated and cooled to yield the crystalline product, which is recovered by centrifuging. A method based on reacting solid potash and nitric acid in the vapour phase at about 330° C and 30 per cent concentration has also been proposed, e.g.:

$$KCl + 2HNO_3 \rightarrow KNO_3 + HNO_3 + HCl$$

A process for potassium nitrate production, based on the use of an organic solvent for promoting the reaction between solid potassium chloride and 60 to 65 per cent HNO_3 without the use of heat, has been developed in Israel (125). The hydrochloric acid formed enters the solvent (e.g., a commercial-grade pentanol), and a simple solid-liquid separation yields solid potassium nitrate. The solvent is washed in a suitable liquid/liquid contactor and recycled. The dilute hydrochloric acid can be concentrated and used for other purposes, e.g., for phosphoric acid manufacture by the Israeli Mining Industries process or for dicalcium phosphate production.

4. *Storage*

The relatively low solubility of potassium nitrate in water at typical atmospheric temperatures results in low hygroscopicity; for example, at 26.7° C, a satured solution corresponds to a relative humidity of about 90 per cent. However, bulk storage is undesirable because of fire and explosion hazards, as potassium nitrate is a strongly oxidizing agent. As a result, storage and shipping are subject to stringent regulations in most countries (121), and precautions must be taken to minimize contact with carbonaceous or other oxidizable materials.

H. CALCIUM NITRATE

1. *General information*

Although simple methods are available for producing calcium nitrate, its use as a fertilizer is offset by extreme hygroscopicity even in moderately humid climates. In fact, when it is produced as a co-product in various nitrophosphate processes, elaborate steps are sometimes taken to ensure either conversion to less hygroscopic salts or removal by crystallization and physical separation. It is possible that the more recent availability of impervious plastic bags (99, 100) may increase the popularity of calcium nitrate for agricultural use. Current annual production, principally in Europe, is of the order of 500,000 tons. Other applications include explosives, pyrotechnics and inorganic chemical operations.

2. *Properties of calcium nitrate*

The properties of calcium nitrate are given in table 45.

TABLE 45. PROPERTIES OF CALCIUM NITRATE

Formula	$Ca(NO_3)_2$
Appearance	White, crystalline
Molecular weight	164.10
Melting-point	555.7° C
Density 20°/4° C	2.36 (anhydride)
Solubility in water	
Temperature (°C)	*Grammes per 100 grammes H_2O*
0	102
100	364
Approximate analysis (fertilizer grade)	
Nitrogen	15.5 per cent
Calcium	36.0 per cent
Critical relative humidities	
20° C(68° F)	54.8
30° C(86° F)	46.5

3. *Production methods*

Most calcium nitrate comes from Europe, where it is produced in two principal ways. In one method (83, p. 35), a direct reaction between calcium carbonate and nitric acid is employed, and in the other (19, pp. 196-200), the calcium nitrate formed as a co-product in some nitrophosphate processes is separated by crystallization and filtration or centrifuging.

(a) *Direct process*

In the direct process, crushed limestone is reacted with 50 per cent nitric acid in towers lined with acid-resistant brick, and the residual acid is neutralized with lime. The liquor, which contains about 40 per cent $Ca(NO_3)_2$, is clarified in settling-tanks and brought to a concentration of 87 per cent in a vacuum evaporator unit. Some 5 per cent of ammonium nitrate is then added as a granulation aid and to raise the nitrogen content to 15.5 per cent, prior to spray-drying in a prilling tower. The granules or prills are cooled, screened and packed in moisture-resistant bags.

The above reaction, which is exothermic, is represented by:

$$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O - 15{,}410$$

(b) *Nitrophosphate/calcium nitrate production*

Reactions between tricalcium phosphate in phosphate rock and nitric acid are complex, and some may be empirically shown as follows according to the raw material ratios used

$$Ca_3(PO_4)_2 + 2HNO_3 \rightarrow Ca(NO_3)_2 + 2CaHPO_4$$

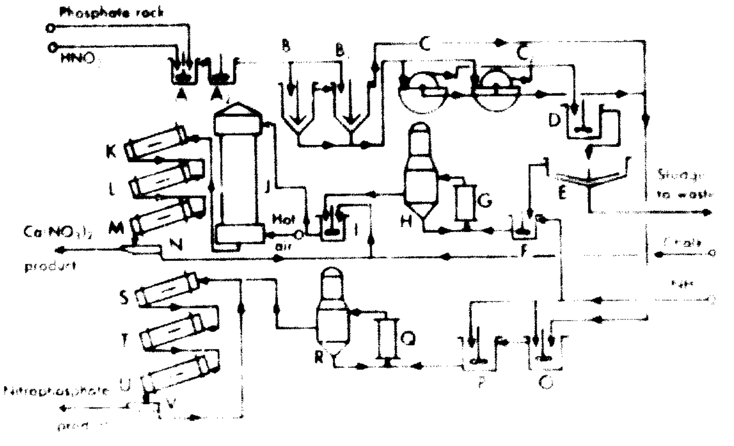
$$Ca_3(PO_4)_2 + 4HNO_3 \rightarrow 2Ca(NO_3)_2 + Ca(H_2PO_4)_2$$

$$Ca_3(PO_4)_2 + 6HNO_3 \rightarrow 3Ca(NO_3)_2 + 2H_3PO_4$$

Nitrophosphate processes can be divided into two categories, namely those in which calcium nitrate is separated from the nitrophosphate liquor, and those wherein calcium nitrate is converted to less hygroscopic compounds, e.g., ammonium nitrate, and no separation is undertaken (19, pp. 196-200).

Most processes in the first category are variations of the original Norwegian "Odda" method in which 1 part of ground phosphate rock is digested with about 1.5 parts of nitric acid at 55° to 70° C in a continuous reaction system. The reaction liquor is then chilled by brine in heat exchangers to precipitate calcium nitrate tetrahydrate, which is separated and washed by means of centrifuges or rotary vacuum filters. The crystals are melted at 42° C, clarified, neutralized with ammonia gas and prilled, cooled and bagged. A flow diagram of this type of process is shown in figure 29.

Figure 29. Separation type of process for nitrophosphate and calcium nitrate



Legend

A1, A2 : Digesters
B1, B2 : Crystallizers
C1, C2 : Vacuum filters
D : Melter
E : Clarifier
F : Neutralizer
G : Ca(NO3)2 evaporator heat exchanger
H : Ca(NO3)2 evaporator
I : Ca(NO3)2 prill-tower slurry tank
J : Ca(NO3)2 prill tower
K : Ca(NO3)2 pre-drier
L : Ca(NO3)2 drier
M : Ca(NO3)2 cooler
N : Ca(NO3)2 screens
O : Nitrophosphate ammoniator No. 1
P : Nitrophosphate ammoniator No. 2
Q : Nitrophosphate evaporator heat exchanger
R : Nitrophosphate evaporator
S : Nitrophosphate granulator
T : Nitrophosphate drier
U : Nitrophosphate cooler
V : Nitrophosphate screens

In some plants, ammonium nitrate is added prior to crystallization to yield the double salt, $5Ca(NO_3)_2 \cdot NH_4NO_3 \cdot 10H_2O$, which has the advantage of reducing cooling requirements, since the crystallization temperature is raised from about 10° C to 25° C. In a Netherlands variation of this process, the decahydrate of the double salt containing 15.5 per cent nitrogen and also anhydrous calcium nitrate containing 16.7 per cent nitrogen are produced in the form of flakes. The decahydrate salt will rapidly absorb water when the relative humidity exceeds 50 per cent and will deliquesce whereas the anhydrous salt, although more hygroscopic, will absorb about 40 per cent of its own weight of water before incipient liquefaction occurs. Both products are promptly packed in moisture-resistant bags to minimize storage and handling problems.

As with many other mixtures and salt pairs, calcium nitrate in conjunction with other salts may result in extremely hygroscopic products and should be avoided. For example, some mixtures of calcium nitrate as distinct from a double salt have critical relative humidities as low as 23.5 per cent. Even when present as contaminants only, the effect of certain salts may appreciably affect critical relative humidities.

Calcium nitrate can also be produced by reactions and processes similar to those described for sodium and potassium nitrate. However, it is doubtful if such methods can compete with the direct reaction method using limestone and nitric acid or the nitrophosphate route, except in special circumstances.

4. *Storage*

Except in very dry climates, calcium nitrate is likely to deliquesce, and storage in moisture-proof bags immediately after manufacture is usually mandatory. As with other nitrate fertilizer salts, precautions should be taken to avoid impregnation of organic material with calcium nitrate, to reduce possible conflagration from a source of heat in the vicinity. For this reason, special storage and shipping regulations may apply in certain countries (40, 121).

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X. PRODUCTION OF UREA

A. GENERAL INFORMATION

Wohler first prepared urea in 1828 by the isomerization of ammonium cyanate (1). Since that time, numerous processes have been developed for urea synthesis. All commercial processes are based on the dehydration of ammonium carbamate (2). The chemical reaction is as follows:

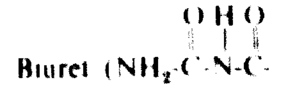
$$\underset{\text{}}{2NH_3 + CO_2} \rightarrow \underset{\text{(Amm carbamate)}}{NH_4CO_2NH_2} \rightarrow \underset{\text{(Urea)}}{NH_2CONH_2} + H_2O$$

Anhydrous liquid ammonia and gaseous carbon dioxide are pumped continuously into a reactor maintained at temperatures usually in the range 180° to 200° C and at pressures of 2,500 to 3,500 pounds per square inch. The reaction does not go to completion; from 45 to 60 per cent of the ammonia is converted per pass (3). There are interrelations between the feed composition, the temperature and pressure maintained in the reactor, the reaction time and the composition of the reaction product (3, 4). The reaction product, a mixture of urea, ammonia, carbon dioxide, ammonium carbamate and water, leaves the reactor continuously through a pressure-reducing valve. The stream then flows to carbamate strippers, where separation into a liquid phase of urea and water (containing small quantities of ammonium carbamate and ammonia), and a gaseous phase of ammonia, carbon dioxide and water vapour takes place. The urea solution can be used as fertilizer solution, or it can be further processed to produce solid urea in the form of crystals, prills or granules. The mixed unconverted ammonia and carbon dioxide removed from the reactor effluent can be recovered and recycled to the reactor or used for the production of other fertilizers, e.g., ammonium sulphate or nitrate.

Depending on the degree of recycling of the unconverted ammonia and carbon dioxide, the processes are called "total recycle", "partial recycle" or "once-through". Plants of the total recycle type are defined as either "gas-separation" recycle units or "carbamate-solution" recycle units, depending on the general physical method of returning the unreacted ammonia and carbon dioxide to the reactor. Recent developments indicate that in large units (about 1,500 tons per day), the use of centrifugal compressors will permit the use of the "hot-gas" recycle process, in which the mixed gases are compressed at higher than normal temperatures and recycled to the reactors without separation. Classification of processes on the basis of degree of gas recycle refers only to the urea synthesis section of the plant. The product urea solution has about the same composition for any of the synthesis processes and can be converted to finished products by several methods, as noted in section C. Some of the synthesis processes are discussed in detail in section B.

The most serious problems associated with urea synthesis are the following:

(a) *Prevention of corrosion.* Earlier units relied on silver linings (5), lower temperatures than those currently used and large excesses of NH_3 feed to prevent corrosion. Recent developments in alloys (sometimes closely guarded secrets of the developers) and the addition of small quantities of oxygen (air) to the reactor have minimized corrosion and permitted higher reactor temperatures and pressures, which result in greater conversion efficiencies. Titanium-lined equipment also effectively reduces corrosion. One troublesome area is that of the carbamate-solution recycle pumps; proper design and operation have reduced this trouble, but spare pumps should be provided.



(b) *Limiting formation of biuret.* Biuret ($NH_2\text{-}\overset{O}{\overset{\|}{C}}\text{-}\overset{H}{\overset{|}{N}}\text{-}\overset{O}{\overset{\|}{C}}\text{-}NH_2$) is formed when urea or concentrated urea solutions are exposed to elevated temperature, as in the evaporation-prilling method of finishing (6). At the lower temperature in the crystallization-prilling method, less biuret is formed and, in addition, it does not crystallize with the urea. Generally, guarantees of a biuret content of less than 0.3 per cent for crystal-prilling and 1 per cent for evaporation-prilling can be obtained. Excessive (> 0.25 per cent) biuret in urea is toxic to citrus plants, particularly when applied as a foliar spray (7). Other crops, for example, potatoes, might also be adversely affected by a biuret content greater than 1 per cent (8). For citrus, crystalline urea (< 1 per cent biuret) can be used, but this is not a standard fertilizer grade and the fine crystals are subject to caking. For other commercial crops, the maximum permissible limit of biuret content is not well defined and does not seem to be significant. With some crops, even straight biuret probably would be acceptable if applied properly (9). Placement of urea with a high biuret content close to seeds or seedlings may kill or stunt the plant; however, this is poor practice with any highly concentrated, soluble fertilizer salt.

(c) *Disposition of unconverted ammonia and carbon dioxide.* The problem here is not related to the mechanical aspects of operation, but to the planning of the over-all plant design and operation, so that optimum plant flexibility and minimum capital investment are obtained for producing the desired amounts and proportions of fertilizer materials. Investment can be reduced by using once-through or partial-recycle operations, but operating flexibility is thereby reduced. The majority of producers favour the flexibility of the total-recycle process; most new plants are of this type.

Some of the well-known urea processes that are in use and are available for installation by licensed engineering firms are (licensed firms in the United States of America are given in parentheses):

(*a*) Inventa, Switzerland and United States;

(*b*) Chemico (Chemical Construction Corp.), United States;

(*c*) Montecatini, Italy;

(*d*) Pechiney (Grace Chemical), France and United States;

(*e*) Toyo Koatsu (Girdler), Japan and United States;

(*f*) Stamicarbon (A. G. McKee, C. F. Braun, Foster-Wheeler), Netherlands and United States;

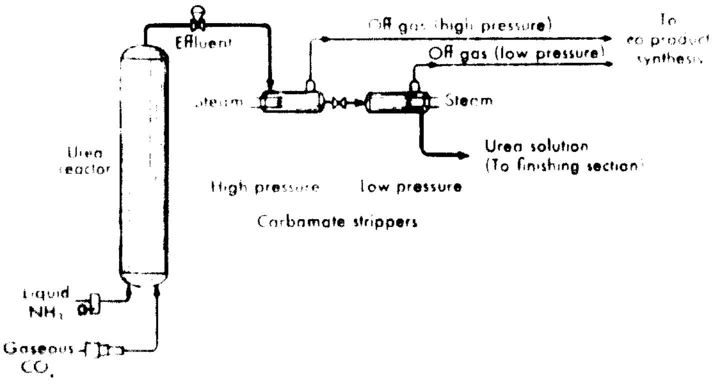
(*g*) Lonza (Lummus), Switzerland and United States.

B. UREA SYNTHESIS PROCESSES

1. *Once-through process*

The once-through method is the simplest and least expensive (in both capital investment and operating costs) of the three basic processes. A typical unit flow sheet (synthesis section only) is given in figure 30. Liquid ammonia and gaseous carbon dioxide are pumped into the urea reactor at about 3,000 psig. The reactor temperature is maintained at about 185° C by regulating the amount of excess ammonia; about 100 per cent excess NH_3 is required, and about 35 per cent of the total NH_3 is converted to urea (75 per cent of the CO_2 is converted). The reactor effluent solution contains about 80 per cent urea after carbamate stripping. The unconverted NH_3 and CO_2 are driven off at moderate pressures by steam-heating the effluent solution in the carbamate strippers.

Figure 30. Typical once-through urea process



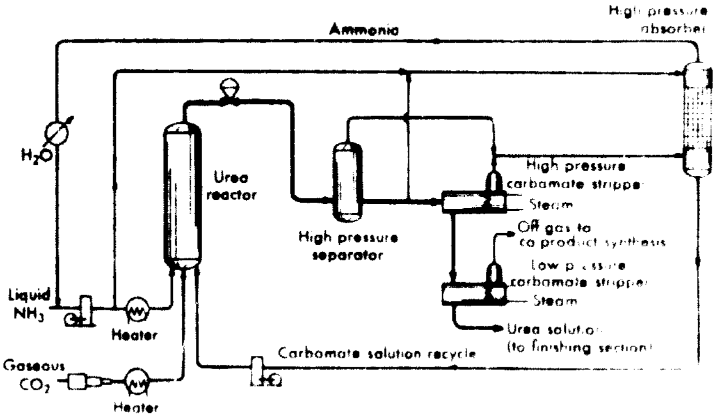
While this process is the simplest of the urea processes, it is the least flexible and cannot be operated unless some provision is made to utilize the large amount of off-gas ammonia. It is thus tied to the co-production of some other material, e.g., ammonium sulphate, ammonium nitrate, nitric acid or ammonium phosphate, for which the ammonia can be used.

2. *Partial-recycle process*

As the name implies, in the partial-recycle process, part of the off-gas ammonia and carbon dioxide from the carbamate strippers is recycled to the urea reactor. Recycling is accomplished by absorbing the stripper gases in a recycle stream of partially stripped urea effluent, in process-steam condensate or in mother liquor from a crystallization finishing process. In this manner, the amount of NH_3 in off-gas is reduced. Any proportion of the unreacted ammonia can be recycled; typically, the amount of ammonia that must be used in some other process is reduced to about 15 per cent of that from a comparable once-through unit.

The Toyo Koatsu partial-solution recycle process flow sheet (10) is typical of the first method and is shown in figure 31. Liquid NH_3 and gaseous CO_2 are pumped to the urea reactor at 3,000 psig. The temperature of the reactor is maintained at about 185° C by proper balance of excess NH_3 and carbamate-solution recycle feed. About 100 to 110 per cent excess NH_3 is used; about 70 per cent of the NH_3 and 87 per cent of the CO_2 are converted to urea. The reactor effluent contains about 80 per cent urea.

Figure 31. Toyo Koatsu partial-recycle process (urea solution)



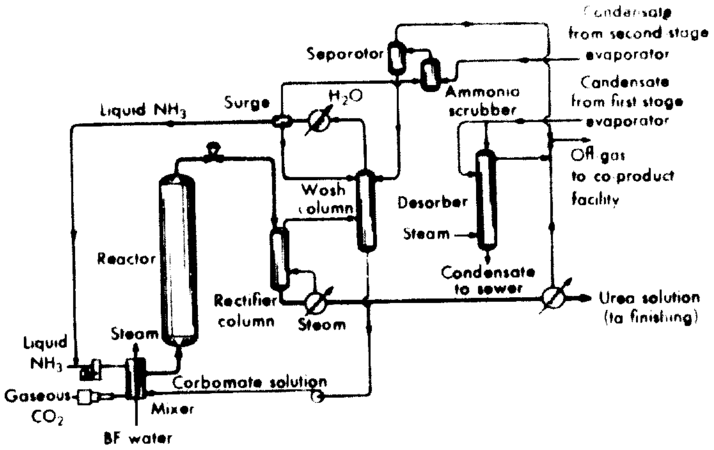
Unreacted NH_3 and CO_2 are separated from the urea solution in the high-pressure separator and in two to three steam-heated carbamate strippers at successively lower pressures. The off-gas from the separator and the first-stage stripper is absorbed in the high-pressure absorber by a side stream of partially stripped reactor effluent from the high-pressure separator. Heat evolved in the absorber reaction is removed (to increase absorption capacity) by the addition and expansion of part of the liquid ammonia feed at this point. Pure gaseous ammonia from the top of the absorber is also recycled to the urea reactor after being condensed.

Since the amount of ammonium carbamate which can be absorbed in the absorber solution described above is limited by its solubility in the system H_2O-urea-NH_3, part of the ammonia and carbon dioxide cannot be recycled and must be used in the production of a co-product nitrogen material, as in the once-through process. Although the rate of co-product production is greatly reduced, as compared with a once-through process, the operation of the urea plant still must coincide with that of the co-product plant.

The Stamicarbon partial-solution-recycle process (11), is typical of the aqueous carbamate solution recycle process and is shown schematically in figure 32. In this form of the partial recycle process, part of the ammonia is recycled from the stripping section to the urea reactor (fig. 32) by expanding the reactor effluent to an inter-

mediate pressure (300 psig) in a rectifier, part of the ammonia (relatively pure) is flashed off and is condensed and returned to the urea reactor. The remaining ammonia and carbon dioxide are driven off in a series of heated strippers along with a portion of the water formed in the urea reaction. This mixed NH_3-CO_2-H_2O vapour is condensed in part in a wash column by cooling with evaporating ammonia. The condensed vapour, in the form of a concentrated solution of ammonium carbamate in water, is recycled to the urea reactor. The remaining gaseous ammonia (containing carbon dioxide) must be sent to a co-product plant for utilization. Conversions of ammonia and carbon dioxide to urea are about 70 and 80 per cent, respectively. About 1.0 ton of ammonium nitrate per ton of urea would be made as a co-product.

Figure 32. Stamicarbon partial-recycle process (aqueous carbamate solution)



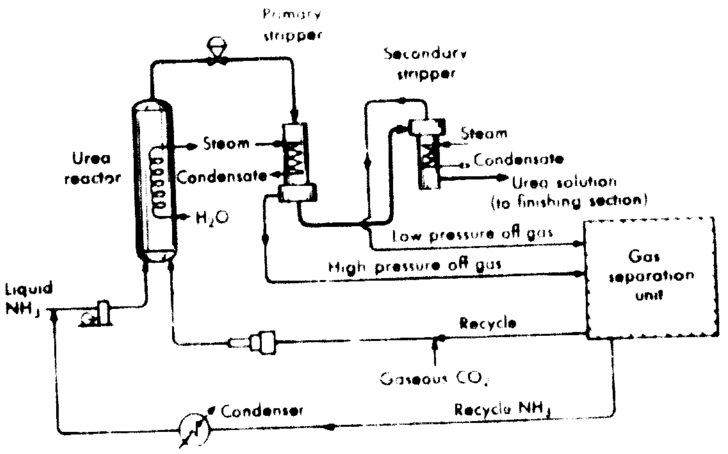
Evaluation of the relative merits of these two types of partial-solution recycle is difficult because of lack of published data. Claims of the licensors (10, 12) indicate that the use of urea solution as the absorbent gives a slightly lower plant investment and utility cost than the use of water. The aqueous solution recycle is more complicated and probably requires more labour and maintenance.

3. *Total-recycle process*

In the total-recycle process, all the unconverted ammonia-carbon dioxide mixture is recycled to the urea reactor (conversion is about 99 per cent), and no nitrogen co-product is necessary. This is the most flexible of the urea processes, as it depends only upon its supporting ammonia plant for operation. However, it is also the most expensive in investment and operating costs. Therefore, if the production of other materials requiring ammonia is planned, an integrated once-through or partial-recycle unit would have lower investment and operating costs. Most producers prefer the total-recycle process, even when a second nitrogen product is desired, because of possible difficulties in synchronizing the operation of the two plants.

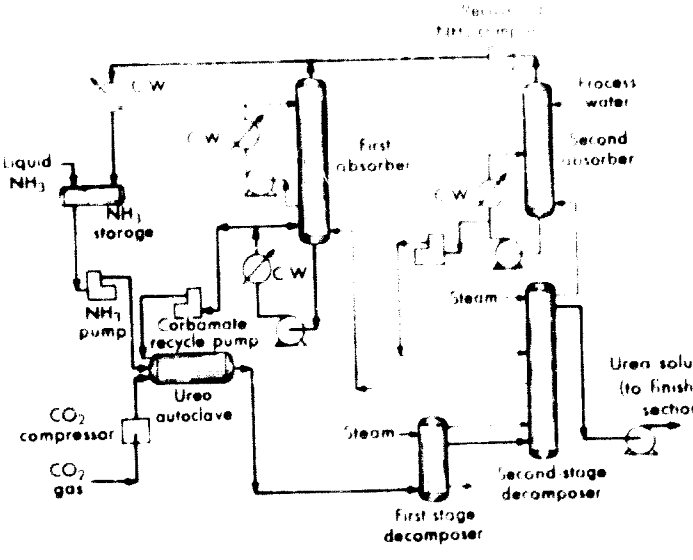
There are two general types of total-recycle systems. In the "gas-separation" type, the ammonia-carbon dioxide mixture from the carbamate strippers is treated with a liquid that preferentially absorbs one of the gases, leaving the second in the gas phase. The second gas is then recompressed and recycled to the urea reactor. The absorbed gas is desorbed from the solvent by heating and is then recycled separately to the urea reactor. The Inventa process is of the gas-separation recycle type. An aqueous solution of urea-nitrate or ammonium nitrate is used to absorb the ammonia preferentially from the mixed gases (13). Monoethanolamine is a common preferential absorbent for carbon dioxide and was used in the Chemico gas-separation recycle process (5). The Inventa process is shown in figure 33.

Figure 33. Inventa total-recycle process (gas separation)



The second general type of total-recycle process is that of carbamate-solution recycle, in which all of the unreacted ammonia and carbon dioxide is recycled to the urea reactor as an aqueous solution of ammonium carbamate; part of the ammonia may be separated first, in a relatively pure state, and recycled after condensation. The Chemico total-solution recycle process, shown schematically in figure 34, is typical of this type of process (14). Other companies offering similar total-solution recycle processes are: Lonza (Switzerland); Montecatini (Italy); Stamicarbon (Netherlands); and Toyo Koatsu (Japan) (4). In the Chemico process, a portion of the ammonia is flashed off the first and second absorbers, condensed and recycled to the reactor. The remaining unreacted ammonia, the carbon dioxide and some water are stripped from the

Figure 34. Chemico total-recycle process (carbamate solution)



urea-water solution effluent in the first-stage decomposer. These gases, plus the water vapour, are contacted in the second-stage decomposer with the carbamate liquor from the second-stage absorber; the resulting exothermic heat of absorption in this unit aids in the stripping of the incoming urea effluent to the second decomposer. Substantial reductions in steam requirements are claimed for this arrangement. The minimum amount of process water is added at the second-stage absorber to produce the concentrated carbamate solution recycled to the urea reactor.

One total-recycle process that has been used in several installations is the Pechiney carbamate-oil slurry recycle process (4). In this process, the entire urea synthesis loop is filled with a high flash-point petroleum oil. The urea-water-carbamate effluent forms an easily broken emulsion with the oil in the reactor. Later, the two components are separated, and the ammonium carbamate is stripped from the urea solution in a conventional stripper. The off-gas (mixed NH_3 and CO_2) from the stripper is then bubbled into the separated oil, where it forms an ammonium carbamate slurry in the oil which is recycled to the reactor. Operating difficulties and high maintenance costs have been reported for the process.

Comparison of the two general types of total-recycle processes is somewhat difficult. Few "average" cost data have been published because these costs are affected by so many factors peculiar to each installation. Comparison of raw material and utility requirements (see section D, table 47) for the gas-separation total-recycle process and a typical total-solution recycle process indicates that the utility requirements of the gas-separation unit are significantly higher than those of some of the solution-recycle processes. Chemico formerly installed gas-separation units, but now uses the solution-recycle process (5).

4. *Special processes*

Recently, a new concept in carbamate recycle was devised by Stamicarbon (11, 15). In essence, the process consists of stripping most of the unreacted feed-gases from the reactor effluent at synthesis pressure by the fresh carbon dioxide feed in a special, indirectly heated stripper. The remaining unreacted gases are stripped and recycled by the aqueous carbamate solution method. The company claims that 90 per cent ammonia conversion can be effected and that, in total recycle, the carbamate solution equipment is much simpler and smaller than in other processes. Furthermore, claims of significantly reduced steam, electrical and cooling-water requirements are made. A similar process, with gaseous ammonia as the stripping medium, has been perfected by A. G. Lonza (4) and Societa Nazionale Metandotti (SNAM).

A second special total-recycle process is one recently patented by Chemico, called hot-gas recycle or Thermo-Urea Process (16). The off-gas from the strippers, consisting of mixed ammonia, carbon dioxide, and minimum water vapour, is compressed at a temperature sufficiently high (425° C) to prevent condensation of carbamate in the system. Sufficient heat is produced to eliminate the need for import steam; however, electric-power requirements offset part of this saving. This is not a new process; the first continuous process, developed in Germany, employed a hot-gas recycle. Maintenance problems with reciprocating compressors at high temperature made the process prohibitively costly. However, a centrifugal compressor gives satisfactory operation at this temperature. Since such compressors are not practical in small sizes, urea production of about 1,500 tons per day would be required for best use of a centrifugal compressor. Thus far, no producer has elected to gamble on this theoretically sound, but untried, process.

Another special innovation in urea synthesis is the Toyo Koatsu integrated ammonia-urea ("loop") process (17), which combines urea and ammonia production into a single unit. Basically, three combined steps have been developed: (*a*) carbon dioxide is scrubbed from the converted gas at synthesis pressure in the ammonia train by carbamate recycle solution from the urea plant absorbers and by fresh ammonia; (*b*) the resulting scrubbing liquor, containing most of the CO_2 from the converted gas, is fed by its own pressure to the urea synthesis reactor; and (*c*) the hot gas from the CO-shift converter is cooled by heating the urea effluent in the decomposers to strip off the unreacted ammonia and carbon dioxide. Aside from these integrated loops, the two plants operate in the normal manner. Most hydrocarbon feed-stocks have $C:H_2$ mole ratios that would yield an excess of CO_2 over that required to convert all the ammonia to urea; therefore, a small auxiliary CO_2 removal system — MEA, for example — must be provided between the shift converter and the integrated CO_2 absorber. Substantial savings in plant investment and operating costs are claimed because of the following items:

(*a*) Elimination of CO_2 compressor;

(*b*) Reduction in size of urea reactor (CO_2 absorber acts as reactor also);

(*c*) Elimination of CO_2 regeneration equipment and steam requirements;

(*d*) Utilization of heat of converted gas in urea plant;

(*e*) Elimination of ammonia purge-gas recovery system;

(*f*) Reduced ammonia pumping requirements.

It is claimed that reductions of 5 per cent in plant investment, 45 per cent in electric power and 60 per cent in steam are feasible. The principal disadvantages appear to be the complete dependence of the ammonia plant upon urea plant operation and the necessity for matching the urea production rate to that of the ammonia plant unless a large stand-by CO_2 removal system were provided. Even so, some advantages would be retained.

C. UREA FINISHING UNITS

The aqueous urea solution produced in the synthesis section contains some 70 to 80 per cent urea, the proportion depending on the amount of recycling. It may be used directly in various nitrogen solutions, but must be concentrated if solid urea is to be produced. Some biuret (0.3-0.4 per cent) may be formed in the synthesis section, but it is in the concentration step that the greatest amount of biuret (see section A) is formed unless provisions are made to prevent a harmful combination of high temperature and long retention time. In practice, some compromise must be made between the biuret content of the urea and the size and costs (investment and operation) of the evaporation equipment. For most commercial crop applications, a biuret content of 1 per cent would be acceptable. For some, less than 0.5 per cent biuret might be required. This can be obtained, but only at higher investment and operating costs than for normal prilled urea. The method of evaporation and solidification should be chosen to give minimum cost for the maximum acceptable biuret content.

There are three commercial processes for producing prilled urea. The differences lie in the method for producing the concentrated melt required for the prilling operation. The processes are atmospheric evaporation, vacuum evaporation and vacuum crystallization followed by melting and prilling (4, 10, 11). A granulation process has also been developed (18).

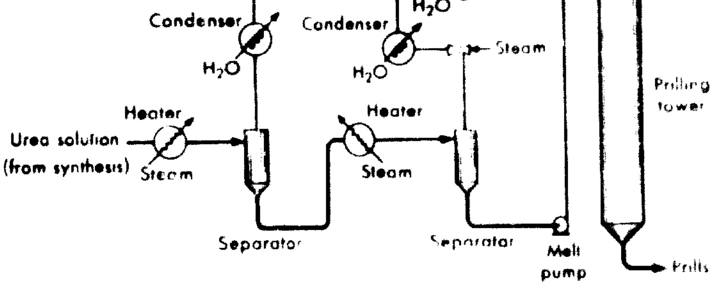
1. *Atmospheric evaporation*

A jacketed, steam-heated, falling-film or wiped-film evaporator is used to evaporate the moisture from a continuously replenished film of stripped urea reactor effluent at about 140° C and at atmospheric pressure. The evaporator units have rotating discs to spray the feed against the jacketed walls or rotating blades that wipe the walls continuously. Both types present maintenance problems associated with bearing lubrication. In some units, a current of inert, dry gas is passed through to carry out the water vapour. The water content is reduced to about 0.3 per cent and the resulting "melt" is sprayed into the top of a prilling tower some 70 to 200 feet high (depending on the type of spray heads). The droplets from the spray solidify upon cooling during their descent. Dehumidified air is circulated in the tower. Further drying is not required. Even though the retention time is only a few seconds in the evaporator equipment, a biuret content of 0.8 to 1.5 per cent is common.

2. *Vacuum evaporation*

A conventional tube-and-shell heat exchanger operating under a vacuum of 20 to 25 inches of mercury (steam ejector) permits the evaporation of water essentially at the melting-point of urea (133° C). This type of unit is the most widely used; a schematic flow sheet is shown in figure 35. Retention time is very short because of the flash evaporation; however, biuret content is generally 0.7 to 1.0 per cent, only slightly lower than that from the evaporators described in the preceding section. Two or more stages of evaporation may be used. The melt is evaporated to about 99.5 per cent [illegible]. This type of evaporation equipment has been [illegible] because it does not have as [illegible] as the types described in section C [illegible].

Figure 35. Vacuum evaporation and prilling



3. *Crystallization*

A conventional vacuum crystallizer (circulating type) is used to produce a solution of urea saturated at 50 to 55° C, from which urea crystallizes. A side stream of the suspension is continuously withdrawn and fed to a centrifuge, where the crystals are separated from the mother liquor. The crystals are dried in a rotary drier. The mother liquor is recycled through the off-gas absorber to the urea reactor. Any biuret formed up to this point is returned in this solution, as biuret does not crystallize with the urea. Under the reactor conditions, the biuret is converted to urea. Toyo Koatsu claims that the wet crystals from the centrifuge can be melted indirectly with high-pressure steam and prilled without exceeding a biuret content of 0.4 per cent (10, 19). Stamicarbon and Chemico offer similar finishing processes.

4. *Special finishing process: granulation*

Another finishing method, developed on a pilot-plant scale, but not on a plant scale, is that of granulating the urea in a tilted-pan granulator. In this unit, stripped urea effluent solution is concentrated at about 130° C to about 95 per cent in a vacuum evaporator. The concentrated solution is sprayed onto a tumbling bed of urea "fines" recycled to the pan from the product screening operation. The sprayed "melt" agglomerates or coats the fines, the tumbling action rounds off the agglomerates and the classifying action of the tilted pan permits adequate build-up of granule size. The granules are dried, cooled and screened in conventional equipment. The process is said to be lower in investment and operating cost than the conventional prilling operation, and it makes possible products of larger particle size than does prilling. Biuret content is about the same as in conventional prilling.

D. RAW MATERIAL AND UTILITY REQUIREMENTS AND PRODUCT QUALITY

As mentioned in previous sections, the various licensed urea processes have somewhat different raw material and

TABLE 46. TYPICAL RAW MATERIAL AND UTILITY REQUIREMENTS FOR VARIOUS TOYO KOATSU PROCESSES

	Quantities per short ton of prilled urea		
Requirements	*Once-through*	*Partial solution recycle*	*Total solution recycle*
Liquid NH_3 feed (tons)	0.57	0.58	0.58
Ammonia off-gas (tons)	1.22	0.19	0
Gaseous CO_2 feed (tons)	0.75	0.76	0.77
CO_2 off-gas (tons)	0.27	0.07	0
Electrical energy (kWh)	180	160	155
Steam (pounds)	2,200	2,700	3,900
Cooling water (gallons)	3,000	14,000	29,000
Labour (man-hours)[a]	0.68	0.89	1.17

SOURCES: J. C. Reynolds and C. R. Trimarke, "Four routes to urea by Toyo Koatsu", *Hydrocarbon Processing and Petroleum Refiner* (Houston, Texas), vol. 41, No. 12 (1962), p. 109; and Toyo Koatsu Industries, Inc., Tokyo, Japan, brochure (May 1965).

[a] Based on production of 150 short tons per day.

TABLE 47. RAW MATERIAL AND UTILITY REQUIREMENTS FOR VARIOUS TOTAL-RECYCLE PROCESSES

	Quantities/short ton prilled urea						
				Stamicarbon			
Raw materials and utilities	*Chemico*	*Lonza*	*Montecatini*	*Conventional*	*CO_2 stripper*	*Toyo Koatsu*	*Inventa*
Liquid NH_3 (short ton)	0.58	0.58	0.58	0.57	0.57	0.58	0.58
Gaseous CO_2 (short ton)	0.75	0.75	0.76	0.77	0.76	0.76	0.76
Steam (pounds)	2,300	3,900	3,000	4,750	2,900	3,900	3,800
Electricity (kWh)	142	155	145	140	135	155	250
Cooling-water (US gallons)	15,000	30,000	38,400	36,000	20,000	29,000	20,000

SOURCES: For Chemico, Lonza and Montecatini: United Nations Interregional Seminar on the Production of Fertilizers, 13 August - 11 September 1965, Kiev, Ukrainian Soviet Socialist Republic, "Design criteria for large tonnage complete recycle urea plants", paper prepared by L. H. Cook. For Stamicarbon: Stamicarbon N. V., Chemical Construction Division, Geleen, Netherlands, brochure (1965); and C. F. Braun and Company, Alhambra, California, United States of America, brochure (1965). For Toyo Koatsu: J. C. Reynolds and C. R. Trimarke, "Four routes to urea by Toyo Koatsu", *Hydrocarbon Processing and Petroleum Refiner* (Houston, Texas), vol. 41, No. 12 (1962), p. 109; and Toyo Koatsu Industries, Inc., Tokyo, Japan, brochure (May 1965). For Inventa: Vulcan-Cincinnati and Mississippi Chemical Corporation, estimated data.

TABLE 48. PHYSICAL AND CHEMICAL CHARACTERISTICS OF UNCOATED PRILLED UREA

	Vacuum crystallization		*Atmospheric crystallization*		*Atmospheric evaporation and prilling*
Characteristics	*Prills*	*Crystals*	*Prills*	*Crystals*	
Nitrogen (percentage)	46.4	46.5	46.4	46.5	46.4
Moisture (percentage)	0.3	0.3	0.3	0.3	0.5
Biuret (percentage)	0.3	0.1	0.8	0.5	0.8
Free NH_3 (ppm)	100	2	200	50	—
Fe content (ppm)	2	2	2	2	—
pH (10 per cent solution)	9.0	7.2	9.3	9.0	—

SOURCES: J. C. Reynolds and C. R. Trimarke, "Four routes to urea by Toyo Koatsu", *Hydrocarbon Processing and Petroleum Refiner* (Houston, Texas), vol. 41, No. 12 (1962), p. 109; Stamicarbon N. V., Chemical Construction Division, Geleen, Netherlands, brochure (1965); and Toyo Koatsu Industries, Inc., Tokyo, Japan, brochure (May 1965).

utility requirements, even for the same general type of process. The data given in table 46 are taken from a particular process, Toyo Koatsu (10, 19), but are considered typical for the indicated general process type. Additional raw material and utility requirement data are given in table 47 to permit comparison of the total-recycle process of various licensors.

The "quality" of urea prills, in so far as fertilizer use is concerned, is dependent on the moisture and biuret content; other characteristics normally given (iron, turbidity, ash etc) relate to the use of urea in plastics, in medicine and as feed supplements. These latter data are shown in table 48 as a matter of general interest.

E. ECONOMIC DATA

The economic data in table 49 are given to permit comparison of typical plant investments, raw material costs and production costs for the three general types of urea processes and to define items that make up these costs. The data are from Toyo Koatsu (10, 19).

Other plant investment cost data and production cost data are summarized with other fertilizer processes in chapter XXI of this manual. Data for a total-solution recycle process are given in the form of graphs, as follows: figure 70, plant investment cost *versus* capacity; figure 71, production costs *versus* plant capacity at various ammonia costs; and figure 72, production cost *versus* ammonia cost (plant with capacity of 300 tons per day).

TABLE 49. PLANT AND PRODUCTION COST DATA FOR UREA PROCESSES

	Costs per short ton of uncoated prilled urea [a]		
Item	*Once-through*	*Partial solution recycle*	*Total-solution recycle* [b]
Raw materials costs			
NH_3 ($45 per short ton)	25.70	25.90	26.10
CO_2 ($3 per short ton)	2.24	2.28	2.30
Operating costs			
Steam ($0.60 per thousand pounds)	1.32	1.62	2.34
Electricity ($.007 per kWh)	1.40	1.26	1.21
Cooling-water ($0.03 per thousand gallons)	0.09	0.42	0.87
Maintenance (6% of plant investment)	2.46	2.88	3.36
Operating labour ($3 per man-hour)	1.86	2.40	3.18
Overhead, 100% labour	1.86	2.40	3.18
Fixed costs			
Taxes and insurance (3% of plant investment)	1.23	1.44	1.68
Depreciation (10% of plant investment)	4.10	4.80	5.60
Manufacturing cost (dollars per short ton)	42.26	45.40	49.82
	Plant investment costs (millions of dollars)		
	2.05	2.40	2.80

SOURCES: J. C. Reynolds and C. R. Trimarke, "Four routes to urea by Toyo Koatsu", *Hydrocarbon Processing and Petroleum Refiner* (Houston, Texas), vol. 41, No. 12 (1962), p. 109; and Toyo Koatsu Industries, Inc., Tokyo, Japan, brochure (May 1965).

[a] Daily production rate, 150 short tons; annual, 50,000 short tons.

[b] Direct prilling.

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XI. PRODUCTION OF NITROGEN SOLUTIONS

A. TYPES OF NITROGEN SOLUTIONS

A nitrogen solution is an aqueous solution of ammonia, ammonium nitrate, or urea, separately or in combination, used either for the manufacture of mixed fertilizers or for direct application. It includes *aqua* ammonia, but does not include anhydrous ammonia or liquid mixed fertilizer containing phosphate or potash.

By-product *aqua* ammonia from coal-gas works was used to a limited extent as a direct application fertilizer in the middle of the nineteenth century, but widespread commercial production of nitrogen solutions dates only from the early 1930s. Rapid growth of the synthetic ammonia industry during the late 1950s and early 1960s was accompanied by an increase in production of nitrogen solutions.

The manufacture of nitrogen solutions can be carried out as an independent process or as an accessory operation integrated with the manufacture of synthetic ammonia, ammonium nitrate or urea. In the manufacture of solid ammonium nitrate (chapter IX) or urea (chapter X), concentrated solutions of the compounds are produced as intermediates. Production of nitrogen solutions in such a plant merely involves drawing off the process liquor, adjusting the concentration and loading for shipment. Nitrogen solution is usually a profitable outlet for at least a part of the production. The entire output sometimes is marketed as solution, thus eliminating the need for prilling towers, driers and other equipment required to produce the solid product. The production of nitrogen solutions as an independent process is described later in this chapter.

Nitrogen solutions have certain advantages over solid fertilizers. Many of the solutions have a higher nitrogen content and a lower cost per unit of nitrogen than solids. They can be applied accurately to the soil without problems of caking or dusting. They are more adaptable than solids to incorporation in irrigation water. Ease of handling is a major advantage; there is no lifting and handling of fertilizer bags. Consideration must be given to climate, as a drop in temperature below the salting-out point can cause trouble from deposition of solids and clogging of equipment.

Ammonia, ammonium nitrate and urea have high mutual solubilities in water, which allows the preparation of a variety of solutions having a wide range of properties. Solutions containing ammonia usually have such a high vapour pressure of ammonia that they require covered or pressurized containers and subsurface injection into the soil to avoid loss of ammonia. Ammoniacal solutions, with the exception of *aqua* ammonia, are primarily intended for use in the manufacture of mixed fertilizers, although they are also used for direct application either in their original concentration or after dilution. Non-ammoniacal solutions of ammonium nitrate or urea, or both, have no vapour pressure of ammonia, can be applied to the surface of the soil and are intended only for direct application as fertilizers.

Nitrogen solutions can be classified according to composition, as follows: (*a*) *aqua* ammonia; (*b*) solutions containing ammonia and ammonium nitrate; (*c*) solutions containing ammonia and urea; (*d*) solutions containing ammonia, ammonium nitrate and urea; and (*e*) solutions containing ammonium nitrate alone or with urea but without ammonia.

1. Aqua *ammonia*

The production of *aqua* ammonia involves the addition of anhydrous ammonia to water, a relatively simple operation that can be carried out independently of an ammonia synthesis plant, thereby saving the expense of transporting water. The operation requires facilities for proportioning the flows of water and ammonia, cooling the freshly formed *aqua* ammonia to remove the heat of absorption, and measuring the concentration of the *aqua* ammonia. Several manufacturers of equipment offer "packaged" units combining all three operations. These range in price from about $6,000 to $12,000 for stationary units capable of converting a 38-cubic metre tank car of anhydrous ammonia to 20 per cent *aqua* ammonia in three to sixteen hours. Comparable portable units suitable for mounting on trailers cost about $8,000 to $17,000, depending on capacity. Packaged converters are generally designed for automatic or semi-automatic operation.

In situations where technical skills are available, a variety of methods can be used for producing *aqua* ammonia. The proportioning of the flows of water and anhydrous ammonia can be regulated by the heat of absorption. Such an arrangement has been described by Tielrooy (1). As shown in figure 36, liquid ammonia flows from a tank car under its own pressure and is line-mixed with a controlled flow of soft water. The ammonia flow is not controlled and may vary during the course of unloading as the tank-car pressure decreases. The streams of water and anhydrous ammonia are brought together in a "T", and the solution passes through a globe valve, which completes the mixing. The pressure drop across the globe valve is manually adjusted to between 0.7 and 1.4 kilogrammes per square centimetre. A temperature recorder-controller measures the temperature of the mixture and automatically maintains this temperature at a predetermined value by adjusting the flow of water. This predetermined value is selected on the basis of the temperature of the incoming water, the initial pressure in the tank car and the desired concentration of the *aqua* ammonia. Since 20 per cent *aqua* ammonia is a commonly

TABLE 50. CONTROL TEMPERATURES AFTER MIXING VALVE TO PRODUCE 20 PER CENT *aqua* AMMONIA[a]

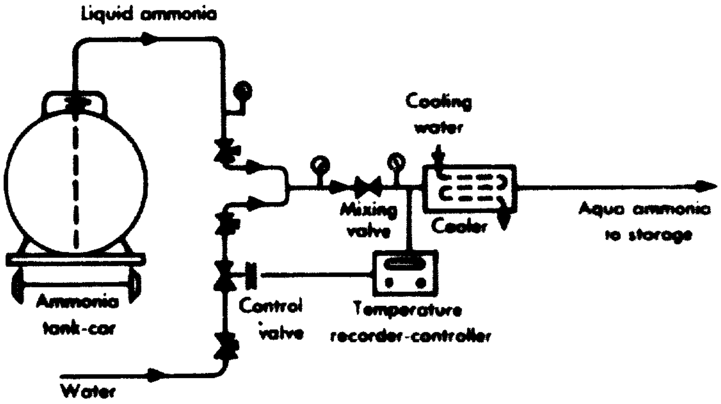
(Centigrade degrees)

Inlet water temperature	*Initial tank-car pressure (Kilogrammes per square centimetre)* *4.2*	*5.6*	*7.0*	*8.4*	*9.8*
°C	°C	°C	°C	°C	°C
10	43	45	46	47	48
13	46	47	48	49	50
15	48	49	50	52	53
18	50	52	53	54	55
21	52	54	55	56	57
24	54	56	57	58	59
27	57	58	59	60	62
29	59	60	62	63	64

[a] See figure 36.

used concentration, values of the control temperature have been calculated for producing 20 per cent *aqua* ammonia (see table 50). Owing to variations in the temperature of the ammonia leaving the tank car during unloading, there will be minor variations in the concentration of *aqua* ammonia produced, but this variation would probably amount to less than 1.0 per cent. An installation using 7.62 centimetre (3-inch) piping for liquid ammonia and 10.16-centimetre (4-inch) piping for water and *aqua* ammonia should permit the unloading of a 38-cubic metre tank car in about six hours.

Figure 36. Production of aqua *ammonia*



Other methods of proportioning the flows of water and ammonia are based on the concentration of a recirculating stream of *aqua* ammonia as indicated by a hydrometer.

The removal of the heat of absorption is a major consideration; roughly 2.7 million kilocalories must be removed per tank car (38 cubic metre) of ammonia converted to 20 per cent *aqua* ammonia. Cooling can be accomplished by various methods, including refrigeration, tube-and-shell heat exchangers or tube-and-spray-tower evaporative coolers. The cooling system usually comprises the main part of *aqua* ammonia converters. The choice of method should take account of such local conditions as the availability and temperature of cooling-water.

In general, the conversion cost will range from about $3.25 to $3.50 per ton of ammonia.

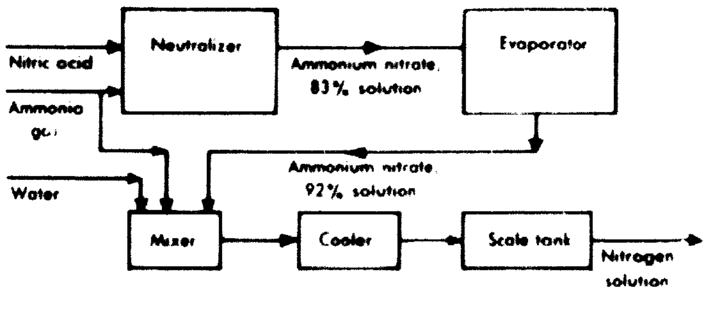
Cast-iron or mild steel equipment is suitable for handling *aqua* ammonia. Storage and applicator tanks should be designed for a working pressure of at least 7 kilogrammes per square centimetre. Equipment for handling *aqua* ammonia is not necessarily suitable for handling other nitrogen solutions, which are generally more corrosive.

Aqua ammonia is used primarily as a direct-application fertilizer. A considerable amount of experience in Europe, Japan and the United States of America indicates that it is a good source of fertilizer nitrogen under many conditions and is sometimes superior to other sources. Application should be subsurface, otherwise, losses by evaporation are likely. In the United States, consumption of *aqua* ammonia in agriculture corresponds to about 140,000 tons of nitrogen *per annum* (1963/1964) and is increasing rapidly. In addition, a considerable amount of *aqua* ammonia is prepared in the field by injecting anhydrous ammonia into irrigation water. Ammonia thus used is not covered by consumption statistics.

2. *Ammonia-ammonium nitrate solutions*

Solutions containing ammonia and ammonium nitrate are produced by injecting ammonia into ammonium nitrate solutions. Although such solutions are usually produced at an ammonia plant, they can also be produced from transported ammonia. In the latter case, a nitric acid plant would be required to convert a portion of the ammonia to nitric acid. The nitric acid would then be neutralized with ammonia to prepare a solution of ammonium nitrate, and ammonia would be added to the ammonium nitrate solution to prepare the final product. Such an arrangement, shown in figure 37, would be economical in locations where the delivered cost of anhydrous ammonia is less than the cost of producing ammonia at the site, for example, where there is a scarcity of the raw materials required for producing ammonia, or where the amount of ammonia required is too small for economical ammonia plant operation. In order to show some of the economics of an independent plant for producing nitrogen solutions, an estimate was prepared, on the basis of a production capacity of 225 tons per eight-hour day, of solution containing 34 per cent ammonia and 60 per cent ammonium nitrate by weight. A plant of this size would require a neutralizer with a capacity of 165 tons per day and a nitric acid plant with a capacity of 135 tons per day. The order-of-magnitude cost of the solutions plant, without the nitric acid unit, would be $400,000. The

Figure 37. Production of nitrogen solution



nitric acid unit would cost about $1.2 million, bringing the total investment to $1.6 million. Table 51 shows the breakdown of estimated manufacturing requirements.

Ammonia-ammonium nitrate solutions are used both for the manufacture of mixed fertilizers (chapter XV) and for direct application to the soil.

Compositions and properties of selected commercial ammonia-ammonium nitrate solutions produced in the United States of America are shown in table 52. The system of designation shows, first, the precentage of total nitrogen multiplied by ten, then (in parentheses) the respective percentages of ammonia, ammonium nitrate and urea, rounded off to the nearest whole number.

The gauge pressures (table 52) are important to the designer of equipment. The salting-out temperatures are important in both fertilizer manufacture and direct application. Most of the solutions can be used throughout the United States for spring operations without risk of salting-out.

TABLE 51. MANUFACTURING REQUIREMENTS PER TON OF NITROGEN SOLUTION CONTAINING 34 PER CENT AMMONIA AND 60 PER CENT AMMONIUM NITRATE

(225 tons of solution per eight hours)

	Requirements
Materials	
Nitric acid (100 per cent HNO_3)	0.472 ton
Ammonia (100 per cent NH_3)	0.467 ton
Utilities	
Electricity	3 kWh
Steam	180 kilogrammes
Cooling-water	12 cubic metres
Labour	
Direct labour (32 man-hours per day)	0.14 man-hour

TABLE 52. COMPOSITION AND PROPERTIES OF SELECTED COMMERCIAL AMMONIA-AMMONIUM NITRATE SOLUTIONS

Solution designation	*Total nitrogen*	*Ammonia*	*Ammonium nitrate*	*Water*	*Salting-out temperature (centigrade degrees)*	*Gauge pressure at 40° C (kilogrammes per square centimetre)*	*Temperature at which gauge pressure is zero (centigrade degrees)*
	(Percentage)						
370(17-67-0)	37.0	16.6	66.8	16.6	9	0.07	38
410(22-65-0)	41.0	22.2	65.0	12.6	6	0.70	26
410(26-56-0)	41.0	26.3	55.5	18.2	32	1.19	20
414(19-74-0)	41.4	19.0	74.0	7.0	18	0.56	26
440(24-70-0)	44.0	23.8	69.8	6.4	−3	1.26	19
440(28-60-0)	44.0	28.0	60.0	12.0	−38	1.75	14
448(25-69-0)	44.8	25.0	69.0	6.0	14	1.19	16
451(26-68-0)	45.1	26.0	68.0	6.0	21	1.68	16
471(30-64-0)	47.1	30.0	64.0	6.0	−36	2.10	8
490(34-60-0)	49.0	34.0	60.0	6.0	−46	3.50	4

SOURCES: J. R. Adams, Official Publication No. 11 (Clemson, S.C., Association of American Fertilizer Control Officials, 1957), pp. 66-69; and United States of America, Department of Agriculture, Agricultural Research Service, *Liquid Nitrogen Fertilizers for Direct Application*, by J. R. Adams, M. S. Anderson and W. C. Hulbert, Handbook No. 198 (Washington, D.C., 1961).

Solutions 370(17-57-0), 410(22-65-0) and 410(26-56-0), analysed in table 52, are advertised as direct-application materials. Others in the list probably are also used in that way.

Ammonia-ammonium nitrate solutions cannot be economically handled in ordinary steel equipment because of corrosion. Equipment made of aluminium or stainless steel (American Iron and Steel Institute Types 304 or 405) is satisfactory.

The solubilities, vapour pressures and densities in the system ammonia-ammonium nitrate-water in the range 0 to 65 per cent ammonia and 0 to 75 per cent ammonium nitrate have been reported by Worthington *et al.* (2).

3. *Ammonia-urea solutions*

Aqueous urea-ammonia solutions are designed for use in the manufacture of mixed fertilizers and are seldom used for direct application. Compositions and properties of selected commercial ammonia-urea solutions are shown in table 53.

These solutions are manufactured by adjusting the composition of process liquor from a urea synthesis plant (chapter X). These solutions containing ammonium carbamate (expressed in terms of carbon dioxide in table 53) contain less water than do equal grades without carbamate, and the liberated carbon dioxide helps to maintain a fire-proof atmosphere in the mixer. Solutions containing formaldehyde undergo polymerization during manufacture of solid mixed fertilizers and produce urea-formaldehyde, a source of slowly available nitrogen.

4. *Ammonia-ammonium nitrate-urea solutions*

Addition of a relatively small proportion of urea to ammonia-ammonium nitrate solution appears to modify and improve the crystal habit of certain compounds in mixed fertilizers prepared from the solution, thereby

TABLE 53. COMPOSITION AND PROPERTIES OF SELECTED COMMERCIAL AMMONIA-UREA SOLUTIONS

Solution designation	Total nitrogen	Ammonia	Urea	Water	Salting-out temperature (centigrade degrees)	Gauge pressure at 40° C (kilogrammes per square centimetre)	Temperature at which gauge pressure is zero (centigrade degrees)
	(Percentage)						
350(20-0-41)	35.0	19.6	40.6	39.8	14	0.63	27
371(25-0-35)[a]	37.1	25.0	35.3	32.8	1	1.19	18
371(25-0-35)[b]	37.1	25.0	35.3	24.8	1	1.68	19
453(31-0-43)[c]	45.3	30.5	43.3	17.6	1	3.85	2
455(37-0-33)	45.5	36.8	32.5	30.7	9	3.99	2
455(37-0-33)[d]	45.5	36.8	32.5	24.8	15	4.97	12
460(31-0-44)	46.0	31.1	43.8	25.1	5	3.57	1
460(37-0-33)	46.0	37.3	32.9	29.8	17	4.20	6

SOURCES: J. R. Adams, Official Publication No. 11 (Clemson, S.C., Association of American Fertilizer Control Officials, 1957), pp. 66-69; and United States of America, Department of Agriculture, Agricultural Research Service, *Liquid Nitrogen Fertilizers for Direct Application*, by J. R. Adams, M. S. Anderson and W. C. Hulbert, Handbook No. 198 (Washington, D.C., 1961).

[a] Contains 6.9 per cent carbon dioxide.

[b] Contains 6.9 per cent carbon dioxide and 8.0 per cent formaldehyde.

[c] Contains 8.6 per cent carbon dioxide.

[d] Contains 5.9 per cent carbon dioxide.

TABLE 54. COMPOSITION AND PROPERTIES OF SELECTED COMMERCIAL AMMONIA-AMMONIUM NITRATE-UREA SOLUTIONS

Solution designation	Total nitrogen	Ammonia	Ammonium nitrate	Urea	Water	Salting-out temperature (centigrade degrees)	Gauge pressure at 40° C (kilogrammes per square centimetre)	Temperature at which gauge pressure is zero (centigrade degrees)
	(Percentage)							
410(19-58-11) . . .	41.0	19.0	58.0	11.0	12.0	−14	0.70	27
440(28-40-15) . . .	44.0	28.0	40.0	15.0	17.0	−17	1.89	11
444(25-56-10) . . .	44.4	24.5	56.0	10.0	9.5	−26	1.54	17
444(25-55-10) . . .	44.4	25.0	55.0	10.0	10.0	−29	1.54	13
444(26-50-12) . . .	44.4	26.0	50.0	12.0	12.0	−22	1.68	12
490(33-45-13) . . .	49.0	33.0	45.0	13.0	8.8	−25	3.50	2

SOURCES: J. R. Adams, Official Publication No. 11 (Clemson, S.C., Association of American Fertilizer Control Officials, 1957), pp. 66-69; and United States of America, Department of Agriculture, Agricultural Research Service, *Liquid Nitrogen Fertilizers for Direct Application*, by. J. R. Adams, M. S. Anderson and W. C. Hulbert, Handbook No. 198 (Washington, D.C., 1961).

lessening the tendency towards caking. These solutions are prepared for use in mixed-fertilizer manufacture and are rarely used for direct application. They are manufactured in the same way as ammonia-ammonium nitrate solutions, with the urea generally being added either as the solid or as a solution free of carbamate. Compositions and properties of selected commercial ammonia-ammonium nitrate-urea solutions are shown in table 54.

5. *Non-ammoniacal solutions of ammonium nitrate and urea*

Incidental to the production and distribution of nitrogen solutions for the manufacture of solid mixed fertilizers, some of the solutions found their way into direct application. A large potential market for nitrogen solutions as direct-application materials soon became evident — a situation promoted also by the growing market for liquid mixed fertilizers, anhydrous ammonia and *aqua* ammonia. Manufacturers of solid mixed fertilizers found that some of their ammoniating solutions, purchased for manufacturing, could be sold locally as liquid fertilizer. The ammoniating solutions could be diluted with water, as desired, to lower the gauge pressure and the salting-out temperature. This permitted the solutions to be handled in non-pressure applicators, but the presence of ammonia in all these solutions was likely to result in losses of ammonia to the atmosphere during application unless the solutions were injected beneath the surface of the soil. Thus, surface application was not entirely suitable. Furthermore, the presence of ammonia increased the corrosiveness of the solutions.

To satisfy the market for non-pressure nitrogen solutions suitable for surface application, aqueous solutions containing ammonium nitrate, alone or with urea or other salts, were produced. Compositions and properties of

TABLE 55. SELECTED COMMERCIAL NON-AMMONIACAL SOLUTIONS OF AMMONIUM NITRATE ALONE AND WITH UREA FOR DIRECT APPLICATION

Solution designation	*Total nitrogen*	*Ammonium nitrate*	*Urea*	*Water*	*Salting-out temperature (centigrade degrees)*
	(Percentage)				
160(0-46-0)	16.0	45.7		54.3	12
170(0-31-0-36) [a]	17.0	30.9		32.9	0
175(0-50-0)	17.5	50.0		50.0	6
190(0-54-0)	19.0	54.3		45.7	1
200(0-48-0-20) [b]	20.0	47.5		32.0	14
200(0-57-0)	20.0	57.3		42.7	6
210(0-60-0)	21.0	60.0		40.0	11
227(0-65-0)	22.7	65.0		35.0	...
245(0-70-0)	24.5	70.0		30.0	...
280(0-40-30)	28.0	39.5	30.5	30.0	17
300(0-42-33)	30.0	42.2	32.7	25.1	9
320(0-44-35)	32.0	44.3	35.4	20.3	0

SOURCES: J. R. Adams, Official Publication No. 11 (Clemson, S.C., Association of American Fertilizer Control Officials, 1957), pp. 66-69; and United States of America, Department of Agriculture, Agricultural Research Service, *Liquid Nitrogen Fertilizers for Direct Application*, by J. R. Adams, M. S. Anderson and W. C. Hulbert, Handbook No. 198 (Washington, D.C., 1961).

[a] Contains 36.2 per cent calcium nitrate.

[b] Contains 20.5 per cent sodium nitrate.

selected commercial solutions of this type, designed exclusively for direct application, are shown in table 55. In addition to the solutions noted in table 55, there is a commercial 83 per cent solution of ammonium nitrate which must be kept above 68° C to avoid salting-out. This is shipped to dealers or consumers having facilities for its dilution prior to application.

As with ammoniacal solutions, the manufacture of non-ammoniacals is usually integrated with an ammonium nitrate plant. These solutions are not as corrosive as ammoniacal solutions and can be handled in plain steel equipment if corrosion inhibitors are added.

B. VOLUME OF PRODUCTION

In 1965, production of nitrogen solutions in the United States of America was about 1.06 million tons, nitrogen basis, compared with 1.03 million tons in 1964 (3). Comparable figures on world production are not available, but it is estimated that nitrogen solutions accounted for about 19 per cent of world fertilizer nitrogen output in 1963/1964 (4).

In 1966, there were about fifty plants producing nitrogen solutions in the United States of America.

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3. United States of America, Department of Commerce, *Quarterly Industry Report, Chemicals*, vol. 13, No. 1 (1966).
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XII. PRODUCTION OF PHOSPHATE FERTILIZERS

A. GENERAL INFORMATION

Phosphorus, which is designated by the chemical symbol P, is one of the elements essential to the growth and development of plants. Fertilizer that contains this element is applied to improve yields, hasten plant maturity, increase resistance of plants to disease and improve quality. The fertilizer reacts rapidly with the soil, and the resulting phosphorus compounds are sparingly soluble in the soil solution. Phosphorus is absorbed from the soil solution by plants as the phosphate ion ($H_2PO_4^-$ or HPO_4^{--}) rather than as the element.

Every living plant cell contains phosphorus. As plants mature, most of the phosphorus within the plant passes into the fruits and seeds. Well-developed, healthy animals and people require food grown in soil that contains an adequate amount of phosphorus either occurring naturally or added as fertilizers.

A phosphorus concentration of only 0.001 to 1 part per million in the soil solution is usually adequate for proper plant growth. However, for plants to receive the total amount of phosphorus required, the phosphorus content of the soil solution in contact with the roots must be renewed continuously during the growth period. Therefore, the solubility of the phosphate fertilizer applied to the soil is quite important. Table 56 shows the weight of phosphorus contained in common crop plants.

The deposits of phosphate rock exist in nature because of the low solubility of the compounds present. A primary objective of the phosphate fertilizer industry is to convert the natural phosphates into more soluble compounds. As discussed later, conversion is accomplished by: (*a*) thermal methods; (*b*) chemical or wet methods, which usually require sulphuric acid or other acids; and (*c*) a combination of the thermal and chemical methods, e.g., the production of furnace acid and its use in the production of triple superphosphate.

Phosphate fertilizer materials vary widely as to their availability or nutrient value to growing crops. Since Liebig showed in 1840 that the fertilizer value of bones was increased by treatment with acid, chemical methods of analysis have been developed to help in judging the value of phosphate materials as fertilizers. The total amount of phosphorus in a fertilizer is easily determined, and most qualified chemists will arrive at essentially the same value. However, the total phosphorus content often bears little relationship to the soluble or truly available phosphorus, which is somewhat more difficult to measure chemically. Although no very strict line can be drawn between the available and the unavailable phosphorus in a fertilizer, the water-soluble and the citrate-soluble forms are regarded generally as being more available to plants than the less soluble forms. It should be understood, however, that no one laboratory method will give results in agreement with crop response for all phosphate fertilizers under all conditions of plant growth. Such physical characteristics of the fertilizer as granule size and the manner of placement in the soil may greatly affect crop response. Such factors cannot be reflected in the laboratory analysis of a pulverized sample of the fertilizer.

TABLE 56. WEIGHT OF PHOSPHORUS CONTAINED IN GOOD YIELDS OF COMMON CROP PLANTS

Crop	Yield per hectare (tons)	Phosphorus (kilogrammes)
Maize	3.8	19
Oats	1.8	7
Wheat	2.0	23
Rice (unmilled paddy) [b]	5.3	19
Soya bean	1.7	15
Lucerne (alfalfa)	6.7	19
Red clover	4.5	22
Hay (mixed)	5.0	15
Tomatoes	22.3	39
Cabbage	33.6	28
Onions	22.4	20
Potatoes	20.2	39
Sugar-beet (roots and leaves)	35.0 23.0	45
Apples	21.5	11
Grapes	9.0	11
Oranges	14.8	34
Tobacco	1.7	22
Cotton (seed and lint)	1.1 0.6	28
Six-year rotation [c]		121

SOURCE: Food and Agriculture Organization of the United Nations, *Efficient Use of Fertilizers*, by V. Ignatieff (Rome, 1958), p. 13.

[a] The root systems of the plants have not been included in the calculations. For potatoes, both the tops and tubers have been included. For trees and grapes, account has been taken of the fruit, the leaves and the yearly growth of wood.

[b] The figures are for Japan, where high yields are obtained. Mention should also be made of silicon, which is absorbed in large quantities by this crop (a crop of this size would absorb over 500 kilogrammes). Paddy benefits by the application of this element.

[c] Five-year rotation includes two-year lucerne. Yields used in calculations are lucerne hay (yield for 2.5 years): 26.88, maize for ensilage: 13.6; sugar-beets: 44.8; and barley: 3.23.

1. *Water-soluble* versus *citrate-soluble phosphate*

Chemical methods which permit a fairly rapid estimate of the water-soluble, citrate-soluble and total phosphorus content of fertilizers are used widely. A brief description

TABLE 57. BASES FOR GUARANTEE AND QUALITY CONTROL OF FERTILIZER PHOSPHORUS

Country	*Total phosphorus*	*Water*	*Neutral*	*Phosphorus soluble in ammonium citrate solution* [a]	
				Alkaline	*Citric acid, 2 per cent*
Australia:					
New South Wales	F	F	—	—	F
Queensland, Victoria Tasmania [b]					
Western Australia	F	F	F	—	—
Belgium	—	A, Fc, Fm, K, S	—	Fc, Fm, Pp, R, Tp, Mp	Bs, Fm
Brazil:					
Bahia [b]					
São Paulo	R, S	S	Fm, S	—	Fm, R
Canada	F	—	F	—	—
Chile	Bm, G, R	—	Fm, S, Tp	—	Bm, Bs, G, R
China (Taiwan) [d]	—	—	Np, S	—	—
Colombia [b]	G, R	—	F [c]	—	—
Denmark	—	S	—	Bs, Fc	—
Federal Republic of Germany	Bm, R, S	Sa, Fm	—	Fm, Np, Pp, S, Tp	Bs, Fm
France	Bm, Bs, R	A, K	—	Fc, Fm, Pp, S, Tp	Bs
Hungary [b]	R	S	—	—	—
India	—	R, Pp, S	R, Pp, S	—	—
Ireland [d]	R	S, Sb	—	Fc, Fm	Bs
Israel [b]	R	S	F	—	—
Italy	Bs, R	—	Fm, G, S	—	Bs, Pp, R
Japan	Bm, Fm, R	A, S	—	Pp, S	Bs, Fm, Pp, Ps, R, Sa
Mexico	Bm, G, R	—	F	—	—
Netherlands	Bm, R	A, Fc, Fm, Np, Sa, S	A, Fc, Fm, Np, Sa, Pp, Tp	A, Fc, Fm, Sa, Np, Pp, Tp	Bs, Np, R
New Zealand [d]	F	F [e]	—	—	F
Norway	Bm, G, R	Fm, S	—	Np, Rp	Bs, Np, R
Philippines [b]	Bm, R	—	F	—	—
Poland [b]	R	S	—	Bs, Fm, Pp	Bs, Pp
Portugal	Bm, Bs, R	A, Fm, S	—	Fm	Bs, Fm
South Africa	Bm, G, R	S	—	—	A, Bs, Fc, Fm, Sb
Spain	R	Fc, Fm, S	—	Al, Bm, Fc, Fm, Pp, S	Bs
Sweden [b]	F	Fm, S	—	Fm, Np, S	Bs, R
Switzerland	Bm, Fm, G, R	Fc, Fm, S	—	Pp, Tp	Bs
United Kingdom	Bm, Bs, G, Pp, Sb	Bd, Fc, Fm, S	—	—	Bs
United States of America	Bm, R	—	F	—	—
Yugoslavia [b]	Bs, R	S	—	Fm, S	Bs

SOURCE: G. L. Terman, W. M. Hoffman and B. C. Wright. "Crop response to fertilizers in relation to content of available phosphorus", *Advances in Agronomy*, vol. 16 (New York, Academic Press, 1964).

Note: The materials are identified as follows: A, ammonium phosphates; Al, aluminum phosphate; Bd, dissolved or vitriolized bones; Bm, bone-meal; Bs, basic slag; F, all fertilizers; Fc, multinutrient fertilizers; Fm, mixed fertilizers; G, guano; K, potassium phosphate; Mp, ammoniated magnesium phosphate; Np, nitric acid-phosphate rock products; Pp, precipitated calcium phosphates; Ps, phosphate rock-magnesium silicate glass; R, raw mineral phosphates for direct application to the soil; S, superphosphates; Sa, ammoniated superphosphates; Sb, basic superphosphate; and Tp, products of mixtures of mineral phosphates and alkali salts.

[a] Includes water-soluble phosphorus.

[b] Not included in survey of Jacob and Hill (1953).

[c] Guarantee is not required for guano and rock.

[d] Changed since survey of Jacob and Hill (1953).

[e] Permitted but not required.

of the methods and definitions of the terms employed follows:

(*a*) Water-soluble phosphorus. This form of phosphorus is generally regarded as the most readily available to the plant. It is determined by extracting a small, finely ground sample of the material with water under prescribed conditions. The amount of phosphorus contained in the filtered solution is determined by chemical methods and constitutes the water-soluble fraction of the phosphorus in the fertilizer;

(*b*) Citrate-soluble phosphorus. The water-insoluble residue is added to a solution of either neutral or alkaline ammonium citrate. It is extracted for a prescribed period of time, and the phosphorus in the filtered extract or in the residue is determined chemically. The amount extracted is the citrate-soluble portion of the phosphorus. In the case of fertilizers that contain little or no water-soluble phosphorus, a sample of the original material may be treated directly with ammonium citrate. A 2 per cent solution of citric acid is used instead of ammonium citrate in some countries, as is discussed later;

(*c*) Available phosphorus. The sum of the water-soluble and citrate-soluble values is taken as an estimate of that fraction of the total phosphorus which is available to plants. The phosphorus content is ordinarily reported as phosphorus pentoxide (P_2O_5), although a few nations report it as the element (P);

(*d*) Total phosphorus. The total phosphorus is the sum of the available and citrate-insoluble fractions. It is determined by treating a sample of the original material with strong acids and analysing the solution for phosphorus.

Laws to control the sale of materials for fertilizer have been enacted in nearly all countries which actively promote agriculture. In most cases, these laws require a description of the nutrient content of the fertilizers. In the United States of America, regulations have been adopted by the individual states and not by the Federal Government. In the case of phosphate fertilizers, a guarantee of the minimum percentage of available phosphorus is required.

The Association of Official Analytical Chemists (AOAC) secures and adopts methods of analysis for fertilizers in the United States. Some states specify AOAC or state methods for enforcement of their laws pertaining to the sale of fertilizers.

The basis for determining the phosphorus in fertilizer materials in thirty countries appears in table 57. In the United States of America the neutral ammonium citrate method is used, while in Europe there is widespread use of the alkaline ammonium citrate method. The AOAC methods are the official ones in Canada, Mexico and the United States of America. These methods or modifications thereof are also used wholly or in part in some states of Australia and Brazil, and in Chile, Colombia, India, Israel and the Philippines.

Most countries require a guarantee for the total amount of phosphorus in relatively insoluble materials, e.g., basic slag, bonemeal, guano or non-acidulated phosphate rock for direct application to the soil. New South Wales and New Zealand require the use of 2 per cent citric acid on all products. Most countries require this procedure for basic slag. There is no country in which water-soluble phosphorus is the sole basis of guarantee for all fertilizer materials. However, many countries do require only this determination for superphosphate fertilizers.

The following three broad classifications of phosphate fertilizer materials are based upon relative solubilities and other properties:

(*a*) Water-soluble phosphates. Such phosphates dissolve most readily and, as a rule, have the quickest effect upon growing plants. The main phosphate fertilizers under this classification are ordinary and concentrated superphosphates;

(*b*) Available but sparingly water-soluble phosphates. Included in this group are the materials which dissolve in ammonium citrate solutions. Degreased bone, basic slag, dicalcium phosphate, defluorinated phosphate rock, calcium metaphosphate and fused magnesium phosphate qualify in this group;

(*c*) Phosphates that are nearly insoluble in water and are only slowly available in the soil. In this category are the natural phosphates, including raw bone, weathered guano, apatite and phosphorite or phosphate rock.

The composition and water solubility of the common phosphate fertilizer materials are given in table 58. It may be seen that the natural phosphates, including phosphate rock, have essentially no water-soluble phosphate. On the other hand, phosphate fertilizers like the superphosphates, which are products of industrial processes, contain as much as 90 per cent of the phosphorus in the water-soluble form.

Many agronomical tests have been made in attempts to define the relative effectiveness of water-soluble and citrate-soluble phosphorus. So many factors other than the solubilities of the phosphates affect the results that no simple, general conclusion is possible. On acid soils and with some crops, citrate-soluble phosphates are essentially as effective as water-soluble phosphates. For most crops on calcareous or alkaline soils, tests indicate that phosphate fertilizer containing at least 50 per cent of its phosphorus in a water-soluble form is desirable.

The granule size of the fertilizer is quite important. Experiments have shown that decreasing the granule size increased the crop response in the case of citrate-soluble fertilizer, but decreased the response in the case of water-soluble phosphate fertilizer. Tests showed also that as the granule size was decreased, the different degrees of water solubility made less of a difference in response. As the growing season progressed, the efficiency of the citrate-soluble material approached that of the water-soluble material. A more complete discussion of the effect of water-soluble phosphorus on plant growth is given in *Fertilizer Technology and Usage*.[1]

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[1] *Fertilizer Technology and Usage*, M. H. McVickar, G. L. Bridger and L. B. Nelson, eds. (Madison, Wisc., Soil Science Society of America, 1963).

TABLE 58. COMPOUNDS PRESENT IN PHOSPHATE FERTILIZER MATERIALS

Material	*Grade*	*Water solubility of phosphorus (percentage)*	*Phosphorus compounds present*		*Major accessory compounds present*
			Major phases	*Minor phases*	
Ordinary superphosphate	0-20-0	85	$Ca(H_2PO_4)_2.H_2O$	$CaHPO_4$	$CaF_2 CaSO_4.2H_2O$,[a] silica
Concentrated superphosphate					
Wet process H_3PO_4	0-45-0	87	$Ca(H_2PO_4)_2.H_2O$	$CaHPO_4$, apatite	$CaF_2 CaSO_4.2H_2O$,[a] silica
Electric-furnace H_3PO_4	0-48-0	90	$Ca(H_2PO_4)_2.H_2O$	$CaHPO_4$, apatite	Silica CaF_2
High-analysis superphosphate	0-54-0	90	$Ca(H_2PO_4)_2$	$Ca(H_2PO_4)_2.H_2O$ apatite	Silica
Dicalcium phosphate					
HCl process	0-40-4	4	$CaHPO_4.2H_2O$	$CaHPO_4$ $CaHPO_4.2H_2O$	Silica
Electric-furnace H_3PO_4	0-48-0	3	$CaHPO_4$		—
Calcium metaphosphate	0-62-0	5	$Ca(PO_3)_2$ glass	Beta $Ca_2P_2O_7$	Quartz R_2O_3
Fused tricalcium phosphate	0-28-0	<2	Alpha-$Ca_3(PO_4)_2$ in glass matrix	Beta $Ca_3(PO_4)_2$, apatite	Quartz R_2O_3
Rhenania phosphate	0-33-0	<2	Ca silico-phosphates	—	Ca, Na silicates
Serpentine phosphate glass	0-22-0	<2	Ca, Mg silico-phosphates	—	Ca, Mg silicates
Basic slag	0-9-0	<2	Ca, silico-carnotite	—	Ca silicates
Colloidal "clay" phosphate	0-22-0	<1	Apatite	Al phosphates	Clay minerals
Pebble phosphate ore	0-32-0	<1	Apatite	—	$CaCO_3$

SOURCE: G. L. Terman, D. R. Bouldin and J. R. Webb, *Advances in Agronomy*, vol. 14 (1962), pp. 268-269.

[a] Usually present as $CaSO_4.1/2H_2O$ in freshly prepared superphosphate.

B. RAW MATERIALS

1. *General information*

The world phosphate industry is based essentially on deposits of phosphate rock — a fluorine-bearing complex of calcium phosphates with various accessory minerals.

The economy of utilizing a particular deposit depends mainly on its size, geology, accessibility to markets, chemical and physical characteristics and the amenability of the ore to beneficiation and processing. But there is a tendency in developing countries to establish, with little regard to cost, an indigenous source of phosphate supply.

In the phosphate rock industry, the P_2O_5 content of the rock is usually expressed in terms of its tricalcium phosphate [$Ca_3(PO_4)_2$] equivalent, commonly designated as "bone phosphate of lime".

Phosphatic slags, obtained as by-products of the manufacture of steel from high-phosphorus iron-ores, supply large quantities of fertilizer phosphorus, mainly in Europe; in certain countries, bones are still important fertilizers. These two materials are discussed in section D, 6 and 7.

Two general types of sulphuric acid are used in the production of superphosphate and in the production of wet-process phosphoric acid:

(*a*) Virgin or new acid, produced from elemental sulphur, pyrites, gypsum and industrial gases;

(*b*) Spent acid derived as a waste product in sundry industries that use large quantities of sulphuric acid in processing various products.

In some instances, the spent acid must be conditioned by suitable treatment for removal of substances that are objectionable in the fertilizers.

By mid-1966, a shortage of sulphur had developed, and higher prices resulted. With increased prices, abandoned sulphur mines were reopened. As the price of sulphur may remain high, it is desirable to consider the production of soluble phosphates by methods which do not require sulphur, for example, by the use of hydrochloric and nitric acids and the production of furnace phosphoric acid.

Phosphoric acid is separately dealt with in section C.

TABLE 59. ESTIMATED WORLD RESERVES OF PHOSPHATE ROCK AND APATITE

Country or area	*Reserves (tons)*
Algeria	1,016,000,000
Brazil	573,000,000
Canada	181,000
China (Taiwan)	55,000
Christmas Island	50,000,000
Europe [a]	435,126,000
Indonesia	1,000,000
Japan (former Japanese-mandated islands)	28,984,000
Makatea (French Polynesia)	10,000,000
Mexico	214,500,000
Morocco	1,000,000,000
Ocean and Nauru Islands	282,245,000
Tunisia	1,500,000,000
United Arab Republic	179,000,000
USSR	7,568,000,000
United States of America	13,290,860,000
Viet-Nam [b]	10,128,000
Other	2,496,000
TOTAL	26,168,475,000

SOURCE: K. D. Jacob, in Vincent Sauchelli, *Phosphates in Agriculture* (New York, Reinhold Publishing Corp., 1965).

[a] Excluding the Union of Soviet Socialist Republics.

[b] Refers to both the Republic of Viet-Nam and North Viet-Nam.

TABLE 60. PRODUCTION OF PHOSPHATE ROCK, 1958-1963 [a]

(Long tons)

Producing country	1958	1959	1960	1961	1962	1963	Estimated tribasic phosphate of lime content or equivalent					
							1958	1959	1960	1961	1962	1963
Commonwealth countries												
Australia												
Phosphate rock	7,251	4,775	2,234	4,759	4,317	4,925	3,300	2,100	1,000	2,000	2,000	2,000
Guano	170	—	87	115	68		100	—	60	80	50	
Christmas Island [b, c]	373,750	494,347	503,440	694,210	520,750	651,461	318,000	420,000	428,000	590,000	443,000	554,000
India [d]	14,572	r16,092	14,685	19,822	28,560	12,920	5,000	6,000	5,000	7,000	10,000	5,000
Jamaica [e]	130	27	64	32	22	—	30	10	20	10	6	—
Nauru Island [b]	1,234,450	1,192,240	1,351,257	1,436,032	1,525,650	1,547,242	1,062,000	1,025,000	1,162,000	1,235,000	1,312,000	1,331,000
Ocean Island [b]	323,800	314,392	319,526	337,533	256,650	356,128	278,000	270,000	275,000	290,000	221,000	306,000
Sarawak [e]	306	619	n.a.	n.a.	n.a.	n.a.	200	300	n.a.	n.a.	n.a.	n.a.
Seychelles [b, d]	16,540	5,526	6,988	7,455	5,338	6,965	10,000	3,000	4,000	5,000	3,000	4,000
Southern Rhodesia [f]	—	1,676	3,437	446	—	—	—	1,000	2,000	300	—	—
Tanganyika [e]	—	—	—	—	19	—	—	—	—	—	10	—
Uganda [d]	2,474	3,124	4,008	395	1,105	6,959	1,200	1,600	2,000	200	500	3,500
TOTAL	1,973,000	r2,033,000	2,207,000	2,501,000	2,343,000	2,587,000						
Other countries												
Algeria	552,088	562,733	554,154	432,666	384,000	343,000	370,000	380,000	370,000	290,000	260,000	230,000
Belgium [g]	17,724	12,973	8,113	13,795	12,285	n.a.	4,000	3,000	2,000	3,000	2,000	n.a.
Brazil												
Apatite	111,034	130,846	199,975	240,056	305,219	211,888	64,000	76,000	116,000	139,000	177,000	123,000
Phosphate rock	108,122	859,638	665,763	r408,931	251,406	62,503	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Chile												
Apatite	40,000	19,101	17,260	13,734	12,295	13,689	24,700	11,000	10,000	8,000	7,000	8,000
Guano	31,000	21,000	r18,000	r19,000	16,000	22,000	12,000	8,000	7,000	7,000	6,000	9,000
China [h, i]	300,000	500,000	600,000	500,000	600,000	700,000	200,000	350,000	r450,000	350,000	450,000	500,000
France [g]	101,697	75,642	57,108	80,200	66,377	43,541	24,000	18,000	13,000	20,000	15,000	11,00
Indonesia	500	2,000	7,000	9,000	2,000	6,000 [j]	200	1,000	3,000	4,000	1,000	3,000
Israel	206,226	201,500	220,639	222,000	226,000	295,000	128,000	125,000	137,000	140,000	142,000	185,000
Jordan	289,296	332,292	356,135	415,839	670,254	604,732	211,000	243,000	260,000	304,000	489,000	441,000
Madagascar	5,000	7,000	—	—	—	—	4,000	5,000		—	—	—
Makatea (French Polynesia)	320,000	362,967	406,684	374,679	312,081	330,000	262,000	298,000	333,000	307,000	256,000	271,000
Mexico	n.a.	29,000	27,000	29,000	30,000h	30,000 [k]	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Morocco	6,235,756	7,050,365	7,374,134	7,824,147	8,033,053	8,413,403	4,490,000	5,080,000	5,310,000	5,767,000	5,913,000	6,190,000
Mozambique [d]	118	90	103	—	—	—	n.a.	n.a.	n.a.	—	—	—
Netherlands Antilles [k]	85,269	96,611	113,097	149,596	129,474	126,254	62,000	71,000	83,000	109,000	95,000	92,000
North Viet-Nam	133,000	256,000	r480,000	r555,000	667,000	a740,000	120,000	220,000	420,000	480,000	580,000	640,000
Peru	164,000	125,000	155,000	r157,000	203,000	189,000	40,000	30,000	40,000	40,000	50,000	50,000
Philippines												
Phosphate rock	—		349	—	3,713	1,049	—		n.a.	—	n.a.	n.a.
Guano	7,116	373	9,877	396	93	1,450	2,000	90	2,400	95	20	350

Continued on page 122

TABLE 60 (*continued*)

Producing country	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*Estimated tribasic phosphate of lime content or equivalent*					
							1958	*1959*	*1960*	*1961*	*1962*	*1963*
Other countries (continued)												
Poland	70,000	40,000	40,000	46,800	55,000	f55,000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Senegal												
Phosphate rock	—	—	105,985	400,541	489,239	462,656	—	—	88,000	333,000	406,000	384,000
Aluminium phosphates	102,928	93,834	103,629	137,179	139,192	123,827	65,000	59,000	65,000	86,000	88,000	79,000
Somalia [k], [l]	—	217	339	n.a.	n.a.	n.a.	—	82	129	n.a.	n.a.	n.a
South Africa												
Phosphate rock [m]	213,087	228,005	263,423	291,904	302,312	447,729	110,000	92,000	155,000	173,000	184,000	264,000
Guano	3,853[n]	5,251	3,636	4,687	4,700	2,552	900	1,300	900	1,100	1,100	600
South West Africa [l]	—	1,187	—	922	574	1,355	—	300	—	200	100	300
Spain	—	387	3,198	—	—	—	—	250	2,000	—	—	—
Togo	—	—	—	116,035	188,577	506,400	—	—	—	92,000	153,000	400,000
Tunisia	2,242,546	2,150,455	2,062,894	1,951,000	2,064,000	2,330,000	1,458,000	1,398,000	1,341,000	1,268,000	1,342,000	1,515,000
USSSR [o]												
Apatite	3,940,000	r4,040,000	r4,720,000	r5,610,000	6,400,000	7,280,000	3,440,000	3,530,000	4,130,000	4,900,000	5,590,000	6,360,000
Phosphate rock	1,970,000	1,970,000	r2,260,000	3,050,000	3,450,000	3,640,000	1,300,000	1,300,000	1,490,000	2,010,000	2,280,000	2,400,000
United Arab Republic (Egypt)	549,000	r619,000	r557,000	617,000	592,000	602,000	340,000	380,000	345,000	380,000	370,000	370,000
United States of America [p]	14,879,000	15,869,000	17,516,000	18,559,000	19,382,000	19,835,000	10,199,000	10,791,000	11,892,000	12,681,000	13,118,000	13,579,000
TOTAL	33,000,000	35,000,000	r39,000,000	r42,000,000	45,000,000	47,000,000						
WORLD'S TOTAL	35,000,000	37,000,000	r41,000,000	r45,000,000	47,000,000	50,000,000						

SOURCE: United Kingdom, Overseas Geological Survey, *Statistical Summary of the Mineral Industry* (London, 1965), pp. 296-297.

Note: Phosphate rock is also known to have been produced in North Korea.

[a] Including apatite.

[b] Exports.

[c] In addition, the following amounts of phosphate dust were exported (long tons): 1958, n.a.; 1959, 68,733; 1960, n.a.; 1961, 76,438; 1962, 79,527; 1963, 80,552.

[d] Phosphatic guano.

[e] Bat guano.

[f] Apatite.

[g] Including phosphatic chalk.

[h] Estimate of United States Bureau of Mines.

[i] Apatite.

[j] Estimated.

[k] Exports.

[l] Phosphatic guano.

[m] Including apatite and aluminium phosphates.

[n] Sales to farmers. Year ended June 30 of that stated.

[o] Estimate of United States Bureau of Mines.

[p] Marketable production.

2. *Phosphate rock and apatite*

Fortunately for agriculture, the earth is well endowed with deposits of phosphate rock, as is shown in table 59 above.

The larger deposits are indirectly or directly of sedimentary origin, having been laid down in ocean-beds and subsequently elevated. The phosphate often is in the form of small pellets, which are cemented together by calcium carbonate. The cementing material has weathered away, leaving loose pellets in some deposits. In others, the whole mass has been compressed to form hard rock.

Frequently, phosphate minerals are associated with clay, limestone or silica sand and, to a lesser extent, with other impurities. Where the quality of the phosphate can be improved without too much expense, mining of the phosphate may be accompanied by a beneficiation operation. Clay is frequently washed from the coarser phosphate particles to obtain phosphate of higher quality. Flotation is used to beneficiate phosphate from some deposits, such as those in Florida (United States of America). The world production of phosphate rock is shown in table 60 above.

Apatite is the predominant phosphate mineral comprising the large and important deposits of the world. In these deposits, the fine-grained crystalline apatite is known as francolite, which includes compositions represented by the formula $Ca_5(PO_4)_3(F, Cl, OH)$. Carbonate is sometimes found as an additional component of such apatite. Table 61 gives the total and the citrate-soluble phosphorus content of typical mineral phosphate materials from various deposits throughout the world. Table 62 shows the composition of similar materials.

TABLE 61. TOTAL AND CITRATE-SOLUBLE PHOSPHORUS CONTENTS OF PHOSPHATE ROCK OF VARIOUS ORIGINS

Type and source of phosphate rock	*Total P_2O_5 (percentage)*	*Citrate-soluble P_2O_5 (percentage of total P_2O_5)*
Christmas Island	40.0	13
Curacao Island	40.7	14
Gafsa	29.2	18
Mexico	31.3	40
Morocco	33.1	15
Nauru Island	38.9	10
Togo	36.9	7
United States of America		
Florida waste pond, Dunnellon	23.6	9
Florida hard rock, Dunnellon	36.0	8
Florida land pebble, Mulberry	35.4	9
Idaho, Conda	32.4	7
Montana, Garrison	36.4	5
South Carolina land rock	26.9	17
Tennessee brown rock, Mt. Pleasant	34.4	6
Tennessee blue rock, Gordonsburg	31.0	5
Wyoming, Cokeville	30.2	6

SOURCES: For Gafsa, Mexico, Morocco and Togo: United States of America, Tennessee Valley Authority, unpublished data. For the remainder of the types and sources listed: B. E. Brown and K. D. Jacob, *American Fertilizer*, vol. 102, pp. 11-12, 28, 30.

TABLE 62. COMPOSITION OF PHOSPHATE ROCK OF VARIOUS ORIGINS

Type and source of phosphate rock	*Chemical analysis (percentage)*					
	P_2O_5	*CaO*	*Fe_2O_3*	*Al_2O_3*	*Acid insoluble (SiO_2)*	*F*
Aruba	24.9	23.5	12.9	7.9	17.3	0.9
Brazil	32.9	44.3	6.1	—	5.9	—
Kola	38.2	51.4	0.1	0.8	1.8	3.3
Mexico	31.3	34.8	1.8	—	20.0	0.2
Morocco	32.8	51.9	0.2	0.4	2.3	4.2
Nauru Island	38.9	54.4	—	0.3	0.2	2.6
Palabora	34.4	52.2	0.7	0.3	—	2.2
Taibi	36.7	52.0	0.9	1.2	1.9	4.0
Togoland	36.1	51.4	0.6	1.2	3.1	3.4
Tunisia	27.5	45.9	0.6	1.4	7.8	3.5
United States						
Tennessee matrix	25.3	36.0	2.8	5.6	25.3	2.5
North Carolina	30.7	49.1	0.7	0.5	3.4	3.7
Idaho	29.2	41.8	1.6	2.7	14.6	3.1
Florida pebble	32.0	47.4	2.1	1.0	8.2	3.9
Florida leached zone	20.0	21.2	3.1	9.0	44.8	1.4
California beach-sand	31.2	46.9	1.4	0.8	2.7	—
Oklahoma	27.7	39.0	1.6	2.3	16.0	3.0
Montana	29.7	46.5	0.9	1.3	12.2	3.1

SOURCES: For Aruba, Brazil, Mexico, Morocco and the United States of America: Tennessee Valley Authority, unpublished data. For Nauru Island and Tunisia: United States of America, Department of Agriculture, Technical Bulletin No. 364 (Washington, D.C.), p. 23. For Kola, Palabora, Taibi and Togo: S. M. Janikowski N. Robinson and W. F. Sheldrick, *Insoluble Phosphate Losses in Phosphoric Acid Manufactured by the Wet-Process: Theory and Experimental Techniques* (London, The Fertiliser Society).

The rock for direct application to the soil usually is concentrated by washing or flotation. It is then dried and finely ground. The P_2O_5 content of phosphate rock varies considerably, as does the availability of the contained phosphorus. There is essentially no water-soluble phosphorus in phosphate rock. There is a correlation between the relative yield of crops and the fraction of the total phosphorus that is citrate soluble. The influence of raw phosphate rock on crop yields has been studied in thousands of experiments, but it is not possible within the scope of this text to consider individually the data obtained. Only a few general statements concerning the effectiveness of raw rock as a source of fertilizer phosphorus are feasible.

On acid soils that are low in phosphorus, raw phosphate rock may be profitably used, but superphosphate generally is more economical. In some tests, phosphate rock produced greater yields than superphosphate, but only when the rock supplied two to three times as much phosphorus as was furnished by the superphosphate.

Phosphate rock should not be used directly on short-season row crops. It should be considered only for use in large amounts and under crop rotations, which include such crops as red clover, which are strong feeders on phosphate rock. A programme of this type has been used successfully in Illinois (United States of America). When such a programme is initiated on soil low in phosphorus, soluble phosphates are needed for the first several years, in addition to the rock, to provide the crops with readily available phosphorus.

In cases where raw rock is an effective fertilizer, its choice should be based on an economic comparison with more available forms of phosphorus.

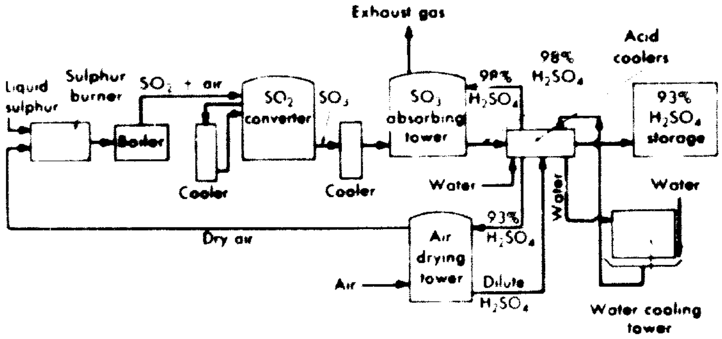
The amounts of ground phosphate rock used throughout the world for direct application are shown in table 63.

3. *Sulphuric acid*

Roughly half of the sulphuric acid used in the production of wet-process phosphoric acid is made from elemental sulphur. Large quantities of by-product and spent sulphuric acid from smelting operations and oil refineries are also used.

A wet-process phosphoric acid plant with a daily capacity of 150 tons of P_2O_5 as acid of 54 per cent P_2O_5 content requires 435 tons of 66° Baumé sulphuric acid per day. An investment of about $1,750,000 is required in the United States of America for a contact sulphuric acid plant of this capacity. Figure 38 gives a diagram of a contact sulphuric acid plant. The plant would include storage for 3,000 tons of molten sulphur, storage for 4,000 tons of acid, water-treatment facilities and a steam-boiler.

Figure 38. Flow sheet of contact sulphuric acid plant



Elemental sulphur, which is shipped either in molten or lump form, is burned with air, and the resulting sulphur dioxide is converted into sulphuric acid of 93 per cent H_2SO_4 content. An operator, an assistant operator and a part-time labourer for eight hours are required to operate the plant. The following materials and utilities are required to produce a ton of sulphuric acid (100 per cent H_2SO_4 equivalent):

Sulphur (ton)	0.344
Cooling water (tons) [a]	28
Electricity (kWh)	12
Labour (man-hour)	0.15
Boiler feed-water (ton)	0.75
Maintenance (dollar)	0.75

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[a] Value could be reduced greatly by use of a cooling tower.

By-product steam is generated at a rate of about 1 ton per ton of acid (100 per cent H_2SO_4 equivalent) from the combustion of the sulphur.

TABLE 63. GROUND PHOSPHATE ROCK USED FOR DIRECT APPLICATION IN EACH CONTINENT, 1956/1957 - 1961/1962

(Thousands of tons of P_2O_5)

Continent	*1956/1957*	*1957/1958*	*1958/1959*	*1959/1960*	*1960/1961*	*1961/1962*
Europe	145	171	179	257	256	356
USSR [a]	163	202	208	242	264	306
North and Central America	253	253	252	204	190	180
South America	17	24	32	49	46	44
Asia	35	39	44	51	75	79
Africa	36	28	54	57	57	60
Oceania	—	—	2	1	—	—
WORLD TOTAL	650	720	770	860	890	1,020

SOURCE: Food and Agriculture Organization of the United Nations, *Fertilizers: An Annual Review of Production, Consumption and Trade, 1962* (Rome, 1963).

[a] Calendar year referring to the first part of the split year.

C. INTERMEDIATES: PHOSPHORIC ACIDS AND SUPERPHOSPHORIC ACID

1. *General information*

The importance of phosphoric acid to the fertilizer industry has greatly increased in recent years. Some acid is applied directly to the soil by way of irrigation water, but its main uses in the fertilizer industry are in the production of triple superphosphate and combination fertilizers, including ammonium phosphates and liquid fertilizers.

As mentioned previously, there are two basic methods in commercial use for the production of phosphoric acid — the wet process and the furnace process. Wet-process acid has a more important role in the fertilizer industry than furnace acid. During the last decade, the production of wet-process acid has increased more rapidly than that of the furnace acid. In the United States of America, in 1963/1964, production of wet-process acid was about 116 per cent greater than that of furnace acid. Information on world production of phosphoric acid is not available, but production in the United States is shown in table 64.

As discussed later, impure wet-process acid which is suitable for use in solid fertilizers can be manufactured in most locations more cheaply than furnace acid. The more expensive furnace acid of higher purity is used extensively in the production of detergents and other products which are more costly than fertilizers. However, the producers of furnace acid in the United States of America have found it profitable to increase plant capacity above that required for the higher priced outlets and to sell some furnace acid at a lower price for use in fertilizers. The higher purity of furnace acid is advantageous in the production of liquid fertilizers, and such fertilizers are produced mainly from furnace acid. In 1963, 19 per cent of the electric-furnace phosphorus produced in the United States was used for fertilizer purposes. By contrast, 90 per cent of the wet-process acid produced in the United States in 1963 was used in fertilizers. Table 65 gives the analyses of typical samples of wet-process and furnace acids.

Wet-process acid requires phosphate rock and sulphuric acid; whereas furnace acid requires phosphate rock, silica pebble, coke or coal and electric power.

2. *Wet-process phosphoric acid*

Much of the wet-process acid is produced and used at sites where triple superphosphate is manufactured. However, in recent years, wet-process phosphoric acid has become more of an article of commerce. The quality of the acid has been improved so that its handling and shipment are less difficult. The crude acid, which is saturated with impurities, is aged and settled, often with the aid of settling agents. Decantation is employed to clarify the acid for shipment. In some cases, the organic content of the acid is reduced by calcination of the phosphate rock prior to its acidulation.

(a) *Process description*

Wet-process phosphoric acid is made by reacting sulphuric acid with finely ground phosphate rock (90 per cent, -100 mesh; 60 per cent, -200 mesh) of about 68 bone phosphate of lime (31.1 per cent P_2O_5). Florida

TABLE 64. PRODUCTION OF PHOSPHORIC ACID IN THE UNITED STATES OF AMERICA, 1951 - 1963/1964

(Tons of P_2O_5)

	1951	*1960/1961*	*1961/1962*	*1962/1963*	*1963/1964*
Furnace acid	299,456	726,730	769,680	810,270	881,460
Fertilizer use	...	...	...	...	165,240
Other uses	...	...	...	...	716,220
Wet-process acid	307,013	1,257,030	1,305,000	1,563,030	1,902,870
Fertilizer use	...	...	...	...	1,731,870
Other uses	...	...	...	...	171,000
TOTAL	606,469	1,983,760	2,074,680	2,373,300	2,784,330

SOURCE: *Phosphorus and Potassium*, October 1964, p. 22.

TABLE 65. ANALYSES OF PHOSPHORIC ACIDS

	Wet-process acid produced from Florida rock			
Analysis	*Filter acid*	*Unclarified concentrated acid*	*Clarified concentrated acid*	*Unpurified furnace acid*
	(Percentage)			
P_2O_5	30.2	53.5	53.8	54.0
H_3PO_4 equivalent	41.7	73.9	74.3	74.6
CaO	0.1	0.6	0.1	0.0003
Fe_2O_3	1.1	2.3	1.4	0.0007
Al_2O_3	1.9	2.3	0.8	0.001
SO_3	3.1	3.3	2.6	0.003
F	2.0	1.4	0.5	0.007
Solids	—	4.0	1.9	—

rock of the following analysis is typical of that used widely for the production of acid:

	Percentage
P_2O_5	31.0 to 31.5
CaO	46.2 to 47.9
Fe_2O_3	1.4 to 2.2
Al_2O_3	0.8 to 1.8
CO_2	3.0 to 4.0
SO_3	0.5 to 0.9
SiO_2	7.4 to 10.7
F	3.4 to 4.0
Organic matter	0.4 to 0.6

Dilute phosphoric acid and precipitated calcium sulphate are formed. The latter material is filtered from the acid. Individual installations for the production of wet-process acid vary considerably in the number and design of the reaction tanks and the types of filters used. Also, calcium sulphate is crystallized in three forms — an anhydrite ($CaSO_4$); the hemi-hydrate ($CaSO_4.1/2H_2O$); or the dihydrate ($CaSO_4.2H_2O$). The form of the calcium sulphate depends on the temperature and concentration involved. The dihydrate process is one of the most popular, and it is described below. The reaction may be represented by the equation:

$$\underset{\text{(Fluorapatite)}}{Ca_5(PO_4)_3F} + \underset{\text{(Sulphuric acid)}}{5H_2SO_4} + 10H_2O =$$

$$\underset{\text{(Gypsum)}}{5[CaSO_4.2H_2O]} + \underset{\text{(Hydrofluoric acid)}}{HF} + \underset{\text{(Phosphoric acid)}}{3H_3PO_4}$$

The acid of 30 per cent P_2O_5 content from the filter or from a settling tank usually is concentrated to 54 per cent P_2O_5 content in vacuum evaporators at a temperature of about 90° C. The forced-convection type of evaporators with Karbate tubes and a rubber-lined flash chamber are generally used.

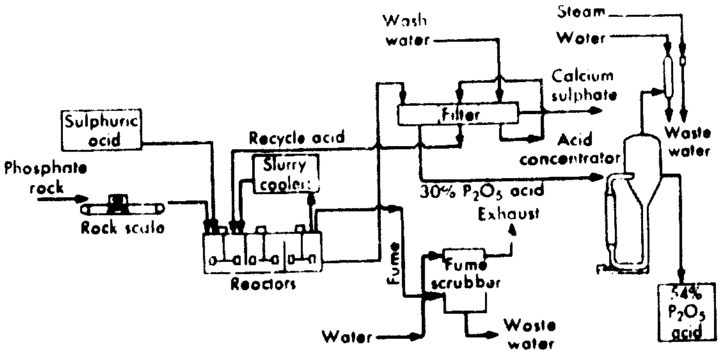
The amount of by-product gypsum from the filter, containing 25 per cent moisture, is 5.5 tons per ton of P_2O_5 produced. This material can be removed dry from the filter and conveyed to a waste pile or discharged wet as a slurry and pumped to a waste pond. The water can be separated, cooled and reused.

The gypsum usually is discarded in the mined-out areas at the phosphate mine. In other places, disposal of the material often becomes a problem. Frequently, it is pumped to waste ponds which are formed by dikes made of gypsum. There are also instances where the material is dissolved in large rivers and in the ocean. In locations where mineral gypsum is not available cheaply, the by-product gypsum may be dried and used as a filler in fertilizers or applied directly as a soil supplement. By-product gypsum also is used in cement and for production of plaster-board.

Fluoride gases evolved in the reactors and the evaporators are exhausted to water scrubbers for removal.

A simplified flow sheet of the basic process for the production of wet-process acid is given in figure 39, with the four main steps in the process outlined below.

Figure 39. Flow sheet of wet-process phosphoric acid plant



(*a*) The reaction of finely ground phosphate rock and sulphuric acid to form phosphoric acid and calcium sulphate (gypsum);

(*b*) Separation of the calcium sulphate from the acid by filtration;

(*c*) Washing the calcium sulphate to remove residual phosphoric acid;

(*d*) Concentration of the acid by heating in an evaporator.

Dilute acid is recycled to the extraction step to help prevent unreacted rock from becoming coated with calcium sulphate, and to ensure crystallization of the calcium sulphate as large crystals that will filter well. Counter-current washing is employed to recover as much acid as possible from the gypsum without excessive dilution of the acid with the wash water.

Concentration of the acid is performed either by direct contact with combustion gases in submerged combustion equipment or by steam in a vacuum evaporator.

(*b*) *Economic data*

A wet-process phosphoric acid plant to produce acid equivalent to 150 tons of P_2O_5 daily costs about $4 million in the United States of America, exclusive of the units for grinding rock and for the production of sulphuric acid, which, as described, would add about $2.5 million more.

The following tabulation gives the material, labour and utility requirements per ton of P_2O_5 for the production of wet-process acid of 54 per cent P_2O_5 content, which is the concentration commonly made:

Phosphate rock (tons)	3.4
Sulphuric acid (tons H_2SO_4)	2.7
Electricity (kWh)	150
Water (tons)	130
Steam, 7 kg/sq cm (ton)	0.2
Steam, 1.5 kg/sq cm (tons)	2.5
Maintenance labour (man-hour)	0.32
Maintenance materials (dollars)	2.50
General supplies (dollars)	0.75
Supervisor (man-hour)	0.05
Foreman (man-hour)	0.16
Operators (man-hour)	0.48
Shift chemist (man-hour)	0.16
Labourers (man-hour)	0.32

(*c*) *Extraction by hydrochloric acid*

A few large pilot plants or small industrial phosphoric acid plants in several countries are based on the use of hydrochloric acid instead of sulphuric acid. The phosphoric acid is separated from the calcium chloride by means of an organic solvent. The solvent is separated from the acid and recycled to the process. The process was developed by Israel Mining Industries and is being studied by several other companies.

The use of a solvent provides acid of higher purity than is obtained directly by standard wet-process methods.

Typical analyses of technical and food-grade phosphoric acids made by this process are given below:

Technical-grade phosphoric acid	*Percentage*
H_3PO_4	95
Fe	0.03
Zn	0.09
As	0.005
V	0.004
Cu	0.009
Cr	0.007

Food-grade phosphoric acid	*Percentage*
H_3PO_4	95
Cl, max.	0.001
Heavy metals as Pb, max.	0.002
Fe, max.	0.002
As	0.0001

SOURCE: Data supplied by Y. Araten, Director, New Fertilizers Division, Israel Mining Industries.

For the production of 1 ton of P_2O_5 in the form of H_3PO_4, 95 per cent, the following are required:

Phosphate rock, 34% P_2O_5	3.0 ton
HCl (calculated as 100%)	2.0 ton
Solvent make-up	4 kg
Steam	4.7 ton
Power	230 kWh
Water for process	7.5 m^3
Water for cooling	150 m^3

SOURCE: Data supplied by Y. Araten, Director, New Fertilizers Division, Israel Mining Industries.

3. *Furnace phosphoric acid*

(a) *Process description*

The first step in the production of furnace acid is to produce elemental phosphorus in an electric furnace. Phosphate nodules or other lump phosphate material, silica pebble, and coke or coal are mixed and fed to the furnace. The electric current which enters the furnace through carbon or graphite electrodes fuses the rock and silica, and the carbon in the coke or coal reduces the phosphate. A mixture of phosphorus vapour and carbon monoxide gas is withdrawn continuously from the furnace. The phosphorus is condensed to a liquid, which is converted into phosphoric acid in a separate plant, often located far from the phosphorus plant. Molten calcium silicate slag and an iron-phosphorus compound known as ferrophosphorus are tapped from the furnace periodically.

(b) *Economic data*

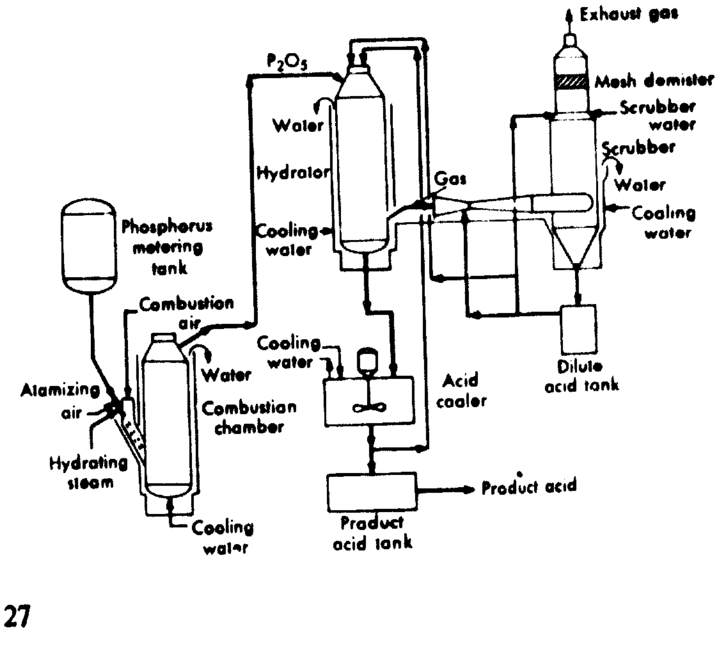
A modern phosphorus plant of a size to be economically attractive in the United States of America usually contains two or more 20,000 to 50,000-kilowatt furnaces and costs upwards of $10 million. Two 20,000-kilowatt furnaces have a capacity of about 72 tons of elemental phosphorus per day, which is equivalent to 165 tons of P_2O_5 per day. The plants are ordinarily located where low-cost hydroelectric power is available. Seasonal and off-peak power may be used advantageously. Operation of the furnace requires about 6,000 kilowatt hours of electricity per ton of P_2O_5 as phosphorus produced. In addition to electricity, the following quantities of materials and labour are required per ton of P_2O_5:

Phosphate nodules (tons)	1.78
Coke (ton)	0.60
Silica pebble (ton)	0.66
Carbon electrodes (kg)	7.70
Steam (thousand kg)	0.97
Cooling water (tons)[a]	34
Supervisor (man-hour)	0.05
Operating labour (man-hour)	0.96
Foreman (man-hour)	0.16
Shift chemist (man-hour)	0.16
Labourers (man-hour)	0.32
Repairs and maintenance	
Labour (man-hour)	1.20
Materials (dollars)	3.27
Supplies (dollars)	1.32

[a] Value could be reduced greatly by use of a cooling tower.

The investment in a phosphoric acid plant to convert phosphorus into acid is much less than that required for the plant to produce the phosphorus. The investment involved in a modern phosphoric acid plant capable of burning 2,720 kilogrammes of phosphorus per hour (equivalent to 150 tons of P_2O_5 per day) is about $1 million in the United States of America. Modern plants are built of stainless steel. A flow sheet of such a plant is shown in figure 40. Liquid phosphorus is pumped to a water-cooled, stainless-steel combustion chamber and burned with air. The gases from the combustion chamber enter the hydrator, where the phosphorus pentoxide vapour is hydrated to phosphoric acid. The phosphoric acid is then collected from the gas stream, cooled and pumped to storage. The raw material, labour and other operating

Figure 40. Flow sheet of furnace phosphoric acid plant



requirements per metric ton of P_2O_5 for the production of acid of three concentrations in this plant are as follows:

Acid concentration (percentage)			
P_2O_5	63.0	76.0	83.3
H_3PO_4 equivalent	87.0	105	115
Phosphorus burning-rate (kg/hr)	2,720	1,815	1,585
Cooling-water (20° C) (tons) [a]	75	75	75
Water to process (ton)	0.80	0.44	0.33
Electricity (kWh)	65	83	90
Compressed air (cu m)	50	75	88
Steam (kg)	15	12	10
Labour (man-hour)			
Foreman	0.05	0.05	0.06
Operator	0.14	0.21	0.24
Maintenance	0.08	0.12	0.13
Maintenance materials (dollars)	0.05	0.07	0.07

[a] Value could be reduced greatly by use of a cooling tower.

The world shortage of sulphur and the development of low-cost nuclear and hydroelectric power may result in greater use of the furnace method for fertilizer production.

4. *Superphosphoric acid*

(a) *Furnace method*

Storage, handling and transportation costs are impelling factors in the trend towards fertilizer materials of higher analysis. A comparatively recent new comer to the list of highly concentrated materials is superphosphoric acid. In research work done by the Tennessee Valley Authority (TVA), it was found that phosphoric acid containing 76 per cent P_2O_5, equivalent to 105 per cent H_3PO_4, was a liquid at room temperature and could be produced from elemental phosphorus at essentially the same cost per unit of P_2O_5 as the ordinary furnace, 75 per cent H_3PO_4 described previously.

The following tabulation shows the difference between furnace acids of ordinary and superphosphoric concentrations:

	Ordinary acid	*Superphosphoric acid*
Acid concentration (percentage of P_2O_5)	54	76
H_3PO_4 equivalent (percentage)	75	105
Lb P_2O_5/gal	7.1	12.2
Percentage of P_2O_5, as poly acids	0	51
Viscosity (centipoises)		
At 40° C	12	400
At 100° C	4	45
Corrosion rate (mils/yr)		
Mild steel at room temperature	523	230
Type 316 stainless steel at 110° C	5	0.5

The superphosphoric acid contains 70 per cent more P_2O_5 per gallon than ordinary acid, and it is less corrosive; on the other hand, it is more viscous than ordinary acid, and crystals form in it at a higher temperature. Superphosphoric acid is liquid at room temperature and will remain so in storage at much lower temperatures because of its strong tendency to supercool. Usually, crystals do not appear unless the bulk of the acid cools below about 5° C. The crystals dissolve when the acid is heated above 16° C, which is the melting-point of the crystals. When the acid is to be stored for several weeks or longer in freezing weather, indoor or heated tanks are desirable. Where the acid is to be shipped in extremely cold weather, the best procedure is to load the acid while still hot into insulated stainless-steel tank cars. The rate of cooling of the acid is so slow that delivery can be effected before the acid has cooled sufficiently to crystallize. Large savings in freight and other transportation costs are possible with this type of acid.

Aside from its much higher P_2O_5 content and the savings in the handling, storage and shipping costs that result, superphosphoric acid contains about 50 per cent of its P_2O_5 in the form of polyphosphoric acids, whereas acid of ordinary concentration is essentially all orthophosphoric acid. The polyphosphoric acids are proving to be advantageous in the production of fertilizers of higher analysis, particularly liquid fertilizers.

(b) *Wet method*

A material somewhat analogous to furnace superphosphoric acid (table 66) is being produced from ordinary wet process acid of 54 per cent P_2O_5 content in evaporators similar to those used in the initial concentration of wet-process acid. This product contains about 71 per cent P_2O_5, equivalent to 98 per cent H_3PO_4. As in the case of the furnace superphosphoric acid, roughly half of the P_2O_5 is in the desirable form of polyphosphoric acids. Research by the Tennessee Valley Authority has shown that in concentrating the acid to this extent, some of the precipitated impurities are dissolved as a result of the sequestering action of the polyphosphoric acids, and acid of improved quality is obtained.

TABLE 66. ANALYSIS OF HIGHLY CONCENTRATED WET-PROCESS PHOSPHORIC ACID [a]

Analysis	*Percentage*
P_2O_5	70.8
H_3PO_4 equivalent	97.8
Percentage of P_2O_5 as polyphosphoric acids	45.3
Fe_2O_3	1.8
Al_2O_3	1.7
SO_3	3.7
F	0.2

[a] Wet-process acid produced from Florida rock.

A cost of about $1 million has been estimated for a plant to concentrate wet-process acid of 54 per cent P_2O_5 content at a rate of 150 tons of P_2O_5 daily to acid of 70 per cent P_2O_5 content. In the following tabulation the requirements per ton of P_2O_5 for production of the more concentrated wet-process acid are given:

Operating labour (man-hour)	0.48
Water (tons)	50
Natural gas (cu m)	85
Electricity (kWh)	33
Supplies (dollars)	0.17
Maintenance (dollars)	1.15
Chemical analyses (dollars)	0.15

The concentrated wet-process acid is now being produced by several companies in vacuum and atmospheric evaporators. There is a great deal of interest in its use in the production of liquid fertilizer and in granular solid fertilizer.

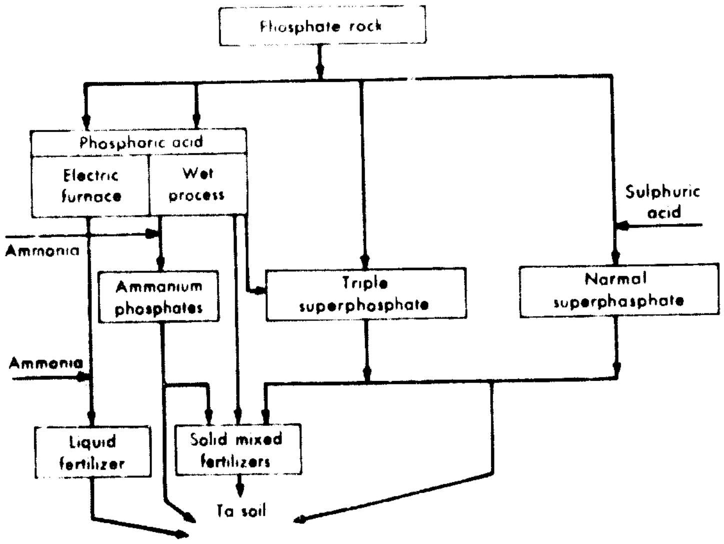
D. PHOSPHATE FERTILIZERS

1. *General information*

The phosphate industry is currently producing annually about 50 million tons of phosphate rock [2] and phosphate fertilizers containing approximately 15.6 million tons of P_2O_5.

World consumption of basic slag, a by-product of the iron and steel industry, is equivalent to about 1.4 million tons of P_2O_5 per annum; 85 per cent of world consumption is in western Europe, and 75 per cent is consumed in the producing countries.

The principal ways of converting the apatite structure of phosphate rock to forms that can be utilized more fully in plant nutrition are shown in the following diagram:



For many years, normal superphosphate held the dominant position as a phosphate fertilizer in the United States of America. Since about 1930, the proportion of triple superphosphate has grown, and the proportion of normal superphosphate has declined. Since 1957, ammonium phosphate has been gaining at the expense of superphosphate (table 67).

TABLE 67. PROPORTIONS OF TOTAL P_2O_5 USED IN THE UNITED STATES OF AMERICA AS NORMAL SUPERPHOSPHATE, CONCENTRATED AND TRIPLE SUPERPHOSPHATE AND AMMONIUM PHOSPHATE, 1930-1962

Year	*Normal superphosphate*	*Concentrated and triple superphosphate*	*Ammonium phosphate*
1930	88	5	1
1940	78	17	2
1950	77	14	3
1955	67	21	4
1956	64	27	4
1957	59	29	7
1958	53	28	8
1959	51	28	8
1960	47	29	10
1961	45	28	10
1962	41	31	12

According to the Bureau of the Census, production in the United States for the years 1963 and 1964, was as follows (in millions of tons):

Year	*Normal and enriched superphosphate*	*Concentrated superphosphate*	*Ammonium phosphate and others*
1963	1.2	1.0	0.95
1964	1.1	1.2	1.4

With regard to total world production, the relative proportions of the different kinds of phosphate fertilizers were as follows:

TABLE 68. PROPORTIONS OF TOTAL P_2O_5 PRODUCED AS VARIOUS TYPES OF PHOSPHATE FERTILIZERS, 1953/1954 - 1959/1960 [a]

Year	*Normal superphosphate*	*Concentrated superphosphate*	*Basic slag*	*Others*
1953/1954	66	9	14	11
1954/1955	63	12	15	10
1955/1956	62	12	16	10
1956/1957	58	11	17	14
1957/1958	54	14	16	16
1958/1959	53	14	15	18
1959/1960	51	14	16	19

SOURCE: United States of America Department of Agriculture and Tennessee Valley Authority, *Superphosphate* (Washington, D. C., 1964), pp. 315, 316.

[a] Total world production.

These data show a trend away from superphosphate in the past few years, on a world-wide basis.

2. *Production of normal superphosphate*

(a) *Definition of superphosphates*

The name "superphosphate" applies to fertilizer obtained by treating finely ground phosphate rock with sulphuric acid, phosphoric acid, or a mixture of the two. The product made with sulphuric acid usually contains 16 to 21 per cent of the available P_2O_5, and it is referred to as "ordinary" or "normal" superphosphate, or simply "superphosphate". The product made with phosphoric acid usually contains 43 to 48 per cent of the available P_2O_5 and is referred to as "concentrated" or "triple" superphosphate.

In this section, the acidulation of phosphate rock with sulphuric acid to produce normal superphosphate is described. The production of phosphoric acid and its use in the production of triple superphosphate are described in other sections. The grinding of phosphate rock and the production of sulphuric acid also are described in other sections.

(b) *Use of normal superphosphate*

Normal superphosphate is produced in larger quantities than any other phosphate fertilizer. Of the approximately 11 million metric tons of fertilizer P_2O_5 produced in 1963/1964, 46.3 per cent was in the form of normal superphosphate. Triple superphosphate was second, with

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[2] *Phosphorus and Potassium*, vol. 15, No. 2 (1965), p. 1.

14.3 per cent, and basic slag was third, with 12.9 per cent. Large proportions of the superphosphates are further processed into combination and mixed fertilizers.

(c) *Process description*

The production of normal superphosphate is basically a simple operation, which largely accounts for the continued popularity of this fertilizer. The only ingredients required are ground phosphate rock and sulphuric acid, which has been produced in large quantities for many years. The main chemical reaction that occurs when finely ground phosphate rock is mixed with sulphuric acid in the manufacture of normal superphosphate may be represented by the following equation:

$$\begin{array}{ccccc} 2Ca_5(PO_4)_3F & + & 7H_2SO_4 & + & 3H_2O \rightarrow \\ \text{(Fluorapatite)} & & \text{(Sulphuric acid)} & & \end{array}$$

$$\begin{array}{ccccc} 3[CaH_4(PO_4)_2 . H_2O] & + & 7CaSO_4 & + & 2HF \\ \text{(Monocalcium phosphate)} & & \text{(Calcium sulphate)} & & \text{(Hydrofluoric acid)} \end{array}$$

The phosphate originally present as apatite in the rock is converted to water-soluble monocalcium phosphate. Calcium sulphate also is formed and is intermixed with the monocalcium phosphate. The reaction releases toxic fluorine compounds, which, in populated areas, often are recovered for their value and to prevent a health hazard. Table 69 below gives a typical analysis of normal superphosphate made from Florida phosphate rock.

For many years, the only method of making normal superphosphate was to mix batches of phosphate rock and sulphuric acid. More recently, continuous methods have been developed, in which a stream of finely ground phosphate rock is reacted with a stream of sulphuric acid. Figure 41 is a diagram of a batch method of producing normal superphosphate. Figure 42 is a diagram of a continuous method of producing normal superphosphate, which involves the use of a cone mixer. The popularity of continuous methods is now increasing rapidly.

Figure 41. Diagram of batch manufacture of normal superphosphate

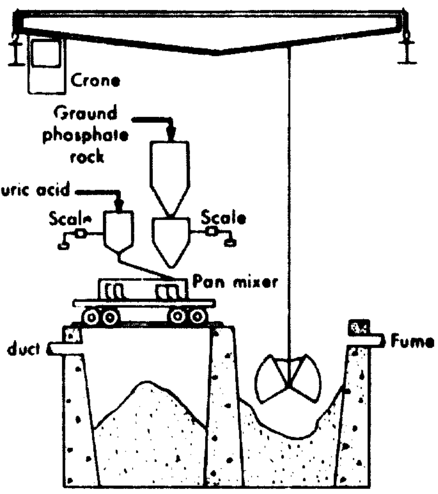
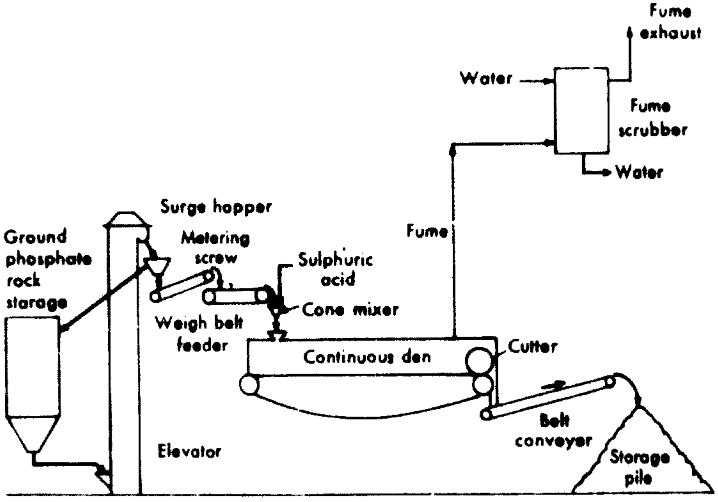


TABLE 69. COMPOSITION OF NORMAL SUPERPHOSPHATE MADE FROM FLORIDA PHOSPHATE ROCK

Analysis	*Percentage*
Total P_2O_5	21.5
Available P_2O_5	20.7
Water-soluble P_2O_5	17.4
CaO	30.5
SO_3	30.7
Al_2O_3	1.2
Fe_2O_3	0.6
F	1.6

Figure 42. Flow sheet of continuous manufacture of normal superphosphate



The manufacture of superphosphate involves the following three operations:

(*a*) Mixing finely ground phosphate rock (90 per cent, -100 mesh) with sulphuric acid. With rock of 34 per cent P_2O_5 content, about 0.58 kilogramme of H_2SO_4 (100 per cent basis) is required per kilogramme of rock. Sulphuric acid normally is available in two concentrations — 66° Baumé (93 per cent H_2SO_4) or 60° Baumé (77 per cent H_2SO_4). The acid usually is diluted to about 75 per cent H_2SO_4 prior to mixing with the rock or, in the case of the cone mixer, the water is added separately to the mixer;

(*b*) Curing and drying of the acidulated material in a den. Superphosphate excavated from the den within one to four hours has a temperature above 100° C. The reaction has not reached completion. Therefore, the material still contains free acid and unreacted rock. The amount of available P_2O_5 will increase with additional ageing;

(*c*) The product is removed from the den and conveyed to storage piles for final curing, which requires from two to six weeks, depending on the nature and proportions of the raw materials and the conditions of manufacture. In large modern plants, a crane with a grab-bucket is employed to remove the superphosphate from storage. The product from the crane is fed to a disintegrator, usually of the hammer-mill or cage-mill type. The product from the mill is discharged onto an inclined screen of about 6-mesh size. The material that fails to pass the screen is returned to the mill for further grinding.

(d) *Economic data*

The production of a ton of normal superphosphate of 20 per cent available P_2O_5 content would require 626 kilogrammes of ground phosphate rock (34 per cent P_2O_5), 390 kilogrammes of sulphuric acid (93 per cent H_2SO_4), and 90 kilogrammes of water. The reaction generates considerable heat. Approximately 8 to 10 per cent of the weight of the ingredients (water vapour and volatiles) is lost in the manufacturing and curing steps.

A typical cone-mixer plant to produce 20 tons of normal superphosphate per hour would have an 80-horsepower electrical load. One operator, two labourers and a part-time supervisor (eight hours per day) would be required to operate the plant. The investment for such a plant varies widely, depending on many factors; a value for a plant with minimum facilities in the United States of America would be about $150,000, not including services, storage facilities and rock-grinding equipment. The plant would utilize ground rock and acid directly from railroad cars. A plant with rock-grinding equipment and provisions for storage of raw materials and product would cost roughly $750,000.

By applying prevailing unit costs, a rough approximation of the direct cost of producing normal superphosphate in a specific location can be obtained. The operating requirements per ton of normal superphosphate are:

Phosphate rock (ton)	0.626
63° Baumé sulphuric acid, 93 per cent H_2SO_4 (ton)	0.390
Water (ton)	0.1
Electricity (kWh)	3
Operating labour (man-hour)	0.15
Supervision (man-hour)	0.017
Maintenance and supplies (dollar)	0.50

There are a great many different makes and designs of mixers used throughout the world for the production of normal superphosphate. Regardless of the mixing process employed, however, the manufacture of superphosphate is still a relatively simple operation. The product is a good fertilizer material which contains in addition to water-soluble monocalcium phosphate, large amounts of calcium and sulphur. These diluents result in the relatively low P_2O_5 content of the product, which is the lowest of any of the major sources of phosphate fertilizer. Therefore, normal superphosphate ordinarily is produced and used in the same location to avoid the high cost involved in transporting material of low analysis.

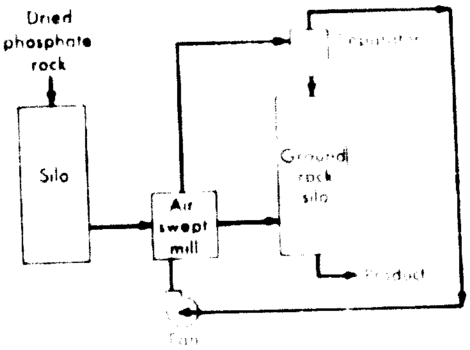
3. *Grinding phosphate rock*

Phosphate rock used for fertilizer manufacture or for direct application must be ground to the proper particle size. The grinding may be done at the mining site or near the point of use.

Figure 43 is a diagram of grinding facilities. Dried Florida pebble rock (1 to 3 per cent moisture) of minus 3/4-inch size and 68 to 77 bone phosphate of lime is used widely. The rock usually is ground to the following Tyler mesh size for acidulation:

(*a*) +100, 10 per cent;
(*b*) −100, 90 per cent;
(*c*) −200, 60 per cent.

Figure 43. Flow sheet of phosphate rock-grinding equipment



It is received by ship or rail and is unloaded and stored in a weather-protected building or silo. A conveying system transfers the rock from storage to the mill-feeder, which regulates flow of rock to the mill. The mill is of an air-swept type and usually is either a roller mill or ball mill. When the rock is ground to the desired size, it is carried out by the air stream to a centrifugal separator. The product is discharged to a storage silo. Air from the separator returns to the mill fan and is recirculated to the mill.

A plant to grind about 50 tons per hour costs about $750,000 in the United States of America. A well-operated plant should produce, at rated capacity, 330 days annually. It requires an operator and an assistant operator. The following utilities, labour and supplies are required per ton of rock:

Electricity (kWh)	13
Labour (man-hour)	0.04
Maintenance and supplies (dollar)	0.035

4. *Production of triple superphosphate*

(a) *General information*

Triple superphosphate was produced commercially early in the history of the phosphate fertilizer industry. However, it did not become an important material until after 1930. In 1930, it accounted for only 5 per cent of the phosphate fertilizer supplied in the United States of America. It climbed to 17 per cent by 1940, and has increased sevenfold since then. Its high plant-nutrient content and its capacity for reaction with ammonia in the production of multinutrient fertilizers are important factors in its growth. It is also the leading phosphate for direct application in the United States. In 1959, triple superphosphate supplied 52 per cent of the phosphate fertilizer used for direct application.

Triple superphosphate normally contains from 43 to 48 per cent of the available P_2O_5 or, as its name implies, nearly three times as much as normal superphosphate (see table 70).

Through the use of superphosphoric acid, described earlier, it is possible to produce a concentrated superphosphate that contains 54 per cent of the available P_2O_5.

Plants that make phosphate fertilizers generally have been located close to the ultimate market instead of near phosphate deposits, primarily because phosphate rock is more concentrated in P_2O_5 than is normal superphos-

TABLE 70. COMPOSITION OF TRIPLE SUPERPHOSPHATE MADE FROM FLORIDA ROCK AND WET-PROCESS PHOSPHORIC ACID

Analysis	*Percentage*
Total P_2O_5	46.3
Available P_2O_5	44.5
Water-soluble P_2O_5	39.4
CaO	20.0
Al_2O_3	1.9
Fe_2O_3	1.4
F	1.6

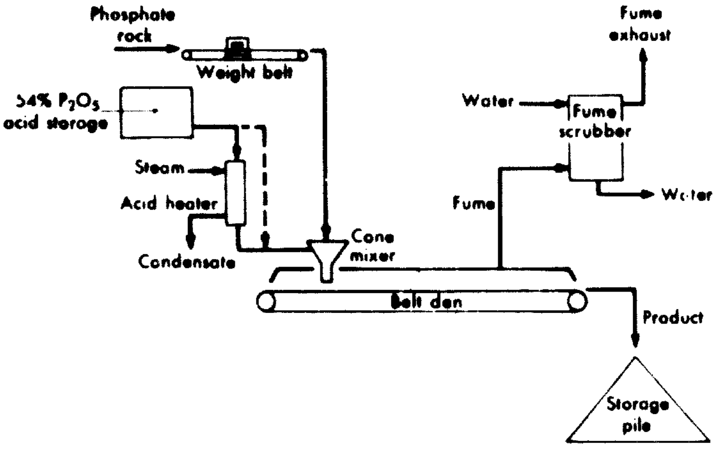
TABLE 71. TREND IN PRODUCTION OF NORMAL AND TRIPLE SUPERPHOSPHATES IN THE UNITED STATES OF AMERICA, 1900-1962

	Percentage of total superphosphate P_2O_5 as	
Year	*Normal superphosphate*	*Concentrated superphosphate*
1900	100	—
1910	100	—
1920	99	1
1930	95	5
1940	82	18
1950	85	15
1955	76	24
1960	62	38
1962	57	43

phate, and is thus cheaper to ship per unit of plant nutrient. However, this situation is changing rapidly as a result of the switch to more concentrated phosphate fertilizers, including triple superphosphate. In table 71 it is shown that the trend in the United States of America has been towards concentrated superphosphate and away from normal superphosphate. It has been predicted that the production of normal superphosphate will level off within a few years and that little increase in production will result thereafter.

An integrated plant for the manufacture of triple superphosphate entails a greater capital investment and is more complicated than one for the production of normal superphosphate. Extra labour and processing costs also are involved, so that the cost of a unit of P_2O_5 in triple superphosphate is higher than that in normal superphosphate. On the other hand, the higher cost of the product at the plant site is frequently more than offset by savings in freight, storage and distribution costs, and the fact that a lower grade, cheaper phosphate rock can be used in the production of the wet-process acid.

Figure 44. Flow sheet of run-of-pile triple superphosphate plant



(b) *Process description*

The main phosphate compound present in triple superphosphate is monocalcium phosphate monohydrate, which is the same as that in normal superphosphate. However, triple superphosphate consists almost entirely of monocalcium phosphate, whereas normal superphosphate contains a large proportion of calcium sulphate. The main reaction that occurs when finely divided phosphate rock is acidulated with phosphoric acid in the production of triple superphosphate may be represented by the following equation:

$$\underset{\text{(Fluorapatite)}}{Ca_5(PO_4)_3F} + \underset{\text{(Phosphoric acid)}}{7H_3PO_4} + 5H_2O \rightarrow \underset{\text{(Monocalcium phosphate}}{5[CaH_4(PO_4)_2 . H_2O]} + \underset{\text{(Hydrofluoric acid)}}{HF}$$

In the manufacture of triple superphosphate, the rock and acid are mixed, the acidulate is denned and the solidified superphosphate is cured in storage. Concentrated superphosphate solidifies much more rapidly than normal superphosphate, and the two operations differ mainly in that respect. The rock particle size generally is the same as for normal superphosphate, that is, 90 per cent through 100 mesh. The acid concentration usually is about 75 per cent H_3PO_4. The acid-to-rock ratio, expressed as the mole ratio of total P_2O_5 to CaO in the acidulate, ranges from 0.91 to 0.95. The conversion of P_2O_5 to the available form after the usual period of curing is 95 to 98 per cent.

Triple superphosphate is now largely produced by means of continuous processes. The cone-mixer process for triple superphosphate is quite similar to that described previously for normal superphosphate, and it is the most popular of the continuous processes (see figure 44).

The finely ground phosphate rock and the phosphoric acid are metered continuously and are discharged onto a belt conveyor. It solidifies before reaching the curing pile. A continuous den, rather than a belt conveyer, may be used. As in the case of normal superphosphate, an extended curing period is required for the reaction to proceed more nearly to completion. About thirty days, on an average, are required.

A superphosphate containing 54 per cent P_2O_5 is produced by diluting superphosphoric acid slightly and preheating it before addition to the rock. The acidulate is held in a den for one hour, where the high temperature developed causes evolution of a substantial portion of the fluorine and other volatiles. Conversion of the phosphate to available form is rapid. The material owes its high analysis to loss of volatiles and to its low content of moisture (free and combined). Anhydrous monocalcium phosphate is the main component.

(c) *Economic data*

With phosphate rock of 34 per cent P_2O_5 content and wet-process phosphoric acid of 53 per cent P_2O_5 content, 417 kilogrammes of rock and 644 kilogrammes of acid are required per ton of product. These quantities correspond to 2.40 kilogrammes of acid P_2O_5 per kilogramme of rock P_2O_5, or a P_2O_5 to CaO mole ratio of 0.97. There is an approximate 4 per cent loss in weight in manufacturing and curing of the product. A plant to produce 20 tons of product per hour has an electrical load of 45 horsepower. Maintenance costs are about $0.15 per ton of product. The investment required for such a plant is about $150,000 in the United States of America, exclusive of storage and facilities for grinding the rock. The plant, complete with storage and grinding equipment, requires an investment of the order of $1 million in the United States. The requirements per ton of product are summarized in table 72.

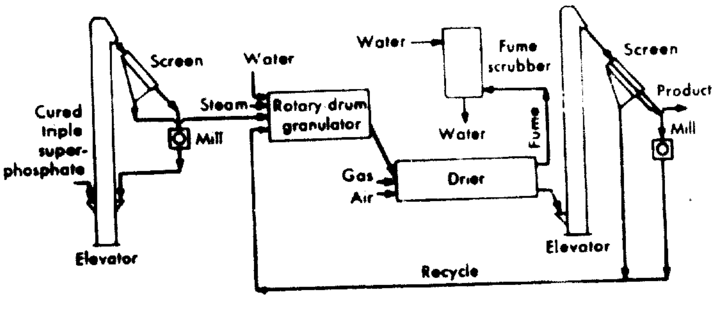
TABLE 72. REQUIREMENTS PER TON OF PRODUCT FOR THE PRODUCTION OF TRIPLE SUPERPHOSPHATE FROM FLORIDA ROCK AND WET-PROCESS PHOSPHORIC ACID

Phosphate rock, 34 per cent P_2O_5 (ton)	0.417
Phosphoric acid, 53 per cent P_2O_5 (ton)	0.644
Electricity (kWh)	2
Supervisor (man-hour)	0.016
Operator (man-hour)	0.05
Labourer (man-hour)	0.10
Maintenance (dollars)	0.15

(d) *Granular triple superphosphate*

Concentrated superphosphate is also granulated in some plants by the procedures shown in figure 45.

Figure 45. Flow sheet of plant for granulation of cured run-of-pile superphosphate



Cured run-of-pile triple superphosphate, three to six weeks old, is removed from storage and fed to a screen. The oversize is milled and recycled; the fine material is conveyed to a rotary drum granulator. Water is sprayed onto the bed of material, and steam is sparged underneath the bed to provide wet granular material. The wet granules are discharged to a rotary drier. The dried granules are screened. The oversize is milled and returned with the fines to the granulator. Dust and fumes from the drier are scrubbed in a water-scrubber.

A few plants feed phosphate rock and acid to the granulator to supply a portion of the phosphates, production cost is lowered, but greater investment is required.

Facilities to granulate superphosphate at a rate of 20 tons per hour cost about $700,000 in the United States of America. The electric power required for such facilities is about 30 kilowatts. Labour requirements are one operator and one assistant operator twenty-four hours per day, and two labourers eight hours per day. Maintenance amounts to about $0.70 per ton of product. The requirements per ton of product are summarized in table 73.

TABLE 73. REQUIREMENTS PER TON OF PRODUCT FOR THE PRODUCTION OF GRANULAR TRIPLE SUPERPHOSPHATE

Cured triple superphosphate (tons)	1.02
Steam, 5 kg sq cm (kg)	75
Water (kg)	250
Fuel (kcal net)	160,000
Electricity (kWh)	1.5
Supervisor (man-hour)	0.016
Operator (man-hour)	0.1
Labour (man-hour)	0.033

Granular triple superphosphate is used for direct application and bulk blending, whereas the ungranulated material is used in the production of combination fertilizers.

5. *Fluorine recovery*

Fluorine compounds are emitted in the production of normal and concentrated superphosphates and wet-process acid. It is desirable to prevent these compounds from escaping into the air and creating a pollution problem.

Proper design and maintenance of mixers and dens is a requirement in collecting fluorine gases. The gases usually are pulled by a fan through scrubbers, where absorption by water gives a dilute solution (10 to 25 per cent) of fluosilicic acid (H_2SiF_6), which is formed by the action of hydrogen fluoride on the silica in the phosphate rock. The solution also contains the phosphate entrained in the gas from the acidulation operation. In most cases, the acid liquor is neutralized, usually with limestone, and discarded. The fluorine in phosphate rock is potentially an important resource, but so far it has not been economically feasible to recover much of it for use.

6. *Slags*

Phosphate slags include several products and by-products that result from the thermal treatment of ores that contain phosphate (see table 74). The application of such slags to the soil often results in additional crop yield, although the phosphorus which they contain is virtually insoluble in water. The phosphorus compounds in some of these products are known, while in others they have not been accurately determined. Prominent in these products are such citrate-soluble compounds as dicalcium and tricalcium phosphates, silicocarnotite and metaphosphates.

TABLE 74. TYPICAL ANALYSES OF SLAGS AND PHOSPHATES PRODUCED BY THERMAL PROCESS

Material	*Percentage of P_2O_5* *Total*	*C.S.*	*W.S.*	*CaO*	*SiO_2*	*F*
Defluorinated phosphate rock	21 [a]	18	—	29	47	0.06
Fused tricalcium phosphate	28	22	—	40	20	0.3
Calcium magnesium phosphate [b]	20	10	—	30	20	2.0
Calcium metaphosphates	63	62	0.8	27	5	0.2
Rhenania phosphate	28	27	—	42	10	1.5
United States basic slag	9	6 [c]	—	41	11	0.15
European Thomas slag	18	16 [c]		47	8	0.008

[a] By adding phosphoric acid and decreasing the amount of silica added, defluorinated products with up to 40 per cent P_2O_5 are made.

[b] 14 per cent MgO.

[c] Citric-acid soluble P_2O_5.

TABLE 75. PRODUCTION OF BASIC SLAG, BY COUNTRIES, 1955/1956-1963/1964

(Thousand tons of P_2O_5)

	1955/1956	*1956/1957*	*1957/1958*	*1958/1959*	*1959/1960*	*1960/1961*	*1961/1962*	*1962/1963*	*1963/1964*
Europe									
Belgium	189	184	171	180	196	183	196	192	184
Federal Republic of Germany	299	362	374	346	491	431	365	405	454
France	348	365	368	400	357	372	381	370	—
Italy	11	13	15	15	16	20	23	21	17
Luxembourg	115	122	112	110	121	128	124	127	125
Poland	—	—	—	—	46	65	66	69	72
Sweden	8	9	7	8	10	6	6	4	5
United Kingdom	83	83	82	84	106	96	122	107	112
United States of America	—	12	14	11	—	—	6	5	5

SOURCE: Statistics of the Food and Agriculture Organization of the United Nations.

When phosphate rock is calcined or fused under certain conditions, the fluorine is volatilized from the apatite, with the resulting formation of tricalcium phosphate. Available phosphates may also be obtained by fusing phosphate rock with alkalis and alkaline earth compounds. Solid solutions of rather indefinite composition result. Fusion of phosphate rock with magnesium ores, e.g., olivine and serpentine, produces a slag containing available phosphorus.

(a) *Basic and Thomas slags*

Basic slag, a by-product of iron and steel manufacture, ranks as a leading phosphatic fertilizer in western Europe, where most of it is produced and consumed. The world production is shown in table 75. The only production of basic slag in the United States of America is that from the high phosphorus iron-ore at Birmingham, Alabama. Production in the United States, which amounts to about 300,000 tons annually, finds outlets as a fertilizer and liming material. This material contains 8 to 10 per cent total P_2O_5 (see table 74), of which 60 to 90 per cent is citrate soluble. It is ground in ball mills so that 80 per cent passes a 100-mesh screen. The fertilizer effectiveness of the material is dependent upon fine grinding.

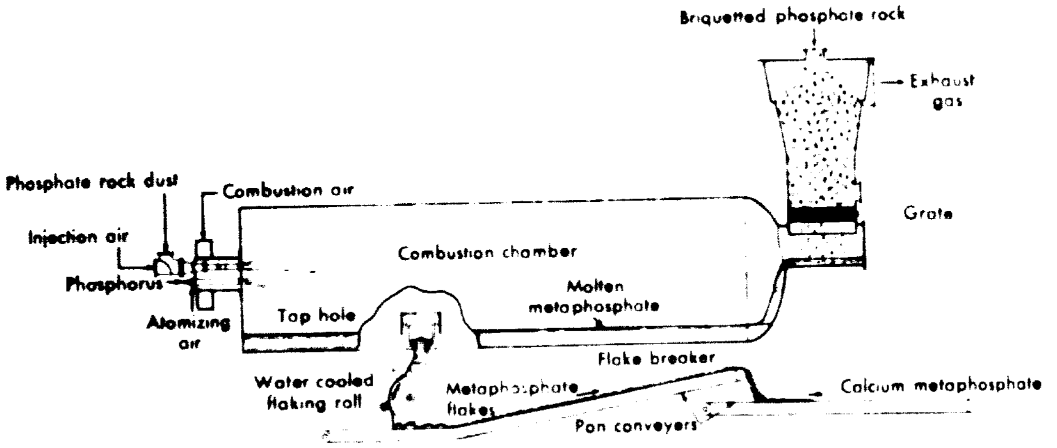
The European material, known as Thomas slag, also is obtained as a by-product of steel production. Thomas slag has a higher P_2O_5 content (18 per cent) than does the slag produced in the United States of America (table 74). It is produced in much larger quantities, as shown in table 75, and has played a more important role in agriculture. Millions of tons of the slag have been used in European agriculture. Prior to the Second World War, slag supplied about 70 per cent of the phosphorus used for fertilizer purposes in Germany, and a considerable portion of that used in Belgium, France and the United Kingdom.

Until recently, basic and Thomas slags ranked second in quantity to superphosphate as a phosphate fertilizer. However, oxygen converters and electric furnaces will be used almost exclusively in new steel plants. Also, there will be a tendency towards the replacement of existing Thomas converters by oxygen converters and of basic open-hearth furnaces by electric furnaces or oxygen converters. These changes in methods of steel production are expected to result in less by-product slag in future years.

(b) *Rhenania phosphate*

Rhenania phosphate is another fertilizer produced thermally. It is made by calcination of a mixture of sodium carbonate, phosphate rock and silica. The process has been carried out commercially in Germany since 1917. A finely ground mixture of sodium carbonate, phosphate rock and silica is dampened with water and fed to a

Figure 46. Calcium metaphosphate plant



coal-fired rotary kiln heated to 1250° C. The kiln product is quenched with sprays of water, dried and pulverized before shipment. A typical analysis of the product is given in table 74. The introduction of sodium carbonate does not result in water-soluble phosphorus. However, the addition of sodium carbonate apparently neutralizes the adverse effect of fluorine, since most of the fluorine remains in the product.

(c) *Calcium metaphosphate*

The Tennessee Valley Authority has produced a glassy, citrate-soluble phosphate fertilizer known as calcium metaphosphate. This material is produced by burning elemental phosphorus in a furnace and reacting the resulting phosphorus pentoxide vapour with phosphate rock at a high temperature (see figure 46). Approximately 70 per cent of the P_2O_5 in the product comes from elemental phosphorus, 27 per cent from pulverized phosphate rock injected into the combustion chamber and 3 per cent from briquetted rock in the absorption tower. About 80 per cent of the fluorine in the phosphate rock is volatilized and absorbed in limestone in a packed tower. The product contains 63 per cent P_2O_5 (see table 74) and is the most concentrated phosphate fertilizer. It is a good fertilizer, especially for use on acid soils. Its effectiveness on alkaline soils with some crops is less than that of water-soluble phosphates. This material is being produced in South Africa.

(d) *Fused magnesium phosphate*

The P_2O_5 in phosphate rock can be made available to growing plants by breaking the structure of the fluorapatite components of the rock. This may be done by defluorination of the rock or by fusion of the rock with such magnesium ores as olivine and serpentine. The fused magnesium phosphate produced in China and Japan contains about 20 per cent P_2O_5 and 15 per cent MgO. Total production exceeds 700,000 tons per annum. It is used in some areas where fertilizer containing sulphate would form H_2S in the soil and damage the crop.

The Japanese material is produced in electric-arc furnaces of the type used for the manufacture of calcium carbide. The furnace charge is prepared by crushing and mixing phosphate rock and serpentine or olivine. It is essential to quench the molten material rapidly, and this is usually accomplished in a trough provided with high-velocity jets of water. Approximately 10 tons of quench water are required per ton of product. The quenched material is allowed to drain and is then dried and ground. The specified fineness is at least 70 per cent through 100 mesh.

Greenhouse tests made by the United States Department of Agriculture showed that the product is, on the average, more effective than superphosphate when used on acid soils. Field tests in Japan have given favourable results on many different crops and soils. The product has a liming value equivalent to 0.5 to 0.7 ton of calcium carbonate per ton of material. The magnesium oxide content is available to growing plants.

In Israel, magnesium phosphate fertilizer of 37 per cent P_2O_5 and 40 per cent MgO is made from phosphate rock and magnesium chloride brine at a temperature of 500° C.

7. *Bones*

Raw bone generally is an uneconomical and ineffective phosphate fertilizer. The grease which it contains causes difficulty in grinding and makes it so resistant to weathering and bacterial action that decomposition in the soil is very slow. Removal of the grease by treatment with steam or solvents changes the physical and chemical properties of the bone, rendering it friable and causing the phosphorus therein to be more quickly available.

Although degreased bone is sometimes treated with sulphuric acid and its phosphate content rendered water soluble, the usual practice is to apply it in a finely ground condition directly to the soil. Degreased, finely ground bone-meal is an effective phosphate fertilizer, even though less than one-half of its phosphorus content is soluble, according to the conventional laboratory tests for availability. Bone-meal contains up to about 28 per cent total P_2O_5 (see table 76), of which about 50 per cent is citrate soluble.

In field tests on acid soils, this material has been found to be less effective than superphosphate in some instances, while in others, it was about equally as effective. On alkaline soils, it is considerably less effective than superphosphate.

The treatment of bone with organic solvents is the most effective way to degrease the material. The raw bones are crushed either between toothed rolls or in a hammer

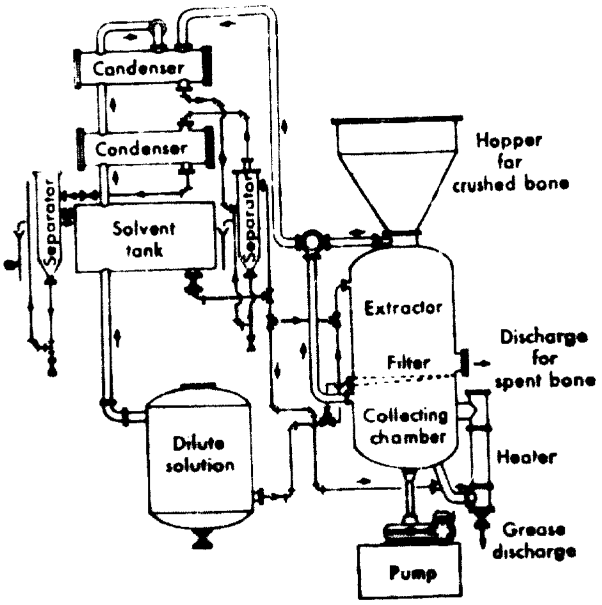
TABLE 76. COMPOSITION OF RAW, DEGREASED AND DEGELATINIZED BONE

	Raw bone	*Boiled bone*	*Steamed bone*	*Fat-extracted and degelatinized bone*
Ingredients				
Moisture	20.46	10.81	10.97	9.25
Organic matter	34.09	25.97	22.48	17.66
Tricalcium phosphate	39.21	53.15	57.17	62.39
P_2O_5	17.96	24.34	26.18	28.57
Magnesia and lime carbonate	4.16	6.28	6.89	8.55
Alkali salts	1.14	0.27	Trace	0.38
Silica	0.94	1 07	0.86	1.77
Contained nitrogen	3.63	2.45	1.74	0.97

SOURCE: W. H. Waggaman, *Phosphoric Acid, Phosphates and Phosphatic Fertilizers*, 2nd ed., (New York, Reinhold Publishing Corp.).

mill. To extract the grease from the crushed bone, petroleum benzine or naphtha is usually preferred. Approximately 10 tons of crushed bone are extracted with hot solvent in a tank with a false bottom. The solvent-grease emulsion is drained from the tanks into a still equipped with a condenser, which permits recovery of the solvent for reuse. After the grease has been removed from the bone, steam is blown through the column to drive off the remaining solvent. The extracted bone is finely ground and marketed as bone-meal or treated further for the recovery of other products. A diagram of bone-extraction equipment is shown in figure 47.

Figure 47. Equipment for degreasing bones



The amount of degreased bone sold as bone-meal for fertilizer represents only a small proportion of the phosphate fertilizer used in agriculture. The demand for bones in the production of bone-black and as an animal-feed supplement reduces even further the amount available for fertilizer.

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XIII. PRODUCTION OF POTASH FERTILIZERS

A. GENERAL INFORMATION

The term "potash" generally refers to any salt used to provide fertilizer potassium. In the early days, potassium carbonate was produced from solutions leached from wood ashes evaporated in iron pots, hence, the term "potashes". In 1857, the soluble potash minerals in waste salt deposits in Germany were found to be valuable as fertilizer, and minerals containing potassium have since been the source of that element for fertilizer use.

The principal minerals currently used as fertilizers are potassium chloride (muriate of potash), potassium sulphate, potassium nitrate and a mixture of potassium sulphate and magnesium sulphate. The potassium content of the minerals is stated in terms of potassium oxide (K_2O).

Pure potassium chloride (KCl) has an equivalent K_2O content of 63.1 per cent. Muriate of potash used for fertilizer purposes is not pure and, hence, varies between 60 and 62 per cent K_2O, as shown in table 77.

Table 78 gives the principal potash minerals mined throughout the world, the formula of the chemical compound contained in them and the equivalent K_2O content.

TABLE 78. PRINCIPAL POTASH MINERALS IN THE WORLD

Serial No.	*Mineral*	*Composition*	*Formula*	*Equivalent K_2O content (percentage)*
Chlorides				
1	Sylvite	Potassium chloride (muriate of potash)	KCl	63.10
2	Carnallite	Potassium chloride . . . . Magnesium chloride . . .	$KCl.MgCl_2.6H_2O$	17.00
Chloride sulphate				
3	Kainite	Potassium chloride . . . . Magnesium sulphate	$KCl.MgSO_4.3H_2O$	18.90
Sulphate				
4	Polyhalite	Potassium sulphate . . . . Magnesium sulphate. . . . Calcium sulphate	$K_2SO_4.MgSO_4$ $2CaSO_4.2H_2O$	15.50
	Langbeinite	Potassium sulphate . . . . Magnesium sulphate. . . .	$K_2SO_4.2MgSO_4$	22.60
Nitrates				
5	Nitre	Potassium nitrate	KNO_3	46.50

The most commonly produced of these minerals is sylvite, which is often found as a mixture with halite (NaCl); 90 per cent of the world potash supply originates as potassium chloride produced from sylvite. The usual method of separating a mixture of potassium chloride and sodium chloride is to grind the mineral and subject the fine material to a flotation process.

TABLE 77. COMMERCIAL GRADES OF POTASH

Subject No.	*Material*	*Potassium oxide (percentage)*
1	Manure salts	20-25
2	60 per cent muriate of potash (flotation grade)	60-61
3	62 per cent muriate of potash (crystallized grade)	62-62.5
4	Chemical grade — muriate of potash . . .	63.1
5	Sulphate of potash	50-51
6	Potassium nitrate	46.5
7	Magnesium potassium sulphate	21.5

Agricultural-grade muriate of potash is sold in various particle sizes and concentrations, usually containing 60-62 per cent K_2O. Crude salts containing 20-25 per cent K_2O are also sold.

Next in importance to potassium chloride are the sulphate and nitrate salts. Sulphate is obtained from langbeinite and other ores, as well as from muriate of potash, by reaction with sulphuric acid. Potassium nitrate is obtained as a by-product of Chilean sodium nitrate refining and by reaction of the muriate with nitric acid.

1. *World output*

The total world production of potash, in terms of K_2O, was about 9 million tons in 1960. It is estimated that in 1970, production will be about 17 million tons. Table 79 shows the world production by countries in 1960 and 1965 and the expected production in 1970. The annual increase is shown in figure 48.

Of the world production of potassium salts, 90-95 per cent is used in fertilizers.

North and Central America have been producing approximately 25 per cent of the world output. Eastern Germany, the Federal Republic of Germany, France, Spain and other parts of Europe have accounted for about 55 per cent, and the Union of Soviet Socialist Republics, for about 14 per cent.

In the United States of America, the major production facilities are near Carlsbad, New Mexico, where 90 per cent of the marketable potassium salts are produced. The quality of ores from Carlsbad has been decreasing recently. Newly worked deposits in Utah are expected to grow in importance.

Figure 48. World production of potash

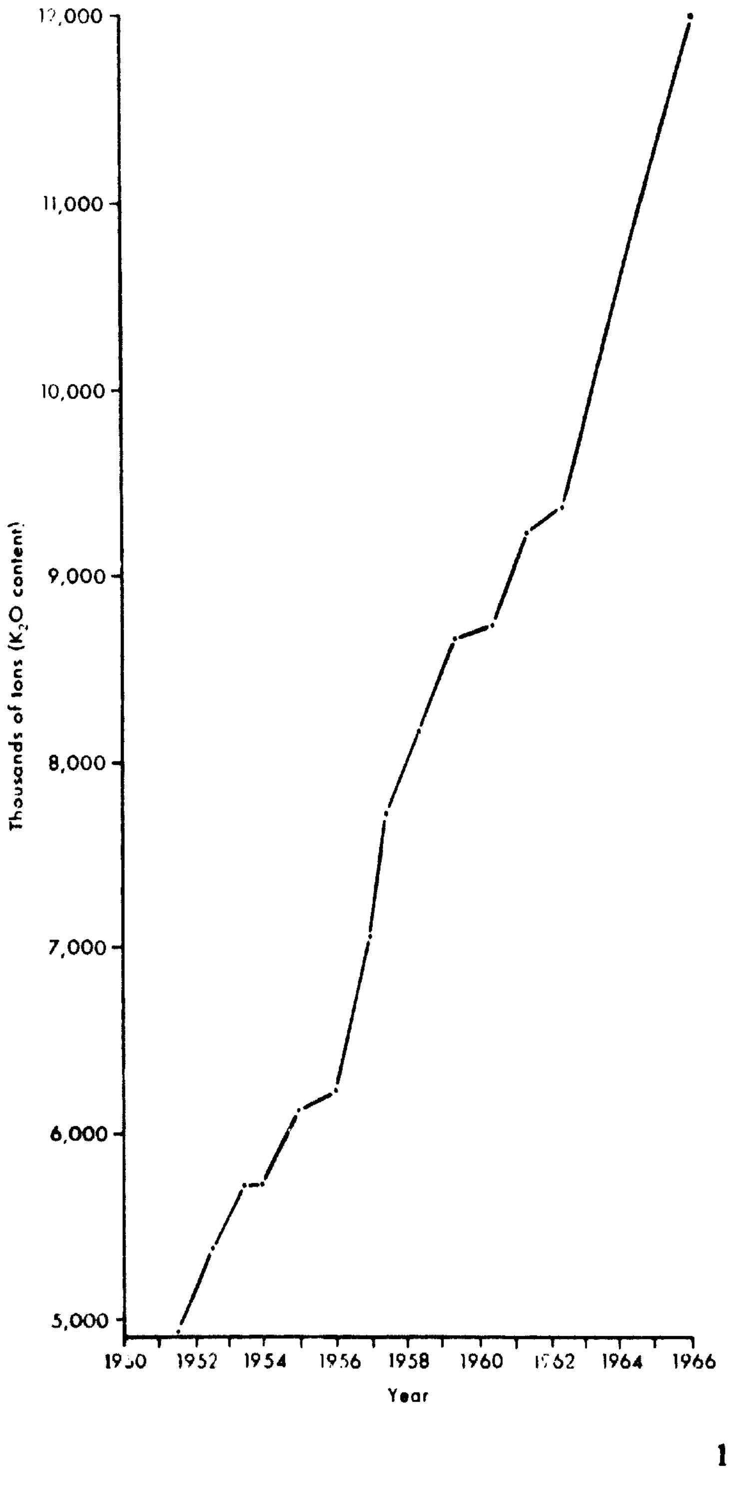


TABLE 79. WORLD POTASH PRODUCTION

(Thousands of tons of K_2O)

Serial No.	Country	1960	1965	1970[a]
1	United States of America	2,394	2,700	3,600
2	Federal Republic of Germany	1,978	2,050	2,100
3	France	1,535	1,700	1,700
4	Eastern Germany	1,600	1,800	2,000
5	USSR	1,110	1,600	2,400
6	Spain	264	300	750
7	Canada	—	1,100	2,700
8	Italy	46	170	250
9	Israel	68	350	750
10	Jordan	—	125	250
11	Congo (Brazzaville)	—	—	350
	TOTAL	8,995	11,895	16,850

[a] Estimated.

Mineral salts for processing to potash fertilizers have been discovered in the USSR, near Lake Chelkar, Kazakhstan. Ethiopia, Israel and Jordan plan production of sizable quantities of potash: Israel and Jordan from the Dead Sea and Ethiopia from the Danakil depression.

Canada is the major potential producer of potash in the world. From 1963 to 1970, production is expected to increase from 650,000 tons *per annum* to 2.7 million tons *per annum*. Deposits are in the Saskatchewan area, where several companies are now producing and many others are engaged in exploration drilling. Although attempts to recover potash in the Saskatchewan province were begun in 1951, and sixteen or seventeen firms have spent nearly $200 million in exploration and technical studies, sizable production was achieved only a few years ago. The recoverable potash reserves are estimated to be nearly 7,000 million tons (K_2O).

B. PRODUCTION OF POTASH IN DEVELOPING COUNTRIES

Facilities for the recovery of potash from brines and ores are being installed in some developing countries or in adjacent regions. Israel is expanding its existing facilities; Jordan has plans to execute a large project; Ethiopia has entered into a contract; and the Congo (Brazzaville) also has undertaken firm commitments. Chile has plans for expansion; Morocco has potentially rich deposits; and it is reported that Pakistan has discovered new ore deposits.

1. *Israel*

The production of salt (NaCl) from sea-water and inland salt-lakes by solar evaporation in shallow pans made of consolidated clay has been practised in arid and semi-arid regions of the world for many years.

The production of potassium salts by solar evaporation has been practised only in recent years. The first significant commercial production of potash by this means was from the brine of the Dead Sea in 1932.

Dead Sea brine is composed essentially of chlorides of sodium, potassium and magnesium (see table 80). Initial

TABLE 80. COMPOSITION OF THE DEAD SEA BRINE

Serial No.	Constituent	Salt content at surface	Salt content at 120 metres
		(Grammes per litre)	
1	Potassium chloride	10	16
2	Sodium chloride	71	87
3	Magnesium chloride	110	169
4	Calcium chloride	31	47
5	Magnesium bromide	4	7

solar evaporation produces sodium chloride, and small amounts of sulphate also crystallize. Crystallization of sodium chloride continues until the solution arrives at the saturation line between sodium chloride and carnallite, a double salt of magnesium and potassium ($MgCl_2 . KCl . 6H_2O$). Approximately two-thirds of the evaporating area is required for the pre-salt evaporation and the crystallization of sodium chloride. When the solution becomes saturated with carnallite in addition to the sodium chloride, it is admitted to the carnallite crystallizing area, where carnallite and sodium chloride crystallize together as mixed crystals. These mixed crystals are harvested for processing to produce potassium chloride. By setting apart approximately one-third of the total evaporation area to carnallite-salt production and two-thirds to pre-salt and salt, it is found that approximately 90 per cent of the potassium chloride in the incoming liquor is deposited in the carnallite area. The residual liquor, consisting largely of magnesium chloride, is returned to the Dead Sea.

Harvesting of the carnallite-salt mixture is done by a floating dredge with a horizontal rotating cutter from which the slurry is pumped to the thickening area. Brine from the thickener is returned to the evaporating pans, and slurry is pumped to the plant for dewatering and processing by flotation or crystallization.

The current cost of production is about $20 per ton of potash containing 60 per cent K_2O. When the anticipated production of 1 million tons *per annum* is reached, the cost is expected to be about $14 per ton.

2. *Jordan*

The Arab Potash Company has a concession covering one-half of the southern end of the Dead Sea. This concession covers over 100 square kilometres and is capable of producing 700,000 to 1 million tons of potassium chloride (420,000 to 600,000 tons of K_2O) annually. The Arab Potash Company has engaged the services of a firm from the United States of America for the engineering and supervision of construction and start-up of a plant to produce 250,000 tons of potassium chloride *per annum*.

Investment is estimated to be about $30 million. The process will be similar to that used by the Dead Sea works in Israel. The cost of production is estimated to be $20 per ton of muriate (60 per cent K_2O).

3. *Ethiopia*

A new major deposit of potash has been discovered in the Dald area in Ethiopia. It is reported that a firm from the United States of America has been given a concession for exploration of this deposit. Underground mining at a shallow depth of about 100 to 200 metres is contemplated. The deposit is understood to be sylvite ore of relatively high grade, which can be processed either by direct flotation or by solution and recrystallization.

4. *Congo (Brazzaville)*

A deposit of major significance has been discovered in Brazzaville, in the Congo. The ore is reportedly sylvinite and is located near Holle. An exploration syndicate expects to produce 600,000 tons *per annum*, equivalent to about 350,000 tons of K_2O. Financing to the extent of $5 million is to be provided by the International Bank for Reconstruction and Development (IBRD), the Republic of the Congo, and potash mining firms of France, Germany (Federal Republic) and Israel. A refinery probably will be added to the Holle operation, to process the ore before shipment to overseas markets.

5. *Morocco*

A few deposits of potash have been found in the area of the Khemisset, Boulekrane and Berrechid Basins, near Meknes. Exploration is planned.

6. *Pakistan*

A deep-lying potash brine was discovered near Dhariala in West Pakistan. It occurs at a depth of about 1,000 metres and is about 10 metres thick with a potassium chloride content of about 7 per cent. Plans have been announced by the Government for potash production from the brine.

C. METHODS OF PRODUCTION OF POTASSIUM CHLORIDE

1. *Solar evaporation*

The solar evaporation method of producing potash salts is employed in Chile and the United States of America in addition to Israel.

(a) *Chile*

Potassium and sodium nitrates are produced in Chile by solar evaporation and further processing of brines made by leaching nitrate ores. Because the solutions are dilute, it has been found economical to process them by solar evaporation.

The brine flows through a series of evaporating ponds where a waste mixture of sodium chloride and astrakanite ($Na_2SO_4 . MgSO_4 . 4H_2O$) crystallizes. The brine is then pumped through refrigerated tanks, where crystals of mixed sodium nitrate and potassium nitrate are separated and the liquor is returned to the solar ponds.

The slurry of sodium nitrate and potassium nitrate is filtered, washed and dried. The product marketed contains approximately 14 per cent K_2O (30 per cent potassium nitrate). Although it is possible to separate the potassium nitrate and sodium nitrate by flotation methods, the combination salt is readily salable.

(b) *Utah*

Bonneville Limited recovers potash from brine in western Utah (United States of America). The source of raw materials at Bonneville is more uncertain and variable than that of the Dead Sea operation.

Brine for the Bonneville operation is drained through trenches from areas surrounding the solar pans. The formation through which the trenches are dug consists of a surface layer of salt, which may be from 15 centimetres to 1 metre thick. Below this are a layer of blocky fissured clay of considerable thickness and a relatively thin layer of salt and clay. These fissures are also filled with salt crystals. Below the fissured clay is a relatively impervious clay. Water from winter snows and the rains which fall on both the area and the adjacent mountains, percolate through the salt layers and the fissured clay into the ditches that radiate from the solar evaporation area. The quantity of brine produced varies with the amount of water that leaches the salt.

Brine from the gathering ditches is pumped into the solar pans approximately at saturation. Sodium chloride is the first salt to crystallize, and the greater part of the solar area is devoted to the crystallization of sodium chloride. As evaporation continues, the solution is saturated with potassium chloride instead of carnallite as in the Dead Sea operation. The brine is then moved into the harvesting pans, and a mixture of sodium chloride and potassium chloride crystallizes. This continues until the major portion of the potassium chloride is crystallized. The salts are harvested and sent to the plant for separation by flotation.

2. *Mining methods*

Most of the world's fertilizer potash is produced by the mining of underground deposits. Methods of mining vary according to type and depth of the ores.

(a) *Shaft mining*

Where sylvite (KCl), carnallite ($KCl.MgCl_2.6H_2O$), or langbeinite ($K_2SO_4.2MgSO_4$) occurs as a solid deposit 300 to 1,000 metres below the surface of the earth, as in Carlsbad in the United States of America, in Saskatchewan in Canada, or in the Federal Republic of Germany, France and other countries, the room-and-pillar mining method is used for recovery of the crude salts. Coal-mining methods are used for underground recovery. Continuous mining machines are used to extract the ore, and belt conveyers are employed for underground haulage. Underground equipment is electrically driven, and the mines are well ventilated and maintained. Primary crushed ore is hoisted to the surface.

It is usual to recover about 60 per cent of the deposit during normal operations, but ultimate recovery may be increased to as much as 90 per cent by removing the pillars at the final stages of mine operation.

The cost of such mining operations primarily depends upon:

(*a*) Depth of the deposit beneath the surface;

(*b*) Nature of underground formations to be traversed;

(*c*) Thickness of the potash deposits;

(*d*) Location and remoteness of the site.

Mining development costs are written off as a percentage of the ore mined over a period of years. Hence, large development costs reflect only a small portion of the cost of ore. Modern machinery minimizes labour costs.

The potash content of the ore is a significant factor in the cost of recovered potash. In Carlsbad, where the average ore analysis is 18 per cent K_2O, and ore cost at the mine mouth, excluding tax, royalties etc., is about $2.20 per ton of ore, the cost of ore required for 1 ton of product (60 per cent K_2O) is about $8.10.

Deposits in Saskatchewan are at a depth of 1,000 metres, compared with 300 metres in Carlsbad. In addition, problems in sinking the shafts (caused by water-bearing formations) result in development costs that are five to six times that in Carlsbad. However, in Saskatchewan, the reserves are enormous, and the veins are thicker than in Carlsbad. It is estimated that, exclusive of royalties, depletion allowances etc., the cost of ore at the surface will be around $2.60 per ton. Since the ore analysis shows 26 per cent K_2O, only 2.6 tons are required per ton of 60 per cent K_2O product. At the mining cost of $2.60 per ton, the ore cost is $6.80 per ton of product.

(b) *Solution mining*

In Canada, potash is recovered by solution mining at depths considered less practical to mine by conventional shaft mining. Water is pumped into the solid potash deposit through drilled holes. The water dissolves the potash and the solution is forced to the surface, where the potash is recovered by concentration and crystallization. Since potassium chloride strata are covered with sodium chloride and both are water soluble, difficulty has been encountered in recovering a relatively pure solution of potash. It is believed that this problem has been solved by injecting a blanket of natural gas over the potassium chloride deposit, to prevent excessive dissolution of sodium chloride.

D. REFINING METHODS FOR POTASSIUM CHLORIDE

1. *Solution and recrystallization*

The solution and recrystallization of potassium chloride from solid ores is a well-established process and is widely used, particularly in Europe. The process is flexible and can be adapted to a wide variation of ores and for the production of relatively pure potassium chloride. Disadvantages include high-temperature processing, corrosive brines, expensive equipment requirements and large fuel and cooling requirements.

The solubility of most salts increases with rising temperature. Sodium chloride is unusual in that it is only slightly more soluble in hot than in cold water. In solutions saturated with both sodium and potassium chloride, the concentration of sodium chloride diminishes as temperatures rise, while the concentration of potassium chloride increases.

The extraction of potassium chloride from sylvinite ore is based upon these differences in the solubilities of sodium and potassium chlorides in hot and cold saturated brines. Ore is leached with hot brine, which dissolves more potassium salt than sodium salt. The saturated brine is then clarified and cooled. Potassium chloride crystallizes freely, but the sodium chloride remains in solution. The crystals are separated and the brine is used

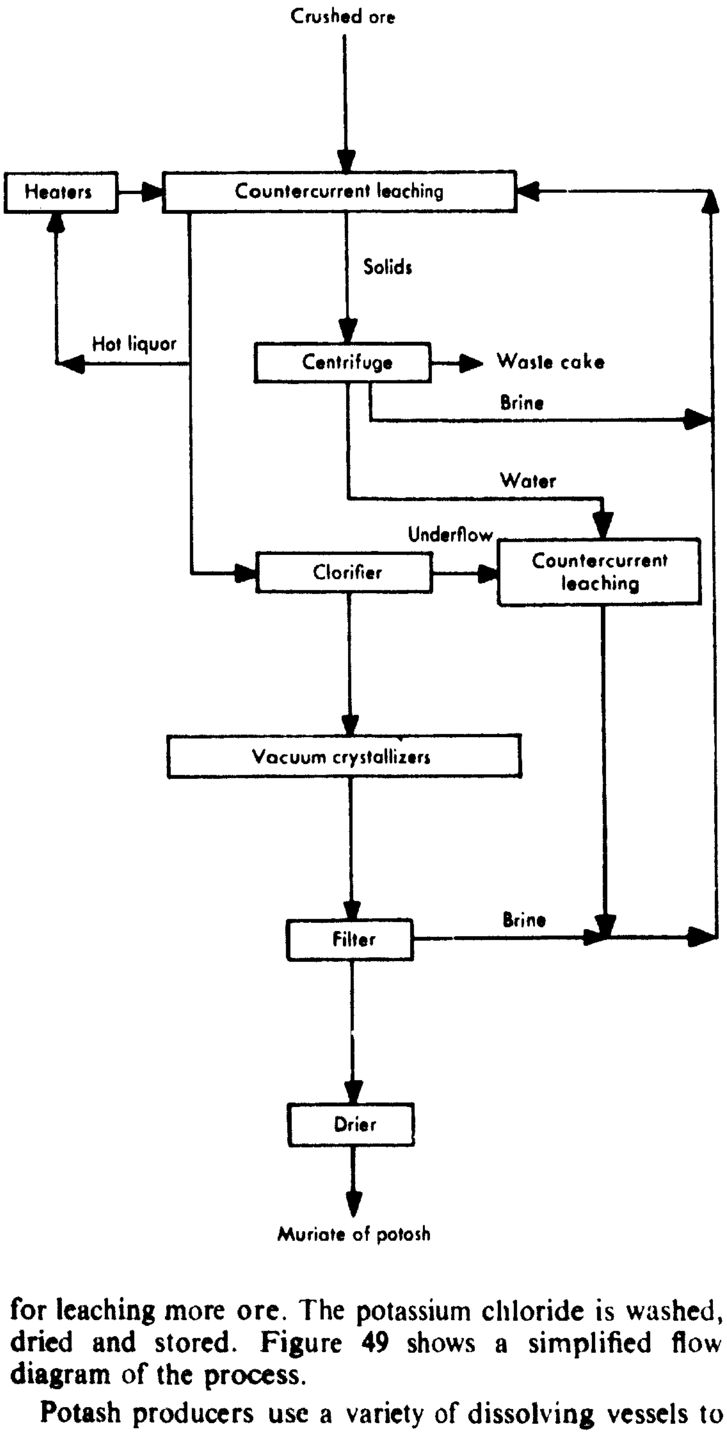


Figure 49. Simplified flow diagram for a solution-recrystallization potash plant

for leaching more ore. The potassium chloride is washed, dried and stored. Figure 49 shows a simplified flow diagram of the process.

Potash producers use a variety of dissolving vessels to promote efficient contact between the brine and the ore. The trough type of vessels, with paddles to mix and advance the solids, are used. The brine is heated by external heat-exchangers and is kept in circulation with large low-head pumps. Vacuum crystallizers of multiple stage and of a classifying type generally are employed. Crystallized potash is conditioned to prevent caking in storage usually with amines of fatty acids.

Crude carnallite ore ($MgCl_2.KCl.6H_2O$) containing 16.25 per cent K_2O mixed with sylvite and halite is leached in vats with a hot saturated brine solution. The potassium chloride and carnallite dissolve, leaving sodium chloride and insoluble matter in the residue. The hot liquor is cooled in vacuum crystallizers, yielding a low-analysis potassium chloride product. The mother liquor is evaporated and cooled to form carnallite. Potassium values are recovered from the crystallized carnallite by a hot leach followed by vacuum crystallization. The potash deposited in this step is of high purity.

2. *Flotation recovery*

Separation of potash from its ore by mineral flotation is widely practised, and most of the potash-producing companies in Carlsbad make partial or full use of this process. Flotation is a separation process in which a solid treated with a selective agent is suspended in an aerated aqueous liquid. The treated solid adheres to bubbles of air, and the froth is floated off the suspension. Non-floating material is removed as a pulp.

The reagent most widely used for sylvite flotation is a mixture of fatty acid amines composed of approximately 25 per cent mono-n-octademyl, 25 per cent mono-n-hexadecyl and 50 per cent mono-n-octademyl neutralized with glacial acetic acid. The amine is used in a 1.0 per cent water solution.

The amine collector is consumed by clay and other water-insoluble gangue materials. Consequently, slimes are reduced to a minimum level. In a typical operation, the ore is crushed and screened, and the minus-10 mesh material is separated for sale as manure salts (run-of-mine ore). The coarser material is washed to remove clay slimes and is then treated with starch or mannogalactan gums to render it inert to amine consumption. The crushed ore is pulped with a potassium chloride-sodium chloride brine. A separation is made at approximately 14 mesh, and the two fractions are then treated in separate, but nearly identical, circuits.

The minus 14 mesh materials pass through classifiers, where the slimes are separated from the scrubbed ore. The slimes are concentrated by mechanical thickeners and washed with water in a countercurrent decantation apparatus.

The clean solids are first reagentized with starch or gums, and then with an amine-acetate for potash flotation. The reagentized pulp is agitated in a mechanical cell so that air is drawn into the pulp to create a frothing condition. The fine air-bubbles attach themselves to the filmed particle and float to the surface, where they are skimmed off. The floated froth is concentrated in a thickener, centrifuged or filtered, washed with water to displace the brine and then dried. The product generally averages 97 per cent potassium chloride. The salt pulp from the bottom of the flotation cell is concentrated in a thickener, washed to remove adhering brine and sent to waste. The separation operates with recovery efficiencies above 96 per cent.

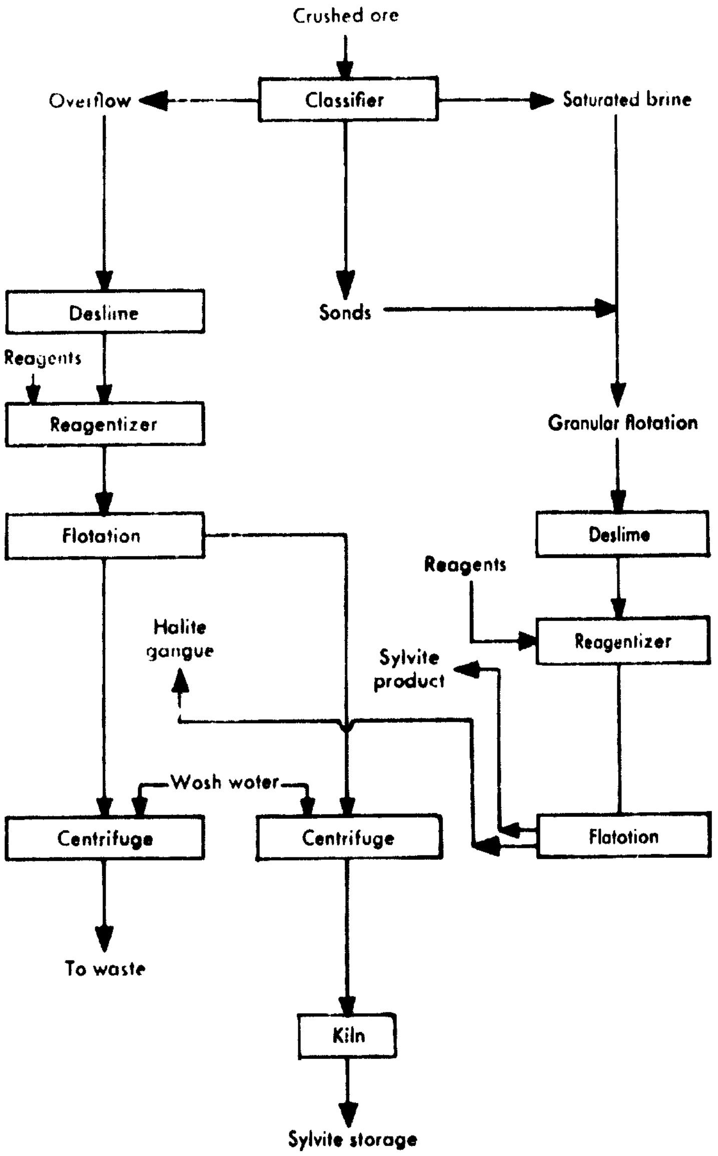
The plus-14 mesh fraction is treated similarly in a cell modified to permit handling the large, quick-settling solids. A simplified flow diagram for a sylvite flotation plant is given in figure 50.

E. PRODUCTION OF POTASSIUM SULPHATE

Potassium sulphate is often associated with other salts in potash deposits.

Except for certain specialized crops, one potash fertilizer is as effective as another. Tobacco is one example

Figure 50. Simplified flow diagram for sylvite flotation plant



of a crop sensitive to chlorides. Quantities in excess of 37 to 45 kilogrammes per hectare as chloride are harmful to the tobacco burning-quality. For this reason, tobacco is generally fertilized with potassium sulphate. It is also thought that potassium sulphate is better for potatoes, citrus fruits and others in certain soils.

Muriate of potash is quoted in the United States of America at $0.35 to $0.40 per unit (9.1 kilogrammes of K_2O); potassium sulphate is quoted at $0.67 to $0.76 per unit of K_2O. The price differential is incentive for producers of potassium chloride to produce potassium sulphate also.

Potassium sulphate is manufactured in a Mannheim furnace, where potassium chloride is reacted with sulphuric acid to form first bisulphate in exothermic reaction and then potassium sulphate, in endothermic reaction. Hydrochloric acid is evolved as a by-product.

The Hargreaves process involves the reaction of potassium chloride and sulphur dioxide. Sulphur is burned to produce sulphur dioxide with the inclusion of sufficient excess air to supply one-half molecule or more of oxygen for each molecule of sulphur dioxide. Sufficient water vapour is added to provide a slight excess of 1 molecule of water per molecule of sulphur dioxide. The composite gas is then passed countercurrent through a series of chambers charged with almond-shaped briquettes of potassium chloride. Each chamber contains approximately 80 tons of potassium chloride to be converted by the sulphur dioxide into approximately 90 tons of potassium sulphate.

A third process for the manufacture of potassium sulphate involves an exchange of ions. On slurrying 60 per cent muriate of potash and ground langbeinite ($K_2SO_4 . 2MgSO_4$) and water in the proper ratio, potassium sulphate becomes stable:

$$K_2SO_4 . 2MgSO_4 + 4KCl \rightarrow 3K_2SO_4 + 2MgCl_2$$

$$K_2SO_4 . MgSO_4 . 4H_2O + 2KCl \rightarrow 2K_2SO_4 + MgCl_2 + 4H_2O$$

To crystallize the maximum quantity of product per unit weight of water used, the liquor (potassium sulphate mother-liquor) must be saturated with potassium chloride and leonite ($K_2SO_4 . MgSO_4 . 4H_2O$). After allowing sufficient time for the solution to approach equilibrium, potassium sulphate is separated from the slurry, dried and stored.

F. Production of potassium nitrate

Potassium nitrate is made by reaction of potassium chloride with sodium nitrate. Solid potassium chloride is added to a hot solution of sodium nitrate. Sodium chloride crystallizes and is separated from the hot potassium nitrate liquor.

A process developed by Israel Mining Industries allows conversion of solid potassium chloride directly into solid potassium nitrate through solvent extraction in one step at ambient temperature, according to the equation:

$$KCl + HNO_3 \rightarrow KNO_3 + HCl$$

An exchange of anions takes place and the HCl formed is separated from the solid product by solvent extraction.

A commercial operation in the United States of America employs a six-step process for reaction of potassium chloride with nitric acid and conversion of the chloride to fine and coarse grades of nitrate.

G. Costs of production

1. *Comparison of costs of production*

The costs of production of muriate of potash at Carlsbad, New Mexico (United States of America) for the crystallization process and the flotation process are given in tables 81 and 82.

The investment for the crystallization process is about 30 per cent more than for the flotation process. The significant difference in cost of production ($17.37 *versus* $15.61) is owing to higher utilities requirement for the crystallization process and greater fixed costs. The cost advantage shows why the flotation process is being adopted for most new installations.

Table 83 gives the estimated costs of production in Saskatchewan, Canada, by the flotation process. The investment is considerably greater than that in Carlsbad, but the cost of production is lower ($14.26). The cost of production is lower because the ore at Saskatchewan

TABLE 81. ESTIMATED COST OF PRODUCTION OF 62.5 PER CENT (K_2O) MURIATE OF POTASH, CRYSTALLIZATION PROCESS, CARLSBAD, NEW MEXICO, UNITED STATES OF AMERICA [a]

		Quantity per ton	Cost per unit (dollars)	Cost per ton of 62.5 per cent K_2O product (dollars)
1.	*Variable costs*			
	a. Power	77 kWh	0.008	0.62
	b. Fuel gas	7.7 million BTU	0.20	1.54
	c. Water	2.4 thousand gallons	0.03	0.72
	d. Operating supplies	—	—	0.22
				3.10
2.	*Semi-variable costs*			
	a. Operating labour	0.3 man-hours ($2.60 per hour)		0.78
	b. Supervision	20% of labour		0.16
	c. Labour overhead	50% of labour and supervision		0.47
	d. Maintenance	5% of investment		0.69
				2.10
3.	*Fixed costs*			
	a. Plant overhead	50% of labour and supervision		0.47
	b. Depreciation	10% of investment		1.37
	c. Local taxes and insurance	1.5% of investment		0.21
				2.05
		TOTAL COST OF REFINING		7.25
4.	Sylvinite ore (18% K_2O)	3.81 tons	2.2	8.40
				15.65
5.	*Royalties and taxes*			
	Royalty	5% of sales value		1.25
	New Mexico sales tax	5% of sales value		0.13
	Severance tax	2.5% of manure-salt value		0.34
				1.72
		TOTAL COST OF MANUFACTURE (excluding depletion)		17.37

[a] Plant capacity of 800,000 tons of muriate (500,000 tons of K_2O) *per annum*. Refinery cost: $11 million.

analyses 26 per cent K_2O, whereas the ore in Carlsbad is only 18 per cent K_2O. It is likely that Saskatchewan will produce the lowest cost muriate of potash in the world in the next few years.

The cost of production of potassium sulphate from muriate of potash and sulphuric acid is given in table 84. The cost of production, using muriate of potash at $40.50 per ton, is $41.16 per ton, or nearly three times the cost of muriate of potash. Also, potassium sulphate has only a K_2O equivalent of 54.06 per cent. Costs can be substantially reduced if captive muriate of potash at low cost is used for potassium sulphate production.

Tables 85 and 86 show the capital requirements and the cost of production of muriate of potash by solar evaporation, assuming no cost for raw materials. This works out to $9.050. Adding fixed costs, the total is $20.04 per ton. This cost is higher by about $4 to $6 a ton than in Saskatchewan or Carlsbad.

2. *Conclusions about costs of production of potash in developing countries*

It is essential that the potash deposits already located in developing countries be exploited quickly and in full. It is also necessary that prospecting for potash deposits be continued in all developing countries.

However, it is necessary to keep costs low to permit production on a competitive basis with potash from other sources. This is especially so for countries whose potential internal consumption is not very great, for example, Ethiopia, Israel and Jordan. Some of these countries are developing their potash industries with plans to export to the Middle East and the Far East. Such plans should reckon with the vast resources of Saskatchewan and the low cost of production from this source.

Adding royalties, profits and freight to the Middle East to the estimated cost of $15 per ton for Saskatchewan potash, the price at a Middle Eastern point can be

TABLE 82. ESTIMATED COST OF PRODUCTION OF 61.6 PER CENT (K_2O) MURIATE OF POTASH, FLOTATION PROCESS, CARLSBAD, NEW MEXICO, UNITED STATES OF AMERICA [a]

		Quantity per ton	*Cost per unit (dollars)*	*Cost per ton of 61.5 per cent K_2O product (dollars)*
1.	*Variable costs*			
	a. Power	127 kWh	0.008	1.02
	b. Fuel gas	0.44 million BTU	0.20	0.09
	c. Water	13.2 thousand gallons	0.03	0.40
	d. Flotation reagents	0.82 pound	0.50	0.41
	e. Operating supplies	—	—	0.17
				2.09
2.	*Semi-variable costs*			
	a. Operating labour	0.3 man-hours ($2.60 per hour)		0.78
	b. Supervision	20% of labour		0.16
	c. Labour overhead	50% of labour and supervision		0.47
	d. Maintenance	5% of investment		0.52
				1.93
3.	*Fixed costs*			
	a. Plant overhead	50% of labour and supervision		0.47
	b. Depreciation	10% of investment		1.04
	c. Local taxes and insurance	1.5% of investment		0.16
				1.67
		TOTAL COST OF REFINING		5.69
4.	Sylvinite ore (18% K_2O)	3.71 tons	2.20	8.20
				13.89
5.	*Royalties and taxes*			
	a. Royalties	5% of sales value		1.25
	b. New Mexico sales tax	1.5% of sales value		0.13
	c. Severance tax	2.5% of salt value		0.34
				1.72
6.	TOTAL COST OF MANUFACTURE (excluding depletion)			15.61

[a] Plant capacity of 800,000 tons of muriate (492,000 tons of K_2O) *per annum*. Refinery investment: $8.5 million.

TABLE 83. ESTIMATED COST OF PRODUCTION OF 61.5 PER CENT (K_2O) MURIATE OF POTASH, FLOTATION PROCESS, SASKATCHEWAN, CANADA [a]

		Quantity per ton	*Cost per unit (dollars)*	*Cost per ton of 61.5 per cent K_2O product (dollars)*
1.	*Variable costs*			
	a. Power	95 kWh	0.009	0.85
	b. Fuel gas	0.44 million BTU	0.30	0.13
	c. Water	10 thousand gallons	0.03	0.30
	d. Flotation reagents	0.50 pound	0.60	0.30
	e. Operating supplies	—	—	0.15
				1.73
2.	*Semi-variable costs*			
	a. Operating labour	0.3 man-hours ($2.60 per hour)		0.78
	b. Supervision	20% of labour		0.16
	c. Labour overhead	50% of labour and supervision		0.47
	d. Maintenance	5% of investment		1.06
				2.47

TABLE 83 *(continued)*

		Quantity per ton	Cost per unit (dollars)	Cost per ton of 61.5 per cent K_2O product (dollars)
3.	*Fixed costs*			
	a. Plant overhead	50% of labour and supervision		0.47
	b. Depreciation	10% of investment		2.12
	c. Local taxes and insurance .	1.5% of investment		0.32
				2.91
		TOTAL COST OF REFINING		7.11
4.	Sylvinite ore (26% K_2O) . . .	2.6 tons	2.50	6.50
5.	Royalty	5% of manure-salt value		0.65
	TOTAL COST OF MANUFACTURE (excluding depletor's allowance) . . .			14.26
	Cost per 10 kilogrammes of K_2O			0.230

[a] Plant capacity of 800,000 tons of muriate (492,000 tons of K_2O) *per annum*. Refinery investment: $17 million.

TABLE 84. ESTIMATED COST OF PRODUCTION OF POTASSIUM SULPHATE, MANNHEIM FURNACE PROCESS [a]

		Quantity per ton	Cost per unit (dollars)	Cost per ton (dollars)
1.	*Variable costs*			
	a. Muriate of potash (60% K_2O)	0.866 ton	40.50	35.20
	b. Sulphuric acid (100% basis)	0.541 ton	16.5	8.90
	c. Power.	121 kWh	0.007	0.85
	d. Water	2.2 thousand gallons	0.03	0.07
	e. Fuel	11.9 million BTU	0.25	0.30
	f. Operating supplies	—		0.25
				45.57
2.	*Semi-variable costs*			
	a. Operating labour	2 men per shift ($3.00 per hour)		1.93
	b. Supervision	1/4 cost of 4 foremen ($8,000 p.a.) 1/4 of 1 superdt. ($13,000 p.a.)		0.45
	c. Labour overhead	30% of labour and supervision	—	0.71
	d. Maintenance	5% of investment	—	1.10
				4.19
3.	*Fixed costs*			
	a. Plant overhead	70% of operating labour and supervision	—	1.67
	b. Depreciation	10% of investment *per annum*		2.20
	c. Local taxes and insurance .	1.5% of investment *per annum*		0.33
				4.20
4.	TOTAL COST OF MANUFACTURE			53.96
5.	By-product hydrogen chloride 0.389 ton (100% basis)		33	12.80
6.	NET COST OF MANUFACTURE			41.16

[a] Plant with capacity of 25,000 tons per year, located in United States of America, Gulf Coast. Investment: $550,000.

TABLE 85. TYPICAL BREAKDOWN OF THE CAPITAL REQUIREMENTS FOR A SOLAR-EVAPORATION SYSTEM IN THE DEAD SEA AREA [a]

(Thousands of dollars)

Serial No.	*Items*		*Serial No.*	*Items*	
1	Pan and dike construction	10,144	9	Transportation and equipment	770
2	Harvesting	1,111	10	Working capital	1,840
3	Carnallite treatment and decomposition	2,700	11	Engineering and consulting fees	300
4	Hot-leach process	2,422	12	Preliminary expenses	665
5	Drying	639	13	Development expenses	1,035
6	Loading and storage	751	14	Interest at 5% during construction	3,140
7	Utilities	3,562			
8	Non-process facilities	1,485		TOTAL CAPITAL INVESTMENT	31,564

Capacity of 250,000 tons of muriate of potash *per annum* (330 days).

TABLE 86. TYPICAL COST OF PRODUCTION OF MURIATE OF POTASH BY A SOLAR-EVAPORATION SYSTEM IN THE DEAD SEA AREA [a]

Serial No.	*Item*	*Quantity*			*Cost*	
		Per year	*Per ton*	*Price*	*Per year*	*Per ton*
					(dollars)	
A.	*Labour* (classes and rates)					
1	Administration	47			134,736	0.539
2	Sales	12			50,000	0.200
3	Laboratory	18			33,672	0.135
4	Maintenance	67			91,526	0.366
5	Pans	28			32,054	0.128
6	Harvesting	68			97,843	0.391
7	Decomposition	33			44,150	0.176
8	Hot leach	32			48,115	0.193
9	Drying	17			21,240	0.085
10	Storage and loading	15			18,684	
11	Storage and loading (port)	12			17,172	
12	Power plant	26			34,630	
13	Steam plant	5			7,324	
14	Other utilities	4			6,000	
15	Trucking	50			54,000	
	TOTAL	434			691,146	2.765
B.	*Raw material*	—	—	—	—	—
C.	*Power* (thousands kW)	42,600	12.162		518,100	2.072
D.	*Fuel*					
	a. Diesel (tons)		54.08			
1	Pan and dike operation				5,000	
2	Harvesting				47,590	
3	Feed preparation, decomposition				3,500	
4	Product haulage				81,000	
5	Diesel plant				22,173	
6	Storage and loading				300	
	TOTAL DIESEL FUEL				159,563	0.638
	b. Heavy fuel oil			21.76		
1	Drying				91,574	
2	Diesel plant				179,085	
3	Steam plant				201,600	
	TOTAL, HEAVY OIL				472,259	2.621
	c. Lube oil				23,600	
	TOTAL, FUEL				655,422	2.621

TABLE 86 *(continued)*

Serial No.	Item	Quantity		Price	Cost	
		Per year	Per ton		Per year	Per ton
					(dollars)	
E.	*Utilities* (see "power" above)					
F.	*Supplies* (miscellaneous)					
1	Pan and dikes				2,500	
2	Feed preparation, decomposition				13,974	
3	Hot leach				17,110	
4	Drying				3,192	
5	Storage and loading				2,755	
6	Diesel plant				11,518	
7	Steam plant				1,495	
8	Product handling				14,800	
9	Oil filtering				360	
10	Water system				230	
	TOTAL, MISCELLANEOUS				67,907	0.272
	Supplies (tires)				330,000	1.320
G.	Supervisory and technical (see "labour" above)					
H.	TOTAL, direct plant costs				2,262,575	9.050

a Capacity of 250,000 tons *per annum* (330 days).

expected to be not more than $25 to $28 per ton. As the production from Canada, together with existing traditional production, will meet future world demands over the next five years or more, developing countries without large potential home consumption will be well advised to keep their cost of production as low as possible and to initiate steps for the progressive reduction of costs. These steps may be summarized as follows:

(*a*) Reduce the capital requirements for potash projects as much as possible by reducing infrastructure and other costs or allocating them to some other account;

(*b*) Increase the capacity for production to the maximum extent possible;

(*c*) Develop the utilization of by-products and co-products;

(*d*) Develop bulk-handling facilities for moving raw materials as well as finished products;

(*e*) Design processing plants in an integrated way and provide facilities for future expansion with minimum costs;

(*f*) Take all necessary steps to attain full capacity quickly, and keep production at full capacity by employing competent personnel, providing adequate exchange funds and ensuring that there shall be raw materials, utilities and product sales.

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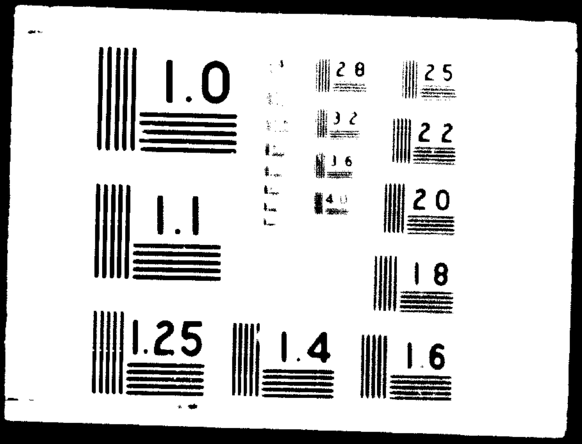

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XIV. PRODUCTION OF NITROPHOSPHATES AND AMMONIUM PHOSPHATES

A. Nitrophosphates

1. *Background information*

Nitrophosphates are fertilizers derived through digestion of phosphate rock with nitric acid. Nitrophosphate fertilizers have been produced for over thirty years in Europe and have been gaining ground recently. Interest has lagged in the United States of America, but, recently, process improvements and heavier production of nitric acid have been improving the prospects for this type of fertilizer. Plants are being constructed or have been completed in a half-dozen Latin American countries and in several Asiatic countries.

The nitrophosphates fit well into the fertilizer production systems typified in Europe (1, 2, 3, 4). Raw materials generally are costly there. Phosphate rock and sulphur for sulphuric acid must be imported. Fuel sources for ammonia production, including coal, coke-oven gas and imported oil, are relatively expensive.

The high raw material costs are offset by large-scale, integrated and continuously operated plants where advanced technology and the most economical processes are used. In many of these operations, it is economical to substitute nitric acid for the sulphuric and phosphoric acids commonly used elsewhere in fertilizer production.

Contrasting with European practice, fertilizers have been produced in the United States of America in smaller plants intermittently operated to satisfy seasonal demand. Phosphate rock, sulphur and sulphuric acid have been commonly available at relatively low costs. These factors have contributed to lessened importance of nitrophosphate processes in the United States. Lately, however the trend towards consolidation of companies and enlargement of plants has improved the prospects of nitrophosphate production. The rising cost of sulphur is becoming increasingly important in considering the choice of process.

This chapter describes the processes, products and costs involved in the production of nitrophosphate fertilizers in integrated facilities where such production is well adapted.

Nitric acid serves two purposes in nitrophosphate production. It directly solubilizes the phosphate (thus avoiding the intermediate step of producing phosphoric acid or superphosphate), and it provides nitrogen as a plant nutrient. This dual function offers an economic advantage, as the cost of the nitric acid is partly offset by the value of the fertilizer nitrogen it contributes.

The simplest way to make a nitrophosphate is by acidulating phosphate rock with nitric acid to produce a "nitric superphosphate". The product contains calcium nitrate and monocalcium phosphate. The moisture absorbency of the calcium nitrate precludes general acceptance of this superphosphate, however, and it is made only in Switzerland (Lonza process) (5).

Most nitrophosphates are produced in the slurry type of operation, which usually involves the digestion of phosphate rock with nitric acid and the subsequent ammoniation of the acidulate (6). In simplified form, the following reactions take place:

$$Ca_3(PO_4)_2 + 6HNO_3 \rightarrow 2H_3PO_4 + 3Ca(NO_3)_2$$

$$2H_3PO_4 + 3Ca(NO_3)_2 + 4NH_3 \rightarrow 2CaHPO_4 + 4NH_4NO_3 + Ca(NO_3)_2$$

Various alternative procedures are employed to deal with the hygroscopic calcium nitrate, which causes caking if present in the final product. Two general procedures are employed to remove the calcium nitrate and handle it separately, or to introduce reactants that prevent its formation.

Removal of excess calcium nitrate is accomplished by cooling the nitric acidulated slurry, allowing part of the calcium nitrate to crystallize and removing the crystals. Chemical conversion usually is accomplished by adding sulphuric acid, sulphates, phosphoric acid or carbon dioxide to the digestion step or to the slurry during ammoniation. The additives and the ammoniation result in the formation of ammonium nitrate and calcium salts of sulphate, phosphate or carbonate.

In general, the nitrophosphate processes, described below in more detail, involve the steps of acidulation, ammoniation, granulation, drying and sizing (7).

2. *Processes*

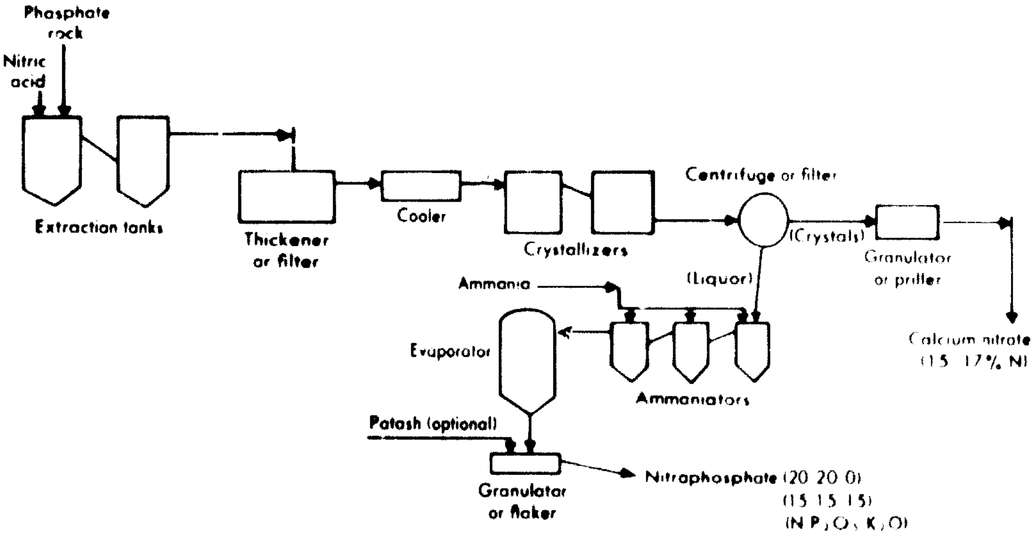
(a) *Calcium nitrate removal*

In processes developed by Odda Smeltwerke, Norsk-Hydro and Dutch State Mines (DSM), phosphate rock is treated with nitric acid, and the acidulate is cooled until there is partial crystallization of calcium nitrate, which then is removed by centrifugation or filtration (3). The calcium nitrate is marketed as a nitrogen fertilizer (15 to 17 per cent N). The remaining solution is ammoniated, and the slurry is flaked on a cooled drum or is mixed with recycled solids in granulating equipment to produce fertilizer containing ammonium nitrate, dicalcium phosphate and varying proportions of ammonium phosphate. Potash may be added.

The flow and typical products of a nitrophosphate process with removal of calcium nitrate are shown in figure 51.

A modified Odda process features treatment of the removed calcium nitrate with ammonia and carbon dioxide to yield ammonium nitrate solution and calcium

Figure 51. Nitrophosphate process: calcium nitrate removal



carbonate (4). The mixture may be converted to a solid fertilizer, or ammonium nitrate solution may be separated from the carbonate and recycled to the ammoniation step or converted into solid ammonium nitrate. The calcium carbonate may be discarded or used for agricultural liming and other purposes. Nitrophosphate combinations range from 15-30-0 to 25-13-0. An outstanding advantage of this widely used procedure is that it requires no sulphur, and, hence, the material costs are low.

(b) *Multiacid processes (phosphonitric, sulphonitric)*

When phosphoric or sulphuric acid is used with nitric acid in the digestion step, the presence of calcium nitrate in the product is avoided. With phosphoric acid added as a reactant, the final product after ammoniation contains ammonium nitrate, dicalcium phosphate and, usually, ammonium phosphate (8). With sulphuric acid added, calcium sulphate is one of the final constituents (9). Granular products made up of these multinutrients have reasonably good chemical and physical characteristics.

A considerable number of modifications of the multiacid processes have been developed by the Société potasse et engrais chimiques (PEC), Tennessee Valley Authority (TVA), St. Gobain, Kampka, Société des phosphates tunisiens and others (5, 6, 10, pp. 1130-1134; 11).

The processes are illustrated in figure 52. Slurry from the extraction tanks is ammoniated in a series of vessels equipped with stirring devices. Vigorous agitation is necessary to keep the slurry in fluid condition. Failure to do so permits undesirable reactions, forming compounds largely useless as fertilizer. Potash salts, usually potassium chloride, may be added to produce triple-component fertilizers. Granulation is accomplished in such devices as blungers or rotating drums, where the slurry is combined with recycled solids and formed into granules. A rotating drum, known as the spherodizer, is commonly used for granulation (6, 12). Slurry is sprayed through a falling shower of partially formed pellets in the drum. The pellets are built up by the slurry and are dried by a current of hot air.

Typical products for each process are listed on the flow sheet. Products of the phosphonitric process, having plant nutrient added as phosphoric acid, are richer in plant nutrients than products of the sulphonitric process.

A process modification by TVA is distinctive in that the acidulate is ammoniated in the solid form, or partly in fluid form and finally in solid form (4, 13). The second alternative is shown in figure 53. Some ammoniation takes place in a pre-neutralizer tank following extraction and is carried to completion in a rotating drum known as the TVA ammoniator-granulator. The partly ammoniated slurry is distributed on a rolling bed of recycled product within the ammoniator. Ammonia is admitted through a sparger under the bed. During and following ammoniation, the semiplastic mass is formed into granules. If preferred, all the ammoniation and granulation can be done in the rotating drum. This process requires considerably less investment and is more versatile than processes in which fluid slurry is ammoniated in multiple vessels and granulation is carried out in a separate step.

Figure 52. Multiacid nitrophosphate process

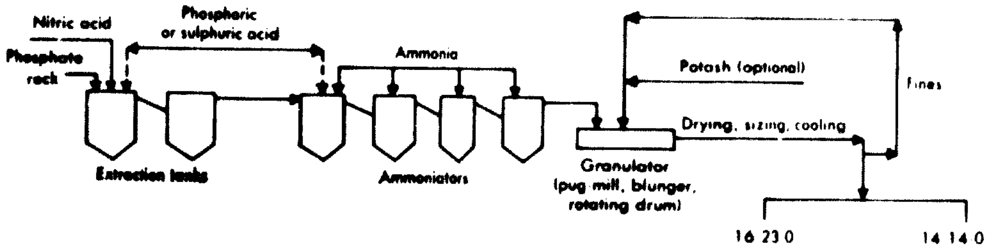
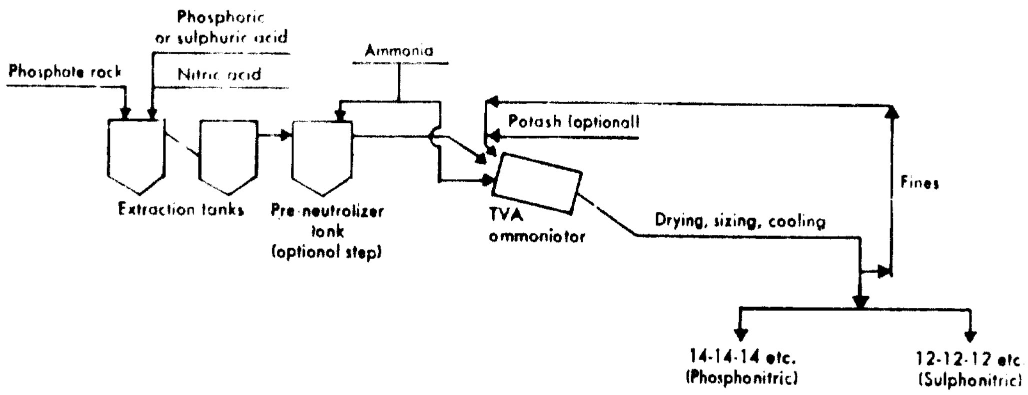


Figure 53. Nitrophosphate process used by Tennessee Valley Authority



(c) *Sulphate addition*

Nitrophosphate process modifications developed by Imperial Chemical Industries, Auby, PEC, TVA, DSM and others avoid the requirement for sulphuric acid by the substitution of sulphate salts for the acid (5, 11, 14, 15). The sulphate serves the same purpose as sulphuric acid in avoiding the presence of calcium nitrate in the final product.

The sulphate salts are added during or after ammoniation of the extraction slurry. Some of the salts used in experimental work and in plant operations include ammonium sulphate, potassium sulphate, langbeinite (potassium magnesium sulphate) and glaserite (sodium potassium sulphate).

Typical products are 12-12-12 with potassium sulphate, and 14-14-0 and 17-13-0 with ammonium sulphate.

In a procedure employed by Dutch State Mines, ammonium sulphate by-product from another process is added to the nitric acidulate in sufficient amount to precipitate all of the lime as calcium sulphate, which is removed by filtration (4). The phosphate in the product is virtually all in the form of water-soluble ammonium salt.

A further alternative, studied by several experimenters, is to react the calcium sulphate with ammonia and carbon dioxide to regenerate the ammonium sulphate for recycling. This method eliminates or greatly reduces the need for sulphur or sulphate.

(d) *Carbon dioxide addition (carbonitric)*

A cost-saving process modification, investigated by PEC, TVA and others, is the use of carbon dioxide to avoid calcium nitrate in the product by fixing surplus calcium as the carbonate (11, 16). Carbon dioxide is a by-product of ammonia synthesis and is usually available at little cost from ammonia plants.

A flow diagram of the carbonitric process, with typical products, is shown in figure 54. As indicated, carbon dioxide is introduced into the slurry during final ammoniation. It was found in experimental work that a small amount of magnesium or potassium sulphate added to the extraction step acts as a "stabilizer" to prevent adverse reactions of phosphate with fluorine and other impurities to form insoluble compounds.

(e) *Other processes*

In a nitrophosphate process modification by Auby, basic slag is used to neutralize a slurry resulting from the reaction of nitric acid, phosphate rock and ammonium sulphate (5). The basic slag not only neutralizes the phosphoric acid in the slurry — no calcium nitrate is present — but also adds phosphate, as the slag contains up to 20 per cent phosphoric oxide. No ammonia is required. Advantages claimed are simpler equipment than usual, good control of neutralization and the addition of phosphate and micronutrients.

Nitric superphosphate products are made by the Lonza method (5). Phosphate rock is acidulated with nitric acid of such concentration as to yield a dry product. The product contains about 6.7 per cent nitrogen and 14.9 per cent phosphoric acid. Over 80 per cent of the phosphate is water soluble. Process variations involve additions of other materials, including potassium sulphate and boric acid, to nitric-acidulated phosphate rock.

Figure 54. Carbonitric process

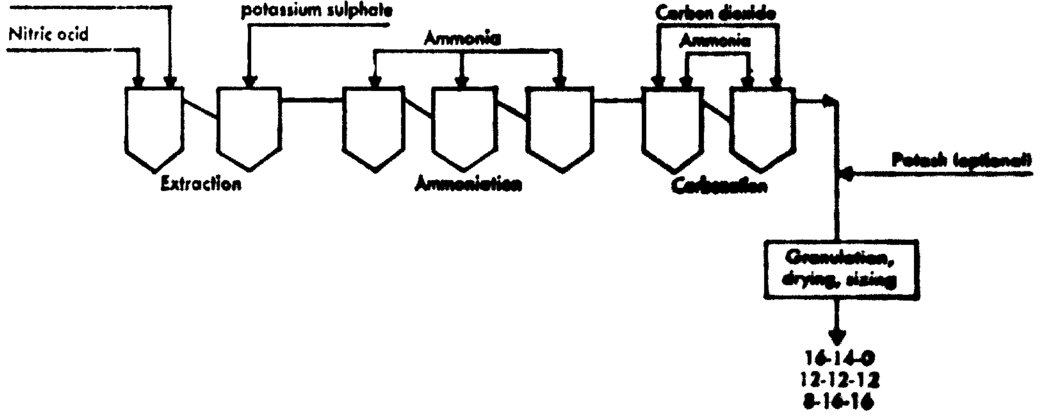


TABLE 87. MATERIALS REQUIRED FOR NITROPHOSPHATE PROCESSES

Calcium nitrate removal	*Carbonitric*	*Sulphonitric*	*Phosphonitric*	*Sulphate addition*	*Auby*	*Lonza*
Phos. rock Nitric acid Ammonia	Phos. rock Nitric acid Ammonia Carbon dioxide Sulphate of magnesium or potassium	Phos. rock Nitric acid Ammonia Sulphuric acid	Phos. rock Nitric acid Ammonia Phosphoric acid	Phos. rock Nitric acid Ammonia Sulphate of ammonia, potassium or magnesium	Phos. rock Nitric acid Basic slag	Phos. rock Nitric acid

3. *Costs*

Nitrophosphates usually have an advantage over other fertilizers in material costs, but are often at a disadvantage in plant investment. The double function of nitric acid in decomposing phosphate rock and providing plant nutrient is economical with regard to materials cost. Counteracting this is the greater complexity — and, hence, the greater investment and operating costs — of most nitrophosphate plants. This is particularly true of a plant employing a calcium nitrate removal process.

The required basic materials for all nitrophosphates, except Auby (basic slag) and Lonza products, are phosphate rock, nitric acid and ammonia. Other materials are required according to process. Table 87 lists the material requirements for the various procedures.

Two of the three normally essential materials are provided by an ammonia plant with a nitric acid unit. Carbon dioxide is also available at an ammonia facility for the carbonitric process. Thus, for economic reasons, almost every nitrophosphate plant is integrated with an ammonia-nitric acid complex.

Extraneous materials in phosphate rock are not critical in nitrophosphate processes except for the calcium nitrate removal method where phosphate low in iron, alumina and silica is superior. Some rock must be calcined before extraction.

TABLE 88. NITROPHOSPHATE PLANT OF TYPE USED BY SOCIÉTÉ POTASSE ET ENGRAIS CHIMIQUES

(Basis: 22.5 tons per hour of 14-14-14) [a]

Investment		
Plant		*Storage facility (20,000 tons)*
$2,000,000 [b]		$250,000 [b]

	Requirements		
	14-14-14 (phosphonitric)	*12-12-12 (sulphonitric)*	*12-12-12 (carbonitric)*
Materials			
Phosphoric acid (as P_2O_5)	34 t/d	11 t/d	16 t/d
Phosphate rock (33-34% P_2O_5)	128 t/d	195 t/d	180 t/d
Nitric acid (basis: 100% HNO_3)	180 t/d	180 t/d	180 t/d
Ammonia	49 t/d	49 t/d	49 t/d
Potassium chloride (60% K_2O)	128 t/d	128 t/d	128 t/d
Coating agent	6 t/d	6 t/d	6 t/d
Sulphuric acid (basis: 100%)		58 t/d	
Carbon dioxide	—	—	20 t/d
Stabilizer (magnesium sulphate)	—		19 t/d
Filler	—	—	27 t/d
Utilities			
Electricity	675 kW	800 kW	800 kW
Fuel	30 million BTU/hr	35 million BTU/hr	35 million BTU/hr
Steam	4,000 lb/hr	4,200 lb/hr	4,200 lb/hr
Cooling water (recirculating)	22,000 gal/hr	22,000 gal/hr	22,000 gal/hr
Cooling water (to sewer)	22,000 gal/hr	22,000 gal/hr	22,000 gal/hr
Labour			
Supervision	30% of direct labour		
Direct labour	6 men per shift		
Maintenance	10% of investment annually		

[a] Plant investment and process requirements are based on 540 tons per day of 14-14-14 (phosphonitric) or 630 tons per day (26.2 tons per hour) of 12-12-12 (sulphonitric or carbonitric). Both 12-12-12 formulations include optionally some phosphoric acid. Daily output of plant nutrients is the same for each grade — 227 tons.

[b] Varies with location and inclusion of ancillary facilities.

TABLE 89. NITROPHOSPHATE PLANT OF TYPE USED BY TENNESSEE VALLEY AUTHORITY

(Basis. 20 tons per hour of 15-15-15 or 14 tons per hour of 20-20-0 of 40 per cent P_2O_5 water solubility)

Investment

Plant	*Storage facility (20,000 tons)*
$1,500,000 [a]	$250,000 [a]

	Requirements	
	15-15-15 (phosphonitric)	*20-20-0 (phosphonitric)*
Materials		
Phosphoric acid (as P_2O_5)	46 t/d	43 t/d
Phosphate rock (33-34% P_2O_5)	81 t/d	76 t/d
Nitric acid (100% HNO_3)	150 t/d	140 t/d
Ammonia	50 t/d	46 t/d
Potassium chloride (60% K_2O)	120 t/d	—
Coating agent	10 t/d	7 t/d
Utilities		
Electricity	950 kW	950 kW
Fuel	12 million BTU/hr	12 million BTU/hr
Steam	1,000 lb/hr	1,000 lb/hr
Water	16,000 gal/hr	16,000 gal/hr
Labour		
Supervision	1 man per shift	
Operators	4 men per shift	
Maintenance	10% of investment annually	

[a] Varies with location and inclusion of ancillary facilities.

A special problem is presented if the calcium nitrate must be marketed separately. This is a popular fertilizer in Europe, but it is used in relatively small quantities elsewhere because of its low nitrogen content. Calcium nitrate may be used to make ammonium nitrate by reaction with water, ammonia and carbon dioxide. There are non-fertilizer uses for calcium nitrate in explosives, matches, incandescent-gas mantles, pyrotechnics and radio-tube manufacture, and as a coagulant for rubber latex.

Nitrophosphate processes may be advantageous in countries lacking sulphur, sulphides or sulphates. The advantages of non-sulphur processes are becoming more important as world demands for fertilizer increase.

Plant size is important in determination of product cost. The investment and retirement charges for a large plant are less per ton of product than for a smaller plant.

Tables 88 and 89 show the investment costs of two types of nitrophosphate plants and the requirements for raw materials, utilities, labour and other needs. The data concern plants of moderate size built in the United States of America.

Included in the investment cost is a storage facility for 20,000 tons. Not included are roads, offices, provisions for utilities or other service facilities necessary for the plant proper. It is assumed that a nitrophosphate unit ordinarily would be installed in conjunction with an ammonia-nitric acid plant. Plans for an isolated nitrophosphate plant should include the additional required services.

Data in these tables may be used for approximate calculations of production costs in any locality through the adjustment of plant investment and the determination of process-requirement costs.

4. *Agronomical characteristics*

The dicalcium phosphate constituent of nitrophosphate is soluble in neutral ammonium citrate solutions, a commonly used reagent for evaluating fertilizer effectiveness, but not in water. By using more phosphoric and sulphuric acids in the process, greater proportions of water-soluble phosphate, such as ammonium or monocalcium salts, result. The water solubility of nitrophosphates ranges from practically none to almost 100 per cent. Those containing little water-soluble phosphate can be compared to heavily ammoniated superphosphates.

There is considerable disagreement on the effectiveness of water-insoluble phosphates. In the United Kingdom of Great Britain and Northern Ireland, where water solubility is the principal method of evaluation, the expansion of nitrophosphate production has been hampered. Throughout continental Europe, nitrophosphates have been generally accepted. A great mass of test data appears to show that nitrophosphates, while sometimes slow in immediate effect, will usually show good subsequent activity and residual effect when they are applied on well-fertilized soils (17, 18). The heavy fertilization practised in Europe builds up phosphorus reserves in the soil and lessens the importance of water-soluble phosphate.

In the United States of America, evidence has pointed to the need for water-soluble phosphates on soils depleted of phosphorus, particularly for crops with restricted root systems or short growing seasons. For such major crops as corn, cotton and cereals, on good soils, nitrophosphates have generally been as effective as other fertilizers (19).

Those who plan nitrophosphate installations should examine well the agronomical characteristics of such fertilizers in relation to their soil and crop needs. Water solubility is one factor for careful consideration. Another consideration, serious in rice-growing countries, is the fact that nitrogen is lost by bacterial decomposition of the nitrate ion in underwater culture. Lack of sulphur in some products may be a handicap on soils deficient in sulphur.

5. *World production*

Available statistics do not show the world production of nitrophosphates as such. The data of the Food and Agriculture Organization of the United Nations (FAO), showing the production of multinutrient fertilizers in various countries, include ammonium phosphates and other products with nitrophosphates (20).

Table 90 shows world output of multinutrient fertilizers by major producing countries during the year 1963/1964. Rough estimates, based on broad assumptions, indicate an annual production of over 5 million tons of nitrophosphate in Europe during the mid-1960s and less than one-tenth that amount in the United States of America.

TABLE 90. WORLD PRODUCTION OF MULTINUTRIENT FERTILIZERS, 1963/1964 [a]

Continent and country	*Multinutrient fertilizers* (Tons of P_2O_5)	*Ammonium phosphate* (Tons of P_2O_5)
Europe		
Belgium	91,922	45,868 [b]
Federal Republic of Germany	300,448	
France	98,900 [c]	
Greece	21,221	19,062 [b]
Italy	231,912	
Netherlands	32,400	
Norway	38,676	
Sweden	16,863	
United Kingdom	173,600	
North and Central America		
Mexico	23,789 [d]	
United States of America	409,000 [e]	801,000
Asia		
Japan	146,950	60,290 [b]
TOTAL	1,585,681	926,220

[a] Includes only countries producing multinutrient fertilizers containing over 10,000 tons of P_2O_5. No data for Canada and the Union of Soviet Socialist Republics.

[b] Included in multinutrient fertilizers.

[c] 1962/1963.

[d] 1961.

[e] All phosphatic fertilizers other than superphosphates, ammonium phosphates and basic slag.

B. AMMONIUM PHOSPHATES

1. *General information*

Fertilizers of the ammonium phosphate type have been produced for over forty years, but, they have become important only in the last decade (21). They are based on ammoniated phosphoric acid, although they are often made by ammoniation of mixed acids or composed of several salts admixed.

Ammonium phosphate may be present in the combinations as the monoammonium or diammonium salt, or mixtures of the two. They may be combined with ammonium nitrate or ammonium sulphate. Most fertilizers of this type are in granular form.

Ammonium phosphates are concentrated fertilizers (up to 74 per cent plant nutrient) and normally have good physical and chemical properties. They may be applied directly or combined in many ways with other materials. Their favourable characteristics have been responsible for their recent accelerating production, especially in North America. The rapidly growing practice of dry mixing or "bulk blending" in the United States of America is based, to a considerable extent, on the use of ammonium phosphate as a primary material.

2. *Products*

(a) *Straight ammonium phosphate*

Monoammonium phosphate containing 11 per cent nitrogen and 48 per cent phosphoric oxide (11-48-0) was one of the early fertilizer products of this type (22). It is made by the ammoniation of wet-process phosphoric acid and contains the iron and aluminium phosphates and other impurities originating in the acid. The degree of ammoniation may be controlled in the process to yield monoammonium phosphate or a mixture of mono- and diammonium phosphate. The latter often is a 16-48-0 grade with about two-thirds of the phosphate as the diammonium salt.

Diammonium phosphate is becoming a more dominant product or constituent in this family of fertilizers. An impure diammonium phosphate of 18-46-0 grade is made with wet-process phosphoric acid. When electric-furnace acid is ammoniated, the result is a crystalline multinutrient product containing 21 per cent N and 53 per cent P_2O_5. Production of the crystalline material is relatively small and is, in most cases, associated with the recovery of by-product ammonia from coke plants.

(b) *Ammonium phosphate sulphate*

By reacting ammonia with mixtures of wet-process phosphoric acid and sulphuric acid, combinations of the salts are produced. Typical products are 13-39-0 and 16-20-0. The latter contains more than half ammonium sulphate — a factor worthy of note in sulphur-deficient areas. Potash may be incorporated with these and other ammonium phosphate combinations to make such grades as 12-12-12.

(c) *Ammonium phosphate nitrate*

The reaction of ammonia with phosphoric and nitric acids produces phosphate-nitrate multinutrient fertilizers. An alternative method is to ammoniate a mixture of solid ammonium nitrate and phosphoric acid. The products are mixtures of ammonium nitrate, monoammonium phosphate and diammonium phosphate. Some typical grades now produced in increasing quantities are 30-10-0, 27-14-0 and 25-25-0. By adding muriate of potash, a grade of 17-17-17 can be produced.

(d) *Urea-ammonium phosphate*

Urea may be mixed with ammonium phosphate to produce such high-analysis combinations as 29-29-0, 25-35-0 and 19-19-19 (with potash). A process, studied on a pilot-plant scale but not yet adopted for commercial use, involves the reaction of urea-plant effluent and phosphoric acid. The process may allow production economies over the separate production of urea and ammonium phosphates.

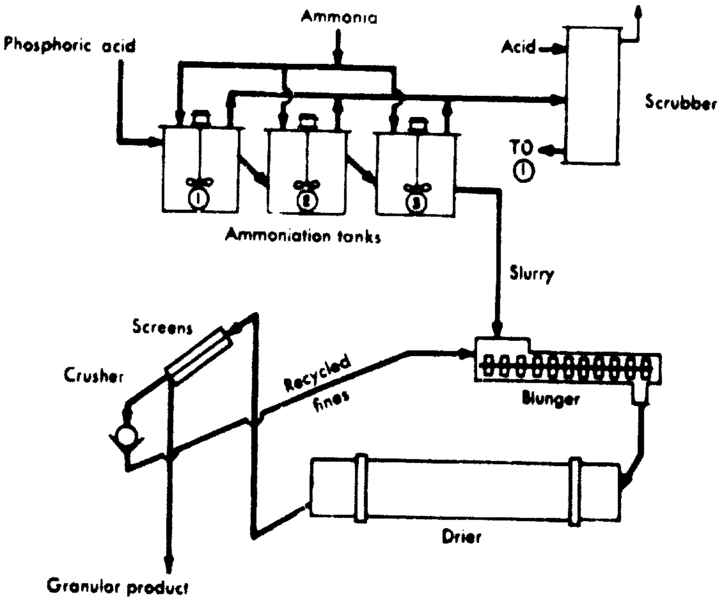
3. *Processes*

Two general methods are used for the production of ammonium phosphate — granulation and crystallization (10, pp. 1127-1130; 23, 24).

(a) *Granulation*

This procedure is by far the most widely favoured because it permits the use of low-cost wet-process phosphoric acid. Until recent years, most ammonium phosphate had been manufactured by a method generally known as the Dorr-Oliver process, or variations of it (24, 25, 26, 27). The process is outlined in figure 55.

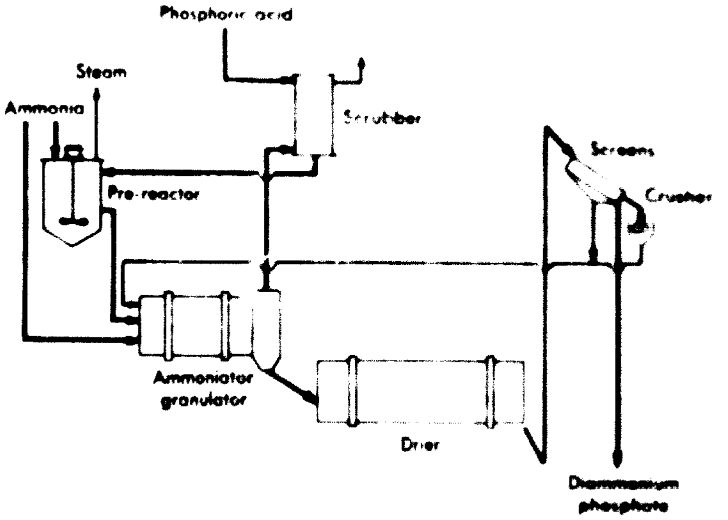
Figure 55. Ammonium phosphate process: slurry ammoniation



Wet-process phosphoric acid is neutralized in a series of tanks where some of the water is evaporated by the heat of reaction. The extent of ammoniation is controlled to produce the desired grade of product. Granulation is accomplished in a blunger or pug-mill, where the slurry is mixed with fine product from the screens. A rotary drum granulator may be substituted for the blunger.

Straight ammonium phosphates of 11-48-0 and 16-48-0 grades are made by the ammoniation of slurry and by granulation, although 18-46-0, essentially all diammonium phosphate, may be produced by carrying ammoniation further in either the ammoniating tanks or the blunger. By adding sulphuric acid to the ammoniators, phosphate-sulphates of such grades as 16-20-0 and 13-39-0 are produced. Less concentrated products containing calcium sulphate can be made by ammoniating unfiltered wet-process phosphoric acid.

Figure 56. Diammonium phosphate process used by Tennessee Valley Authority: slurry and solids ammoniation

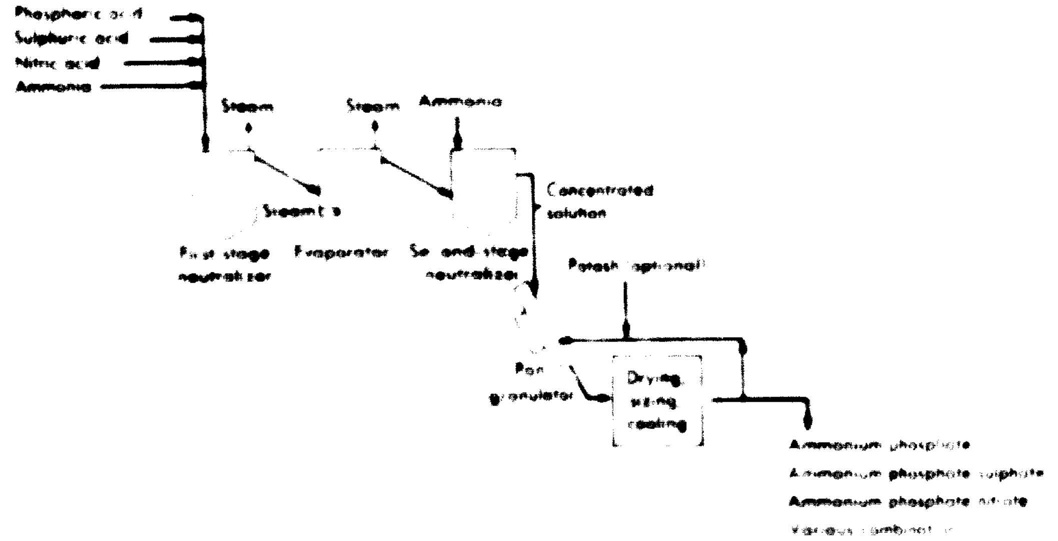


The granulation process shown in figure 56 was developed a few years ago in the United States of America, by the Tennessee Valley Authority (23, 28, 29). The rotating ammoniator-granulator is the essential equipment in this method, but both the slurry and the solids are ammoniated. The procedure allows economy in the evaporation of water by the heat of ammonia-acid reaction. Less drying equipment is needed than in slurry-ammoniation methods. Acid (40 per cent P_2O_5) is partially ammoniated in a pre-neutralizer to an intermediate point between mono- and diammonium phosphates and the slurry is fed to the ammoniator-granulator with recycled fines. The moist solid is further ammoniated to drive the reaction to diammonium phosphate. The recycle requirement is about four to one for diammonium phosphate and less for other grades. This is a considerably lower recycle rate than for most other methods. Excess ammonia from the ammoniator is recovered in a scrubber with incoming phosphoric acid. In this, as in the other methods, sulphuric acid, ammonia-ammonium nitrate solutions or various solid fertilizer materials, e.g., potash, may be added to the process stream.

This process is being used in most of the new plants in the rapid current expansion of diammonium phosphate production in the United States of America (30). A similar process, in which initial ammoniation is carried out in a series of tanks rather than a single one, is used in Europe.

In another process, used by a large manufacturer in the United States, all the ammonia is added in the rotary drum to produce an impure diammonium phosphate of 18-46-0 grade (31). Wet-process acid is distributed on a rolling bed of recycled dry fines in the drum.

Figure 57. Pan-granulation process



Ammonia is introduced through a sparger under the bed. Heated air is passed through the drum to reduce the moisture content to a proper level for granulation. About 15 per cent of the ammonia is unreacted and passes into a scrubber, where it is recovered by incoming acid. Material from the drum is dried and sized.

(b) *Pan granulation*

Recent studies by TVA and others have resulted in a pan-granulation method for the production of the ammonium phosphate type of fertilizers from concentrated solutions (32). A large-scale plant incorporating the process is in operation. As shown in figure 57, granulation is accomplished by spraying a highly concentrated solution, or slurry, of the desired salts on to a cascading bed of recycled fines in an inclined, rotating pan. Successive layers of solidified material build up as the saturated solution cools on the rolling particles. The granular product is dried and sized. The solutions are prepared by partially neutralizing acids with gaseous ammonia, concentrating them by evaporation and further ammoniating to neutrality.

The process is highly versatile and may be adapted to the production of various combinations of ammonium salts of phosphates, nitrates and sulphates. A limitation imposed by this method of ammoniation allows the production of a combination of monoammonium and diammonium phosphates containing a maximum of about 50 per cent of the diammonium salt. Some of the granular fertilizers made in small-scale units were 24-6-12, 17-17-17 and 21-0-21 grades.

(c) *Crystallization*

During the last ten years, several coke producers in the United States of America have converted their ammonia-recovery units from ammonium sulphate production to diammonium phosphate production (33). Coke-oven gases, after suitable cleaning, are passed through a saturator, where the ammonia reacts with electric furnace phosphoric acid. Diammonium phosphate crystallizes as the solution becomes saturated. The crystals are removed by centrifuges and dried. The relatively pure product contains 21 per cent nitrogen and 53 per cent phosphoric oxide.

4. *Costs*

The advantage of the high concentration of ammonium phosphates is reflected by lower costs, in terms of plant nutrient, for storage, bagging, shipping and handling. Material costs for ammonium phosphates are somewhat higher than those for superphosphates or most nitrophosphates because the intermediate or semi-refined material, phosphoric acid, is required instead of the cheaper raw material, phosphate rock.

Ideally, an ammonium phosphate unit should be integrated with a complex providing both ammonia and phosphoric acid. Some of the largest installations are so situated. Large units are often tied in with phosphoric acid plants which are remote from an ammonia supply. Fewer plants are parts of ammonia complexes without phosphoric acid plants. Where a choice is possible, the ammonium phosphate unit should be located at an acid-plant site rather than at an ammonia-plant site. Ammonia can be shipped more economically and with fewer problems than can wet-process phosphoric acid.

Choice of process, product and site requires the assessment of many factors, including the marketability or agricultural need of products, the availability of raw materials or intermediates, storage and shipping problems, and others.

Tables 91 and 92 show investment costs for two types of ammonium phosphate plants and requirements for materials, utilities, labour and other needs. These figures are for plants having a capacity of 20 tons per hour, built in the United States of America. Table 92 includes an estimate for a bagging and shipping facility.

Service facilities, utilities, transportation arrangements, etc. would be provided by the phosphoric acid plant, ammonia plant or complex with which the unit would be connected.

The plant investment for units of various sizes and the manufacturing costs for diammonium phosphate are given in chapter XXI, figures 76 and 77.

5. *Agronomical characteristics*

Ammonium phosphates are more broadly useful as fertilizers than are highly ammoniated superphosphates

TABLE 91 DIAMMONIUM PHOSPHATE PLANT, SLURRY AMMONIATION

(Basis: 20 tons per hour of 16-48-0)

Investment	
Plant	*Storage facility (20,000 tons)*
$1,100,000 [a]	$250,000 [a]
Requirements	
Materials	
Ammonia	98 tons/day
Phosphoric acid	235 tons P_2O_5/day
Utilities	
Electricity	565 kW
Fuel	11 million BTU/hr
Steam	4,000 lb/hr
Water	Minor quantity for process, sanitary water for drinking
Personnel [b]	
Operators	2 per shift
Chief operator	1 per shift
Maintenance	10% of investment annually

[a] Varies with location and inclusion of ancillary facilities.

[b] Does not include supervision or analytical support.

TABLE 92 DIAMMONIUM PHOSPHATE PLANT OF TYPE USED BY TENNESSEE VALLEY AUTHORITY

(Basis: 20 tons per hour of 18-46-0)

Investment		
Plant	*Storage facility (20,000 tons of product)*	*Shipping and bagging facilities (150 t/hr shipping, 30 t/hr bagging)*
$1,000,000 [a]	$250,000	$675,000 [a]
Requirements		
Materials		
Ammonia		109 tons/day
Phosphoric acid		223 tons P_2O_5/day
Utilities		
Electricity		560 kW
Fuel		8 million BTU/hr
Steam		2,000 lb/hr
Water		Minor quantity for process, sanitary water for drinking
Personnel		
Operators (plant)		2 per shift
Foreman (plant)		1 per day
Chemist, anal. (plant)		1/2 per day
Operators (shipping, bulk)		3 per shift
Operators (bagging)		7 per shift
Foreman (shipping, bagging)		1 per day
Maintenance		
Manufacturing plant		10% of investment annually
Storage and shipping		3% of investment annually

[a] Varies with location and inclusion of ancillary facilities.

and most nitrophosphates. They are soluble in both water and citrate solutions. Important agronomical differences are not evident between monoammonium and diammonium phosphates.

Crop yields on acid soils with ammonium phosphates are consistently similar to those with superphosphate, although the calcium and sulphur in superphosphate may be of benefit in some soils. Ammonium phosphates are acid-forming fertilizers, and heavy application on acid soils should be accompanied by proper liming. The toxicity of ammonium phosphate in contact with seeds is similar to that of ammonium sulphate. This salt effect may be avoided by placement away from seeds.

The characteristics of high water-solubility, residual acidity and the combination of ammonium and phosphate ions contribute a degree of superiority to ammonium phosphates on alkaline and calcareous soils. On such soils, better responses are usually obtained with ammonium phosphates than with superphosphate-based fertilizers or nitrophosphates.

On some soils, nitrogen in nitrate form is superior to that in the ammonium form. In such cases, phosphate-nitrate would be preferable to straight ammonium phosphate. Similarly, phosphate-sulphate fertilizers could be superior under certain conditions.

6. *World production*

The FAO statistics (table 90, nitrophosphate) indicate that about three-fourths of the world supply of ammonium phosphate is produced in the United States of America, where production has risen very rapidly in the last few years. Announced plans for new ammonium phosphate plants and expansions in the United States indicate an installed annual capacity of 8 to 9 million tons by the end of 1966 (21).

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XV. PRODUCTION OF MIXED FERTILIZERS

A. GENERAL INFORMATION

The term "mixed fertilizers" is used to denote multinutrient fertilizers, containing two or three primary nutrients — nitrogen (N), phosphorus (P_2O_5) and potash (K_2O). Mixed fertilizers can be classified into two principal types:

(*a*) Dry mixed fertilizers which are made by mechanical mixing of fertilizer materials containing two or three of the primary plant nutrients. In such mixing there is no significant chemical change. The product may be in pulverized form or it can be granulated;

(*b*) Ammoniated mixed fertilizers are multinutrient fertilizers produced by wet mixing of fertilizer primary nutrient elements. Such mixing is accompanied by significant chemical change. All such products are based on the reaction of ammonia with superphosphate. Such products are usually granular.

Granulated fertilizers have certain advantages in so far as handling, distribution and storage are concerned. Granulated materials are more suitable for countries where fertilizers are applied to the soil by mechanical placement. In countries where fertilizers are applied by human labour, granulated fertilizers also have an advantage inasmuch as the windage losses are much less than with pulverized material. In any case, it is desirable in all mixing plants to install a granulator unless the product is automatically produced in granular form.

Mixed fertilizers have certain advantages over single-nutrient fertilizers, especially in regions where farmers are not well acquainted with the use of chemical fertilizers. It is possible, on the basis of scientific tests, to predetermine the proper kinds and amounts of nutrients that should be used on a given soil and crop. Mixed fertilizers can then be prescribed to meet local needs, and the farmer is required only to apply the recommended mixture in the recommended amounts. In the developed countries, mixed fertilizers of a composition best suited to the particular crops grown in the locality can usually be obtained. About 60 per cent of the primary nutrients used in the United States of America are in the form of mixed fertilizers. This percentage has remained fairly constant for many years. Much smaller percentages of mixed fertilizers are used elsewhere in the world.

B. CHOICE OF GRADES OF MIXED FERTILIZERS

It is possible to decide beforehand, depending on the soil conditions and the crops to be grown in that area, what mixtures should be manufactured in a fertilizer-mixing plant. It should be borne in mind also that a large number of mixtures with different proportions of N, P and K will not be possible in regions where single-nutrient fertilizers of different types and containing different quantities of plant food are not made. For a while, this deficiency can be supplied by imports, until a local fertilizer industry is developed to supply the needed materials.

In a developing country like India, certain specified mixtures have been used for paddy, for example, 9-10-10 and 6-12-6; and for potatoes, 7-10-5. In India, the Ministry of Food and Agriculture, in collaboration with the United States Technical Cooperation Mission, made a study of the mixed fertilizers needed and came to the conclusion that six compositions would meet all of the fertilizer needs in India.

As regards the total percentage of plant food in mixed fertilizers, this depends on the raw materials used for mixing. Thus, for example, if only ammonium sulphate and single superphosphate are available, it will not be possible to get a mixed fertilizer from these two materials containing more than 20 per cent plant food. If muriate of potash containing 60 per cent K_2O is also available, mixtures containing more than 30 per cent plant food will be possible. Similarly, if such high-analysis materials as urea or ammonium phosphate are available, mixtures containing larger percentages of plant nutrients can be made. Generally, 30 per cent plant food in a mixture is taken as the dividing line between high-analysis and low-analysis fertilizers. The distance which the fertilizer must be transported from the plant to the farm governs the economics of high-analysis *versus* low-analysis fertilizers. The latter are cheaper to make, but more expensive to ship and apply.

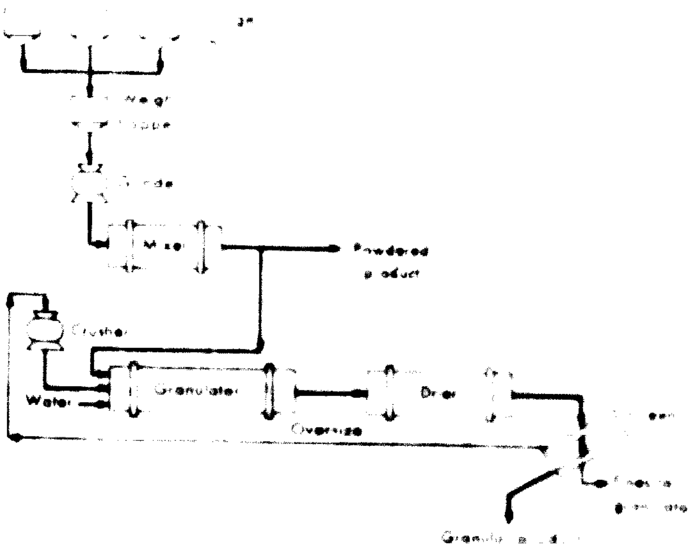
C. PROCESSES FOR THE MANUFACTURE OF MIXED FERTILIZERS

1. *Dry mixing of pulverized materials*

The oldest method for making mixed fertilizers consists of charging weighed batches of dry, pulverized materials to a rotary mixer. The product discharged from the mixer can be used directly, although its powdery nature makes it difficult to apply evenly to the soil or to avoid losses by dusting. Because of this, the mixer product is usually granulated by moistening, in a rotating drum, with water or other liquids, followed by drying and screening. A flow sheet of the process is shown in figure 58.

The principal sources of primary nutrients for dry mixing are ordinary or triple superphosphate, potassium chloride and ammonium sulphate. One disadvantage of this process is its inability to utilize fully such low-cost nitrogen materials as ammonia, nitrogen solutions, ammonium nitrate or urea. For this reason, dry mixing of pulverized materials has been largely displaced by other methods for making mixed fertilizers. The method is now used mainly for no-nitrogen or low-nitrogen mixtures.

Figure 58. Mixed fertilizers from pulverized materials



2. Dry mixing of granular materials: bulk blending

In the early days of the fertilizer industry raw materials were seldom marketed in granular form. Today a wide variety of granular fertilizer materials are commercially available, as shown in table 93. If two or more granular materials having similar particle sizes are blended, the resulting blend has little tendency to become segregated or unmixed. This is the basis of bulk blending, a relatively new method of preparing mixed fertilizers (1).

As in the dry mixing of pulverized materials, no chemical reactions occur. Since the raw materials are granular, so is the product. An advantage over the dry mixing of pulverized materials is that such low-cost nitrogen materials as prilled ammonium nitrate or urea can be used as raw materials, even though ammonia or nitrogen solutions cannot be used. Since no granulation of the product is needed, plant requirements are simple,

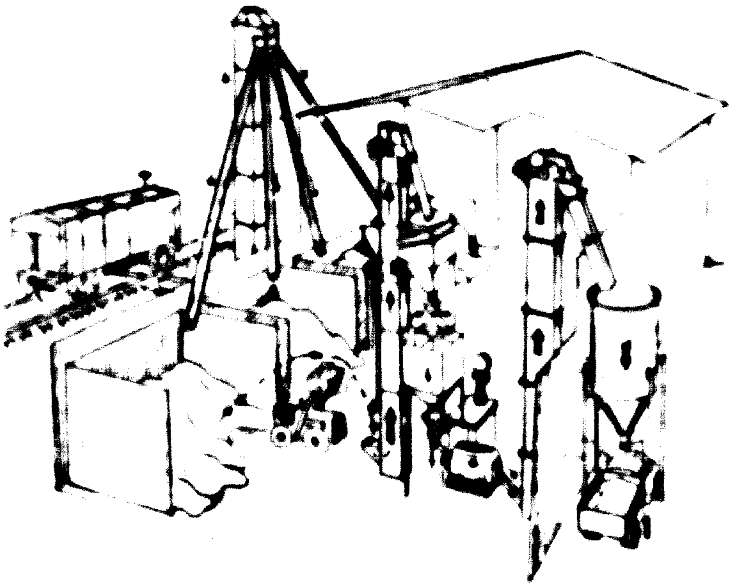
TABLE 93. COMMERCIAL GRANULAR FERTILIZER MATERIALS

	Apparent specific gravity	Grade	Tyler screen range (weight percentage) +6	−6 +8	−8 +10	−10 +16	−16
Ammonium nitrate							
Prills	1.29	33.5-0-0	0	6	65	25	4
Prills (high density)	1.65	33.5-0-0	0	0	8	89	1
Granules	1.50	33.5-0-0	1	35	54	8	2
Flakes	1.63	33.5-0-0	0	25	43	28	4
Ammonium nitrate sulphate							
Granules	1.51	30-0-0	2	29	56	10	3
Urea							
Prills, unconditioned	1.32	46-0-0	0	1	17	78	4
Prills, conditioned	1.31	45-0-0	0	0	1	94	5
Ammonium sulphate							
Compacted flakes	1.64	21-0-0	0	6	46	41	7
Crystals	1.75	21-0-0	0	2	38	51	9
	1.75	21-0-0	0	4	20	51	25
Ammonium phosphate nitrate							
Prill-like granules	1.27	30-10-0	0	5	63	31	1
Granules	1.56	30-10-0	0	33	55	9	3
Diammonium phosphate							
Granules (from wet-process acid)	1.63	18-46-0	0	5	83	12	0
	—	18-46-0	0	42	57	1	0
Crystals (from furnace acid)	1.62	21-53-0	0	8	45	39	8
Triple superphosphate							
Granules	2.12	0-46-0	< 1	29	56	14	< 1
	—	0-46-0	1	21	37	31	10
High-analysis superphosphate							
Granules	1.90	0-54-0	< 1	29	41	27	2
	2.15	0-56-0	< 1	14	37	46	2
Potassium chloride							
Flotation product, granular [a]	1.97	0-0-60	2	36	52	10	0
Flotation product, coarse [a]	—	0-0-60	0	0	19	51	30
Solution-rounded crystals	1.93	0-0-62	0	5	29	58	8
Compacted flakes	1.96	0-0-60	0	14	65	20	1
Filler							
Crushed limestone	2.53	0-0-0	0	9	60	26	5
	2.56	0-0-0	0	22	42	24	12

[a] "Granular" and "coarse" are terms used by the industry; "granular" usually is 6 to 20 mesh, and "coarse" is mainly 10 to 28 mesh.

and plant investment costs are of the order of $40,000 for blending plant with a capacity of 3,000 tons per year like that shown in figure 59

Figure 59. Bulk-blending plant



In the United States of America, many of the bulk-blending plants are owned wholly or partially by large producers of the raw materials used in bulk blending. This assures a supply of properly granulated raw materials for the blending plant. The full advantages of bulk blending are attained only if the product is loaded directly into spreader trucks which take it to the farm and apply it to the soil. In fact, intermediate storage and handling may cause segregation.

Various formulations for making a 12-12-12 grade of mixed fertilizer by dry mixing are shown in table 94, which illustrate the diversity of the raw materials that can be used to prepare a single product.

3. *Ammoniated mixed fertilizers*

When ammonia is added to superphosphate a series of chemical reactions take place and heat is generated (2). By adding other materials, e.g., potassium chloride, to the reaction mixture, granular mixed fertilizers of a wide range of nutrient content can be produced. This is known as the ammoniator-granulator method for producing mixed fertilizers. Unlike the dry-mix methods, it can utilize gaseous and liquid raw materials, for example, ammonia and acids. Unlike the bulk-blending process, it can utilize the cheapest form of raw materials and even produce certain raw materials in process. Thus, the ammoniator-granulator method can use a wide range of raw materials, an important factor in a seasonal industry like fertilizer manufacture.

Since chemical reactions are fundamental to the process, not only in forming new compounds, but also in generating most or all of the heat required for granulation and drying, operation of the ammoniator-granulator method must take into account chemistry and chemical engineering factors which do not enter into dry mixing. This does not mean that a high degree of technical competence is required to operate an ammoniation plant. Equipment, operating controls and formulations have been standardized sufficiently to permit satisfactory operation with relatively little professional supervision.

There are three established processes for the ammoniation-granulation method, based on the type of mixer used. These are the batch-mixer process, the pug-mill process and the rotary-drum process. Flow sheets for these processes are shown in figure 60.

In addition, other types of mixers have been used for preparing ammoniated granulated mixed fertilizers, including pan granulators and fluidized beds. These other methods, however, are relatively new and are currently used mainly for ammoniating superphosphate.

The formulations used in the ammoniation method must take into account the chemistry and physics of the process. If the heat generated by the reactions is insufficient to dry the product, external heat will be required. If too much heat is generated, addition of water will be required to remove the excess. This subject has been discussed in the literature (3). Many satisfactory formulations have been published so that inexperienced operators need not calculate formulations (4). Table 95 shows eight different formulations suitable for making a single grade of product by the various ammoniation processes.

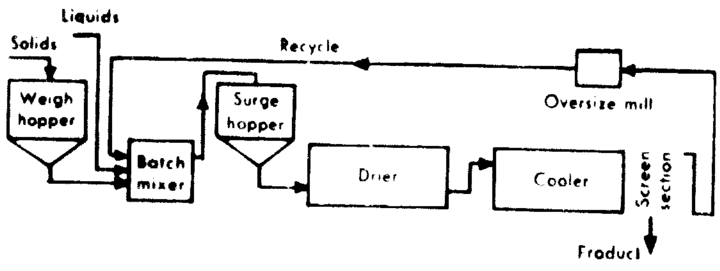
A plant for producing ammoniated mixed fertilizers is far more complex than a bulk-blending plant. Further-

TABLE 94. FORMULATIONS FOR PRODUCING A 12-12-12 GRADE OF DRY-MIXED OR BULK-BLENDED FERTILIZER

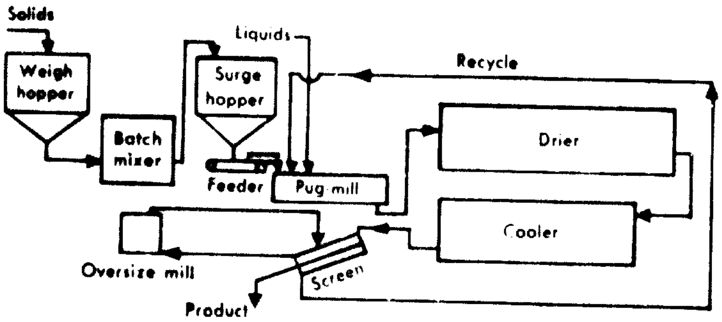
Type of material	*Amount of material required per ton (kilogrammes)* (1)	(2)	(3)	(4)
Ammonium sulphate (21 per cent N)	510	—	445	423
Urea (45 per cent N)	29	268	—	—
Ordinary superphosphate (20 per cent P_2O_5)	—	478	—	205
Triple superphosphate (46 per cent P_2O_5)	261	54	—	—
Monoammonium phosphate (11-48-0)	—	—	250	—
Diammonium phosphate (18-46-0)	—	—	—	172
Potassium chloride (60 per cent K_2O)	200	200	200	200
Filler	—	—	105	—

Figure 60. Flow sheets of ammoniation processes for making mixed fertilizers

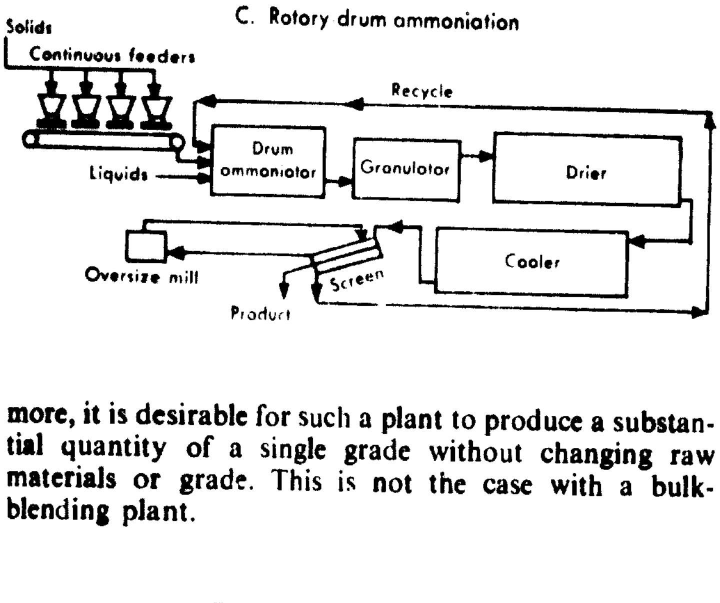
A. Batch mixer ammoniation



B. Pug mill ammoniation



C. Rotary drum ammoniation



more, it is desirable for such a plant to produce a substantial quantity of a single grade without changing raw materials or grade. This is not the case with a bulk-blending plant.

4. *Liquid mixed fertilizers*

Liquid mixed fertilizers are water solutions containing two or three primary nutrients. Thus, the term does not include anhydrous ammonia or nitrogen solutions (chapter XI).

Basically, liquid mixed fertilizers are made by neutralizing phosphoric acid with ammonia to form a solution of ammonium phosphate. This solution can be used as it is or such materials as urea, ammonium nitrate or potassium chloride may be added to make a variety of grades. Formulations are governed by mutual solubilities of the compounds in water (5). It is important that liquid mixed fertilizers do not deposit salts ("salt out") if they become chilled in the course of storage, transportation or application, because such deposits can be difficult to redissolve and are likely to clog the equipment. In the United States of America, 0° C is generally taken as the lowest temperature likely to be encountered by liquid fertilizers; thus, formulations there are usually designed to avoid salting out at temperatures down to 0° C. This value would be higher for a warmer climate and lower for a colder one.

The neutralization of the phosphoric acid can be done in batches or continuously. A flow sheet for a liquid mixed fertilizer plant is shown in figure 61.

Figure 61. Flow sheet for the production of liquid mixed fertilizers

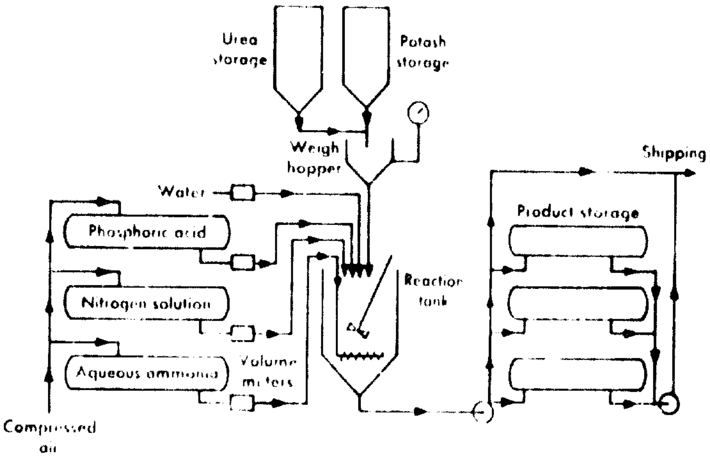


TABLE 95. FORMULATIONS FOR PRODUCING A 12-12-12 GRANULAR AMMONIATED MIXED FERTILIZER

Type of material	*Amount of material per ton of product (kilogrammes)* *Continuous-drum ammoniation*						*Pug-mill*	*Batch drum*
Nitrogen solution [a]	25	325 [b]	223	250	223	170 [c]	220	293 [d]
Anhydrous ammonia	60	—	—	—	—	—	—	—
Ammonium sulphate	296	—	68	100	147	158	170	48
Urea	—	—	—	—	—	35	—	—
Diammonium phosphate	—	—	166	—	—	—	—	—
Ordinary superphosphate	75	365	387	257	380	206	268	348
Triple superphosphate	228	104	—	156	—	186	145	107
Phosphoric acid (75% H_3PO_4)	—	—	—	—	84	—	—	—
Potassium chloride	200	200	204	204	200	200	194	200
Sulphuric acid (100% basis)	130	69	70	70	31	105	58	28

[a] Containing 41 per cent nitrogen and 22.2 per cent ammonia except as noted (see chapter XI).

[b] Containing 37 per cent nitrogen.

[c] Containing 45.5 per cent nitrogen (urea-ammonia solution).

[d] Containing 45 per cent nitrogen (ammonium nitrate-ammonia solution).

Despite the limitations of liquid mixed fertilizers as discussed above, liquids can be a useful adjunct to the fertilizer programme of a developing country. For example, where farmers are accustomed to using natural liquid manures, or where irrigation systems are developed, liquid mixed fertilizers merit consideration.

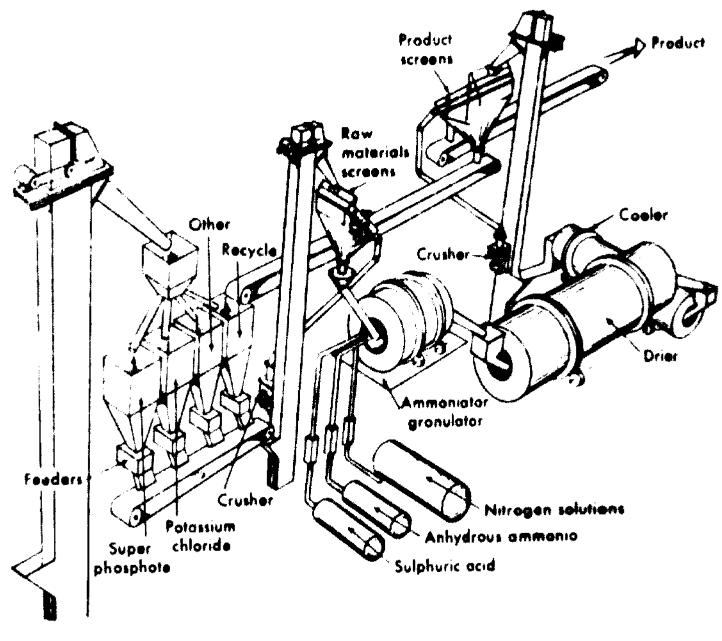
D. ECONOMICS OF MIXED-FERTILIZER PROCESSES

In the following estimate, costs of ammoniated mixed fertilizers are compared with costs of bulk-blended mixtures (1). The comparison is intended to reflect common practice in the United States of America in the manufacture and distribution of these two types of fertilizers.

1. *Investment costs*

Diagrams of the two plants are shown in figures 59 and 62. The ammoniator plant investment cost is assumed at $500,000 and its annual output is 27,000 tons. The bulk-blending plant is assumed to cost $40,000, and its annual output is 2,700 tons.

Figure 62. Rotary-drum ammoniator mixing plant



2. *Raw materials costs*

For purposes of this estimate, the costs are based on producing a 12-12-12 grade of fertilizer in the ammoniator plant and a 14-14-14 grade in the bulk-blending plant. The formulations and raw materials costs are shown in table 96. The raw materials costs are based on published market prices in the United States of America for the spring of 1964, plus freight costs to a plant site in the south-central United States. As shown in table 96, the cost of raw materials per kilogramme of primary nutrients for the 12-12-12 mixture is lower than that for the 14-14-14 blend.

3. *Production costs*

The total estimated costs for the ammoniated mixture and the bulk blend are shown in table 97. The sum of the raw materials, operating, sales and return on plant invest-

TABLE 96. RAW MATERIALS COSTS

(Dollars)

Material	*Kilogrammes per ton of product*	*Cost* Per ton of material	Per ton of product
Ammoniated mixed fertilizer (12-12-12)			
Ammonium sulphate (21 % N)	92	31.00	2.86
Nitrogen solution (41 % N)	247	54.50	13.42
Single superphosphate (20 % P_2O_5)	279	16.30	4.55
Triple superphosphate (46 % P_2O_5)	42	50.00	7.11
Muriate of potash (60 % K_2O)	200	36.20	7.25
Sulphuric acid (93 % H_2SO_4)	85	16.50	1.40
TOTAL			36.61
Bulk-blended fertilizer (14-14-14)			
Diammonium phosphate (18-46-0)	305	78.60	23.90
Ammonium sulphate (21 % N)	455	35.70	16.10
Muriate of potash (60 % K_2O)	233	38.50	8.97
Filler	8	4.00	0.03
TOTAL			49.00
***Material** cost* (per kilogramme of primary nutrients)			
12-12-12 mixture			0.123
14-14-14 blend			0.142

TABLE 97. PRODUCTION COSTS OF AMMONIATED MIXED AND BULK-BLENDED FERTILIZERS

(Dollars)

Cost item	*Cost per ton* Ammoniated mixture	Bulk blend
Direct labour	0.625	0.952
Supervision and clerical	0.318	0.318
Plant maintenance	0.608	0.480
Supplies	0.308	0.245
Power and water	0.218	0.045
Property tax and insurance	0.308	0.245
Plant depreciation [a]	1.000	1.210
Operating overhead	0.935	1.000
Analyses	0.090	0.045
SUBTOTAL	4.41	4.54
Sales	2.72	2.72
Return on investment (25 %)	3.78	2.84
Raw materials [b]	36.61	49.00
TOTAL, PRODUCTION COST	47.52	59.10
Transport to dealer	2.72	—
Dealer's profit	4.46	—
Farmer's cost:		
Per ton of fertilizer	54.70	59.10
Per kilogramme of primary nutrient	0.152	0.141

[a] Based on fifteen years for ammoniator plant and ten years for bulk-blending plant.

[b] See table 96.

ment is about the same per kilogramme of primary nutrient. But when the transport costs to the dealer and the dealer's profit are added to the ammoniated mixture, the farmer's cost is about 8 per cent higher per kilogramme of primary nutrients than for the bulk-blended mixture. The bulk blender pays more for raw materials, but he sells direct to the farmer and this accounts for his economic advantage.

4. *Size of plant*

The quantity of products made and sold counts heavily in the economics of mixed-fertilizer plants of all types. An output of 2,500 to 3,000 tons *per annum* is generally required for efficient operation of a bulk-blending plant. For an ammoniation plant, the output generally must be at least 30,000 tons *per annum* for profitable operation.

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XVI. SECONDARY AND MICRONUTRIENTS

In the past decade or so, there has been a growing need for the inclusion in fertilizers of nutrients other than the primary elements, nitrogen, phosphorus and potassium. There are several reasons for this. Fertilizers have been increased in grade to decrease handling and shipping costs, with the result that there is less room for the secondary and micronutrients that formerly were included incidentally because they were present in the original raw materials. Furthermore the problem of supplying micronutrients is expected to become increasingly important as the natural supply in the soil becomes depleted. Needs have developed in some areas and for some crops for specific micronutrients in fairly large amounts — larger than would be supplied even by unpurified raw materials. More instances of need for micronutrient elements are being discovered also by research and by improved methods for identifying deficiencies.

The need for including additives in fertilizers has introduced several problems in production. In making solid mixes, it is difficult to get good mixing of the small amount of additives with the other materials and, once mixed, segregation may take place in handling. Moreover, some of the additives may not be chemically compatible with the main constituents of the mixture. In the production of liquid fertilizers — liquid mixed and nitrogen liquids — the problem of incorporating the additive thoroughly is often simplified but, unfortunately, many of the additive materials needed are not very soluble in the usual types of such liquids.

This chapter covers methods for incorporating secondary nutrients (calcium, magnesium and sulphur) and micronutrients (boron, copper, iron, manganese, molybdenum and zinc) in the solid, liquid and suspension types of fertilizers. These nutrients are just as essential to proper plant growth as the primary nutrients. Particular emphasis is placed on the use of solid-fertilizer carriers, as this is the principal current practice.

A. SECONDARY NUTRIENTS

The importance of the secondary nutrients, calcium, magnesium and sulphur, in agriculture has been realized for some time, and the addition of sources of these elements to soils is commonly practised in areas where modern fertilizer technology is applied. In addition to serving important functions as plant nutrients, they are also used extensively as soil amendments to correct undesirable soil conditions. Maintenance of the proper soil pH, generally 6 to 7, is most important in order to obtain efficient utilization of nutrients by the plants.

Certain soils are naturally productive, however, to retain their high productivity, the addition of the amendments is necessary. In soils that are naturally unproductive because of excessive acidity or alkalinity, these conditions must be corrected before the soils can become economically productive. Furthermore, many soils which are currently considered unsuitable for agricultural purposes could quite possibly be amended economically and used satisfactorily.

1. *Calcium and magnesium*

Calcium and, to a lesser extent, magnesium are present in many of the commonly used fertilizer materials (table 98). However, in recent years there has been a trend towards the separate application of calcium and magnesium compounds. The growing use of liquid fertilizers has contributed to this trend, since the commonly used calcium and magnesium compounds generally are not soluble in such liquids. Futhermore, some agronomists prefer separate application in advance of fertilizer application to avoid potential losses in nitrogen.

TABLE 98. COMMON FERTILIZER MATERIALS WHICH ALSO CONTAIN SECONDARY NUTRIENTS

Fertilizer	*Formula of principal compound present*	Analysis (percentage by weight)					
		N	*P_2O_5*	*K_2O*	*CaO*	*MgO*	*S*
Ammonium nitrate-limestone	$NH_4NO_3 + CaCO_3 + MgCO_3$	21			11	7	—
Ammonium phosphate sulphate	$(NH_4)_2HPO_4 + NH_4H_2PO_4 + (NH_4)_2SO_4$	16	20		—		15
Ammonium sulphate	$(NH_4)_2SO_4$	21		—	—	—	23
Ammonium sulphate nitrate	$(NH_4)_2SO_4 \cdot NH_4NO_3$	26	—		—	—	12
Calcium cyanamide	$CaCN_2$	21			70	—	—
Calcium nitrate	$Ca(NO_3)_2$	15			27	2	—
Phosphate rock	$3Ca_3(PO_4)_2 \cdot CaF_2$	—	30-36		45-50	0.1-1	—
Potassium magnesium sulphate (langbeinite)	$K_2SO_4 \cdot 2MgSO_4$	—		21	—	9	22
Potassium sulphate	K_2SO_4			50			17
Ordinary superphosphate	$Ca(H_2PO_4)_2 \cdot H_2O$		20		28		13
Triple superphosphate	$Ca(H_2PO_4)_2 \cdot H_2O$		46		19	—	1

Calcium and magnesium are important constituents of plants, and symptoms of deficiencies in these nutrients are shown in table 99. However, the sources of calcium and magnesium are supplied commonly in amounts required to adjust the soil pH, rather than in response to an indicated plant deficiency. The usual materials are finely ground agricultural limestone (principally calcium carbonate) and dolomite (a limestone composed principally of a double carbonate of calcium and magnesium). Other sources include burnt or hydrated limes, marl and such calcareous wastes as oyster shells, sludges or slags. The material used depends principally upon local availability and economic considerations. The relative neutralizing values of pure materials are shown in table 100.

The fineness of limestones used for this direct application, called liming, varies widely in the United States of America and ranges from limestone "meal" of about 8-mesh size to limestone "flour" of 100-mesh or smaller size. The finer a liming material is ground, the more quickly it becomes effective. Fertilizer manufacturers generally prefer a limestone with a particle size of 80 to 100 mesh (1).

TABLE 99. SYMPTOMS OF CALCIUM, MAGNESIUM AND SULPHUR DEFICIENCIES IN PLANTS

Secondary nutrient	*Symptoms of deficiency*
Calcium	In most plants, root growth is reduced, root rotting frequently occurs and the roots are affected before the tops show any symptoms. In moderate stages of deficiency, the young leaves become distorted, fail to grow and show spotting or necrotic areas. In the acute stage, there is a general collapse of growing points and a die-back of the terminal buds
Magnesium	Deficiency symptoms are frequently found on lower leaves of plants. In cotton, a reddening of the lower leaves occurs, while in potatoes, an orange-yellow colouration appears on the lower leaves and along the veins. In corn, there is a striping or chlorosis between the veins and if the deficiency is severe, a crimson-red colour frequently appears on the lower leaves
Sulphur	Sulphur deficiency symptoms tend to resemble those of nitrogen deficiency. Under a continuous low supply of either element, plant appearance does not provide an assured means of differentiating between deficiencies of sulphur or nitrogen. With a diminishing supply, however, a distinction may be observed. With nitrogen deficiency, the plant may become a uniform yellowish-green colour, and with some plants, the lower leaves may turn yellow and fall from the plant. With sulphur deficiency, the older leaves remain green, and the younger leaves become yellow-green and, in severe cases, chlorotic

SOURCE: K. C. Berger and P. F. Pratt, "Advances in secondary and micronutrient fertilization", in M. H. McVickar, G. L. Bridger and L. B. Nelson, eds., *Fertilizer Technology and Usage* (Madison, Wisc., Soil Science Society of America, 1963), pp. 287-340.

TABLE 100. RELATIVE NEUTRALIZING VALUES OF PURE LIMING MATERIALS

Liming materials	*Relative neutralizing values*	*Pounds of liming materials equivalent to 1 ton*	
		Calcium carbonate	*Calcium oxide*
Calcium carbonate	100	2,000	3,570
Magnesium carbonate	119	1,680	3,000
Calcium oxide	178	1,120	2,000
Magnesium oxide	250	800	1,430
Calcium hydrate	135	1,480	2,640
Magnesium hydrate	172	1,160	2,070
Dolomite	108	1,850	3,330
Dolomitic hydrate	175	1,145	2,040

SOURCE: R. S. Boynton, "Calcium and magnesium in mixed fertilizers", in Vincent Sauchelli, ed., *Chemistry and Technology of Fertilizers* (New York, Reinhold Publishing Corp., London, Chapman & Hall, 1960), p. 447.

The application of these calcium and magnesium compounds to many soils results in striking increases in plant growth beyond that expected from a simple response to the deficient nutrient element (2). These benefits are:

(a) *Improved phosphorus availability*. With low pH soils and soils high in aluminium and iron oxide content, phosphates are made less available because of their reaction with these compounds. Liming to a pH of 6-7 increases phosphate availability because of the precipitation of the iron and aluminium in forms other than as the phosphate. At higher pHs, the availability is decreased, however, because of the precipitation of calcium or magnesium phosphates;

(b) *Nitrification*. Most of the organisms responsible for conversion of ammonia to nitrates require calcium;

(c) *Nitrogen fixation*. This process is favoured by the addition of liming agents;

(d) *Micronutrient availability*. Except for molybdenum, the availability of micronutrients increases with a decrease in soil pH. This can be detrimental because of the toxic nature of these elements in other than small concentrations. Depending upon the soil, a pH of 6-7 is usually most satisfactory from the standpoints of nutrient availability and toxicity. Molybdenum deficiency generally decreases with an increase in soil pH, and a pH greater than 7 is preferred; however, liming soil to this high pH is discouraged because of previously stated reasons;

(e) *Physical condition of soil*. Liming improves the structure of fine-textured soils.

2. *Sulphur*

The use of sulphur compounds as soil amendments to correct alkali conditions in soils (presence of excess sodium salts, particularly sodium carbonates) is commonly practised. Large tonnages of finely ground calcium sulphate (gypsum) are used for this purpose in the calcareous soil areas of western United States of America and in other parts of the world (3). Elemental sulphur also is used.

Until recently, the essential role of sulphur in plant nutrition had not been given much publicity, nor had it required much attention. From its very beginning, fertilizer manufacture has relied heavily on sulphuric acid as a reagent to free phosphate from the ore — as in the production of superphosphate — and to fix ammonia in a solid form — as in ammonium sulphate. Much of the sulphur in the acid remained in the fertilizer. In addition, sulphur is present in the air as sulphur dioxide and is brought down and made available for plant nutrition by rainfall in amounts that vary from perhaps 4 to 40 pounds per acre *per annum*, depending largely on the proximity of areas where sulphur containing fuels are used. Sulphur also occurs naturally in some soils in ample amounts.

Changes in recent years have tended to decrease these sources, and attention is now focused on how best to supply sulphur to many of the crops being grown. One of these changes is the trend towards higher analysis fertilizers. Another is that the amount of sulphur available from the atmosphere is decreasing. Greater emphasis is being placed on the control of atmospheric pollutants, sulphur dioxide included, and the use of low-sulphur or sulphur-free fuels is increasing. Combustion of coal in power-generating plants releases large quantities of sulphur into the atmosphere, but this source will diminish as atomic power comes into wider use.

Symptoms of sulphur deficiencies in plants are given in table 99. A deficiency is corrected either by adding a sulphur-containing fertilizer or by separate application of a sulphur compound, depending generally on economic considerations (4). Usually, the sulphur is applied separately in amounts of 10 to 50 pounds per acre. The analyses of many of the common sulphur-containing fertilizers are given in table 98.

3. *Incorporation of secondary nutrients in granular fertilizers*

Even though significant quantities of calcium are present in many of the common fertilizer materials (superphosphates, nitric phosphates, calcium cyanamide and calcium nitrate), calcium is commonly applied directly to the soil in the form of powdered dolomite, which also is the common source of magnesium. On some soils, however, magnesium is needed, and dolomite addition is undesirable because the soil pH is already high. Magnesium potassium sulphate, or magnesium oxide or sulphate is incorporated in the fertilizer for these soils (5); generally 20 to 59 pounds of magnesium are supplied per acre.

In some European countries, the addition of magnesium to fertilizers is quite common. Kieserite ($MgSO_4.H_2O$) is the usual form. With heavy applications of nitrogen on grass land, the magnesium need becomes acute in some areas. The need for supplying magnesium in fertilizer in the United States of America probably will increase as fertilization rates approach those in European countries.

Several methods for incorporating sulphur compounds in granular fertilizers have been developed (5, 6). Elemental sulphur has been incorporated successfully in concentrated superphosphate by granulating the superphosphate and sulphur with steam and water in a rotating drum. Commercial-scale production of granular high-analysis fertilizer with added elemental sulphur has been reported. Furthermore, a prilled mixture of urea and sulphur (40 per cent N and 10 per cent S) is a relatively new material now being produced in the western part of the United States of America.

Ammonium nitrate, or any other undiluted nitrate fertilizer, should not be combined with elemental sulphur (7). The sulphur is an oxidizable material, and, in such mixes it constitutes a potential explosion hazard. Nitrates can be combined safely with sulphates, however, and one such product, ammonium sulphate nitrate (26 per cent N and 12 per cent S), is commercially produced. Care should be exercised also if elemental sulphur is dry mixed with granular fertilizers. To avoid the possibilities of explosions, it is essential that dusting in enclosed areas be minimized and that any possible source of ignition in the vicinity be avoided. Adequate ventilation must be provided. Some operators have found that the use of steam or water fog is helpful in minimizing dusting and the development of static electric charges (3).

In Europe, enriched superphosphate with a sulphur content between that of ordinary and triple superphosphates is commonly used. This material is produced by acidulating the phosphate rock with a mixture of phosphoric and sulphuric acids. In Australia and New Zealand, ordinary superphosphate is fortified with elemental sulphur to give mixtures of 18-36 per cent sulphur content. Generally, the materials are simply mixed; in one case, however, the sulphur is added during the acidulation step.

4. *Secondary-nutrient addition to liquid fertilizers*

Of the secondary elements, calcium and sulphur are the ones most often added to liquid fertilizers (8). The addition of calcium is restricted mainly to western United States of America, where it is used in the form of calcium nitrate in ammonium nitrate solution. The solution produced there commercially contains 36 per cent calcium nitrate and 30 per cent ammonium nitrate, with a total of 17 per cent nitrogen. The solution is applied directly rather than being mixed with other solutions.

Calcium is not compatible with the usual type of neutral liquid-mixed fertilizers (those made from orthophosphoric acid), since it precipitates as the phosphate. There appears to be little need for adding it to mixed liquids, however, as the direct application of lime from local sources generally is more economical.

Furthermore magnesium is used in liquid fertilizers. Like calcium, it precipitates as phosphates from the liquid-mixed fertilizers containing phosphate.

Sulphur is added to nitrogen solutions and to liquid-mixed fertilizers in three forms, as ammonium polysulphide, as ammonium bisulphite and as ammonium thiosulphate solutions. The ammonium polysulphide solution is compatible with anhydrous or *aqua* ammonia, but it is not soluble to any useful extent in mixed liquids containing phosphate. The ammonium bisulphite solution (8.5 per cent nitrogen and 17 per cent sulphur) can be mixed with any of the fertilizer solutions. Typical grades with ammonium nitrate solution are 18-0-0-2 (N-P_2O_5-K_2O-S) and 14-0-0-7. With mixed liquids, such grades as 10-10-0-3, 8-8-0-8 and 15-5-0-1 are reported.

Addition of the ammonium bisulphite solution to a 10-34-0 grade ammonium polyphosphate liquid fertilizer gave liquid products with such grades as 10-30-0-3 and 10-26-0-5. As is discussed below in the micronutrient section, this 10-34-0 grade liquid, which contains about half of its phosphate as orthophosphate and half as polyphosphate, is an effective sequestering agent. Its use in the liquid fertilizer industry is increasing rapidly. Ammonium sulphate and ammonium sulphite were somewhat less soluble in such solution.

Ammonium thiosulphate is used as a 60 per cent aqueous solution which contains 12 per cent nitrogen and 26 per cent sulphur. The solution is compatible in any proportion with neutral or alkaline phosphate-containing solutions, as well as with aqueous ammonia and nitrogen solutions. Addition of this solution to 8-24-0 grade orthophosphate solution or 10-34-0 grade polyphosphate solution gives such grades as 10-12-0-13 and 11-17-0-13.

One promising way of incorporating sulphur into liquid fertilizers is to dissolve the sulphur in anhydrous ammonia. As much as 15 per cent of elemental sulphur can be dissolved in ammonia, and the solution may be applied in standard liquid fertilizer equipment with little modification. Sulphur precipitated from the solution in soil is in a finely divided state and is quickly converted to sulphate.

5. *Secondary-nutrient addition to suspension fertilizers*

The best method for incorporating magnesium and other insoluble materials in liquid products probably is the recently developed suspension technique (9). The insoluble material, in fine particle size, is combined with a suspensing agent to give a stable, non-settling suspension. In work at the Tennessee Valley Authority (TVA), a 3-9-9 suspension containing three units of MgO as dolomite has been prepared. The suspension was stabilized with 1 per cent of attapulgite clay, and the dolomite was ground to less than 100 mesh in size. Very little settling occurred in storage for a week, and the product could be pumped and sprayed without difficulty through a 5/64-inch nozzle.

Other studies at TVA showed that it is possible to produce successfully N-P-K suspensions which also contain significant amounts of metallic sulphate (see section B) or elemental sulphur. Examples of grades containing elemental sulphur were 12-12-12-20 (N-P_2O_5-K_2O-S) and 9-18-18-10.

B. MICRONUTRIENTS

The micronutrient elements — boron, copper, iron, manganese, molybdenum and zinc — are just as essential to plant growth as are the primary elements (nitrogen, phosphorus and potassium) and the secondary elements (calcium, magnesium and sulphur). As crop yields are pushed upwards by more adequate fertilization with primary nutrients, the need for one or more of these micronutrients often becomes the limiting factor. Each year more cases of economically significant response to added micronutrients are found, often in areas where deficiencies were previously unsuspected.

Progressive farmers are [illegible] deriving from micronutrient [illegible] these benefits, but [illegible] nutrients are needed for [illegible] formidable. Even if this information [illegible] is no guarantee that it would [illegible] years. Micronutrient needs are likely [illegible] variety of reasons: exhaustion of [illegible] soil pH, repression of availability by [illegible] other nutrients and removal of [illegible]

Generally, the micronutrients are [illegible] standard chemical fertilizer and added to [illegible] the normal fertilization programmes. In some [illegible], however, they are applied directly to the soil or used in foliar sprays. Many manufacturers mix the micronutrient with the fertilizer at the time of shipment. Others incorporate the micronutrients during manufacture of the fertilizer to give "premium" fertilizers which supply moderate quantities of several micronutrients. Some agronomists object to this approach, however, because the use of unneeded elements wastes the farmer's money, and the indiscriminate use of micronutrients may cause adverse effects. The first point is an economic question of whether the insurance is worth what it costs. Failure to supply needed micronutrients also wastes the farmer's money, and determination of micronutrient needs is often expensive, cumbersome and uncertain. As to the second point, adverse effects are unlikely when the premium fertilizer supplies approximately the amount of micronutrients that will be removed by the crops.

When micronutrients are combined with fertilizers, however, chemical reactions may occur forming new compounds. As a result, the solubility of the micronutrients and, hence, their agronomical effectiveness may be altered — for better or worse. Use of a water-soluble micronutrient carrier does not necessarily mean that the element will be water soluble in the mixture. Conversely, when insoluble micronutrient carriers are incorporated in mixtures, the micronutrient may become soluble.

There is not much information available to answer the question of whether water solubility of the several micronutrient elements is agronomically important. However, it is likely that micronutrients in granular fertilizers will be more effective if they are at least partly water soluble as this is usually true of the primary elements. Some insoluble compounds are known to be effective micronutrient sources when finely ground and mixed with the soil, but when supplied in granular form, they usually are less effective.

The principal sources of micronutrients now commonly used are borax (sodium tetraborate decahydrate), sodium molybdate and the soluble sulphate salts of the metallic elements. Other materials that are used include (*a*) oxide and carbonate salts; (*b*) frits, prepared by fusing micronutrient salts and silica into a glass or slag, and (*c*) chelates, complexes of micronutrients and organic compounds, e.g., ethylenediaminetetracetic acid. Costs of some micronutrient sources in the United States of America are shown in table 101.

The amounts of micronutrients supplied in actual practice are quite variable, depending upon soil condi-

TABLE 101. COST AND MICRONUTRIENT CONTENT OF SOME MICRONUTRIENT SOURCES

Material	*Formula of principal compound present*	*Micronutrient content (Percentage by weight of element)*	*Approximate cost per ton of element*[a] *(dollars)*
Sources of boron			
Sodium tetraborate decahydrate (borax)	$Na_2B_4O_7\cdot 10H_2O$	11	445
Sodium tetraborate pentahydrate	$Na_2B_4O_7\cdot 5H_2O$	14	440
Sodium tetraborate-pentaborate		20	645
Sources of copper			
Cupric oxide	CuO	79	2,100
Cuprous oxide	Cu_2O	86	2,020
Cupric sulphate monohydrate	$CuSO_4\cdot H_2O$	35	1,640
Cupric sulphate pentahydrate	$CuSO_4\cdot 5H_2O$	25	980
Sources of iron			
Ferric sulphate nonahydrate	$Fe_2(SO_4)_3\cdot 9H_2O$	20	165
Ferrous sulphate heptahydrate	$FeSO_4\cdot 7H_2O$	20	175
Sources of manganese			
Manganous carbonate	$MnCO_3$	46	565
Manganous oxide (impure)	MnO	48	325
Manganous-manganic oxide	Mn_3O_4	69	725
Manganous sulphate monohydrate	$MnSO_4\cdot H_2O$	24	415
Sources of molybdenum			
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}\cdot 4H_2O$	54	5,560
Sodium molybdate (anhydrous)	Na_2MoO_4	46	3,825
Sources of zinc			
Calcined zinc concentrate (impure ZnO)	ZnO	74	270
Zinc carbonate (by-product)	$ZnCO_3$	56	340
Zinc oxide	ZnO	80	370
Zinc sulphate monohydrate	$ZnSO_4\cdot H_2O$	36	515

[a] F.o.b. plant in United States of America.

tions and the crop to be fertilized. Typical application rates are tabulated below:

Micronutrient	*Pounds of micronutrient element (B, Cu, Fe, Mn, Mo, Zn) applied per acre*
Boron	0.1-1
Copper	5-20
Iron	3-10
Manganese	5-20
Molybdenum	(1/8 to 1 oz)
Zinc	5-10

In the United States of America, in 1964, fertilizers enriched with boron, copper, iron, manganese and zinc contained, on the average, 0.09 per cent B, 0.36 per cent Cu, 0.46 per cent Fe, 0.63 per cent Mn and 0.39 per cent Zn (10). Micronutrient deficiency symptoms in plants are shown in table 102.

1. *Micronutrient addition to granular fertilizers*

Several methods are available for combining micronutrients with granular fertilizers. These are: (*a*) dry mixing with product granules; (*b*) coating on product granules; and (*c*) incorporation during manufacture of the fertilizer. In methods (*a*) and (*b*), the micronutrient may be combined with the fertilizer granule at the time of its manufacture or later at a bulk-blending plant. The

TABLE 102. SYMPTOMS OF MICRONUTRIENT DEFICIENCIES IN PLANTS

Micronutrient	*Symptoms of deficiency*
Boron	Stunted growth of the younger parts of plants, frequently combined with a red or yellow colouration. Common symptoms are disintegration and decomposition of tissues in root crops and in stalks of members of cabbage family
Copper	Wilting and eventual death of leaf tips
Iron	In early stages, leaves are pale without veinal patterns. The next stage consists of an interveinal chlorosis in the leaves. In the most severe stage of deficiency, the veins are yellow
Manganese	Plants with net-veined leaves develop chlorosis in interveinal tissues, while veins remain green. Plants with parallel veins develop a general chlorosis condition and such secondary symptoms as grey specks on cereals
Molybdenum	Foliage is yellow or greenish yellow, similar to nitrogen deficiency symptoms. Leaf blades fail to expand
Zinc	In most plants there is a decrease in the rate of terminal growth with a decrease in stem length accompanied by a rosetting or whorling of the leaves

SOURCES: "The use of additives is theme of liquid fertilizer meeting", *Agricultural Chemicals* (Caldwell, N.J.), vol. 19, No. 12 (1964), pp. 46, 48, 50; and K. C. Berger and P. F. Pratt, "Advances in secondary and micronutrient fertilization", in M. H. McVickar, G. L. Bridger and L. B. Nelson, eds., *Fertilizer Technology and Usage* (Madison, Wisc., Soil Science Society of America, 1963), pp. 287-340.

advantages and disadvantages of each method are discussed below.

(a) *Addition at time of shipment*

Micronutrients are now commonly incorporated with granular fertilizers as the fertilizer is removed from the manufacturer's storage pile for shipment. Such a method provides wide flexibility in types and proportions of micronutrients for various customers. The chief problem with such a procedure, however, is that of providing a non-segregating mixture of the powdered micronutrient and granular fertilizer. If segregation of micronutrients occurs during handling or application of the fertilizer, crop responses may be spotty. In the case of some micronutrients, overdosages are toxic, so it is possible that non-uniform application on the field will result in poor yields in spots where the supply of micronutrient is excessive, as well as in spots where the supply is inadequate.

One possible way of obtaining a non-segregating mixture of micronutrient with granular fertilizer is to furnish the micronutrient in granular form with particle size matching that of the fertilizer; some micronutrient manufacturers are now producing their materials in such a form. This method, however, may not be entirely satisfactory from an agronomical standpoint. The proportions of micronutrients usually added to fertilizers are so small that only a relatively small number of granules would be added, thus, the distances between granules of micronutrient on the field could be excessive. For example, use of a micronutrient as 8-mesh granules at the rate of 1 pound per acre would result in the application of less than one granule per square foot of field surface.

An alternate method of producing non-segregating mixtures is to coat the fertilizer granules with micronutrient in finely divided form (11). Since each granule of fertilizer has a coating of micronutrient, the density of distribution of micronutrient on the field is as uniform as that of the fertilizer. In most cases, a binder is required to promote adherence of the micronutrient materials to granules. In work at TVA, micronutrient materials were blended with granular fertilizers for one minute in a small rotary mixer; then oil (usually waste motor-oil) or water was added and the mixing was continued. (This procedure was better than adding the binder before adding the micronutrient.) Over 90 per cent adherence of various micronutrient sources (salts, oxides or frits) was obtained by the use of small amounts of oil (1.5-3 per cent by weight) or water (1.5-2 per cent). The proportions of micronutrient materials ranged from 2 to 12.5 per cent by weight of the fertilizer.

The treated products were dry in appearance and were free-flowing. When treated with oil, no loss of adherence of the micronutrient was noted after one month's storage. However, in some cases, the bags were discoloured and weakened. While the treatment with water promoted adherence with many combinations, the water treatment lost most of its effectiveness after one week of storage. Also, it caused some mixtures to cake in storage. This treatment should be useful, however, when the materials are spread immediately after mixing, as is the common practice with bulk blends.

Since micronutrient requirements vary widely in different areas and with different crops, provision of the proper micronutrients fits in well with the custom formulation service that bulk blenders usually offer (12). The addition of micronutrient materials during blending offers the blender the greatest flexibility in formulation and does not require additional storage for fertilizer.

(b) *Incorporation in granules during manufacture*

Incorporation of micronutrients in granular fertilizers during manufacture eliminates the problem of segregation of the micronutrients from the fertilizer granules. The method also probably has economic advantage in the production of large quantities of fertilizer containing micronutrients. Disadvantages arise from the inflexibility of the method. Manufacturers cannot economically make and store small lots of special products containing various kinds and proportions of micronutrients.

2. *Micronutrient addition to liquid fertilizers*

Foliar application of soluble micronutrient sources is another method of combating micronutrient deficiency. This method has the advantage of fast crop response. Furthermore, with some soils, foliar application is often the best way to supply the micronutrient. The major disadvantage is that with some nutrients an excessively large number of dilute applications are required to supply sufficient amounts of the micronutrients.

(a) *Addition to liquid-mixed fertilizers*

The incorporation of micronutrients in liquid-mixed fertilizers would be advantageous since little difficulty would be encountered in homogeneously supplying the small amounts required. However, only sodium borates and sodium molybdate have adequate solubility in the usual type of such fertilizers, those made from orthophosphoric acid, to supply agronomical needs. The solubilities of copper, iron, manganese and zinc salts in such liquids are practically nil.

One method of incorporating these micronutrients is through the use of a sequestering agent, which forms complexes with the nutrients and makes them resistant to precipitation by the phosphate. Organic sequestering agents have been used to some extent; however, their cost is quite high. An inorganic sequestering agent, e.g., ammonium polyphosphate liquid fertilizers of 10-34-0 or 11-37-0 grade, appear to be a better choice because of their relatively low cost. Such solutions contain about 50 and 70 per cent, respectively, of their P_2O_5 as polyphosphates (the remainder is present as orthophosphates) and are produced from ammonia and superphosphoric acids (4, 13). Studies by TVA have shown that the solutions are effective sequestrants for the metallic trace elements, with the exception of manganese (13). The solubilities at 80° F of several of the micronutrient salts in ammonium polyphosphate solution of 11-37-0 grade and in ammonium orthophosphate solutions of 8-24-0 grade are tabulated below:

Micronutrient source added	*Solubility (percentage by weight of element: B, Cu, Fe, Mn, Mo, Zn)*	
	In 11-37-0 ammonium polyphosphate solution	*In 8-24-0 ammonium orthophosphate solution*
Sodium tetraborate decahydrate ($Na_2B_4O_7 . 10H_2O$)	0.9	0.9
Cupric oxide (CuO)	0.7	0.03
Cupric sulphate pentahydrate ($CuSO_4 . 5H_2O$)	1.5	0.13
Ferric sulphate nonahydrate [$Fe_2(SO_4)_3 9H_2O$]	1.0	0.08
Manganous-manganic oxide (Mn_3O_4)	0.2	< 0.02
Sodium molybdate dihydrate ($Na_2MoO_4 2H_2O$)	0.5[a]	0.5[a]
Zinc carbonate ($ZnCO_3$)	3.0	0.05
Zinc oxide (ZnO)	3.0	0.05
Zinc sulphate monohydrate ($ZnSO_4 . H_2O$)	2.0	0.05

[a] Largest amount tested. Maximum solubility not determined because only small amounts of molybdenum are required for plant growth and the amount solubilized was adequate.

Ferrous sulphate ($FeSO_4 . 7H_2O$), ferric oxide (Fe_2O_3), manganese dioxide (MnO_2), manganese sulphate ($MnSO_4 . H_2O$) and manganese carbonate ($MnCO_3$) were much less soluble in the 11-37-0.

Use of the sequestering effect of ammonium polyphosphate solutions to incorporate micronutrients in liquid fertilizers appears attractive. Aside from the sequestering effect, its use is advantageous because the grade of the product is increased. Thus, the sequestering effect is an incidental advantage, without extra cost for a sequestering agent. The incorporation of trace elements by sequestration has the advantages, in comparison with solid mixes, that good mixing can be obtained easily and that segregation cannot occur after mixing. Moreover, there are no undesirable reactions between the trace elements and other constituents of the fertilizer, as sometimes occur in solid mixes. One disadvantage is that the amount of trace element which can be dissolved may not give the amount per acre desired in some cases. Practice is so varied in regard to application rate that this disadvantage is difficult to evaluate.

(b) *Addition to suspension fertilizers*

The suspension type of technique discussed earlier appears to be especially applicable for use with micronutrients, since the solubility of the micronutrient carrier is immaterial except in so far as it affects the agronomical properties (9). If insoluble, the micronutrient should be fine enough that it will not settle rapidly or clog spray nozzles. The only restriction to the amount that can be added is the viscosity of the final product, as dictated by the type of application equipment.

Experimental N-P-K suspensions have been made with micronutrient additions from fritted trace elements, copper sulphate, zinc sulphate, manganese sulphate or iron sulphate. In general, these materials had no important effect on the physical properties of the suspensions when the amount added was about 5 per cent.

Suspensions applied soon after preparation present no difficult problems of settling and crystal growth. They can be applied with some types of standard liquid fertilizer equipment, although larger nozzles usually are required. If suspensions are stored for days or weeks, provision should be made for agitation. Crystal growth may be troublesome in long storage.

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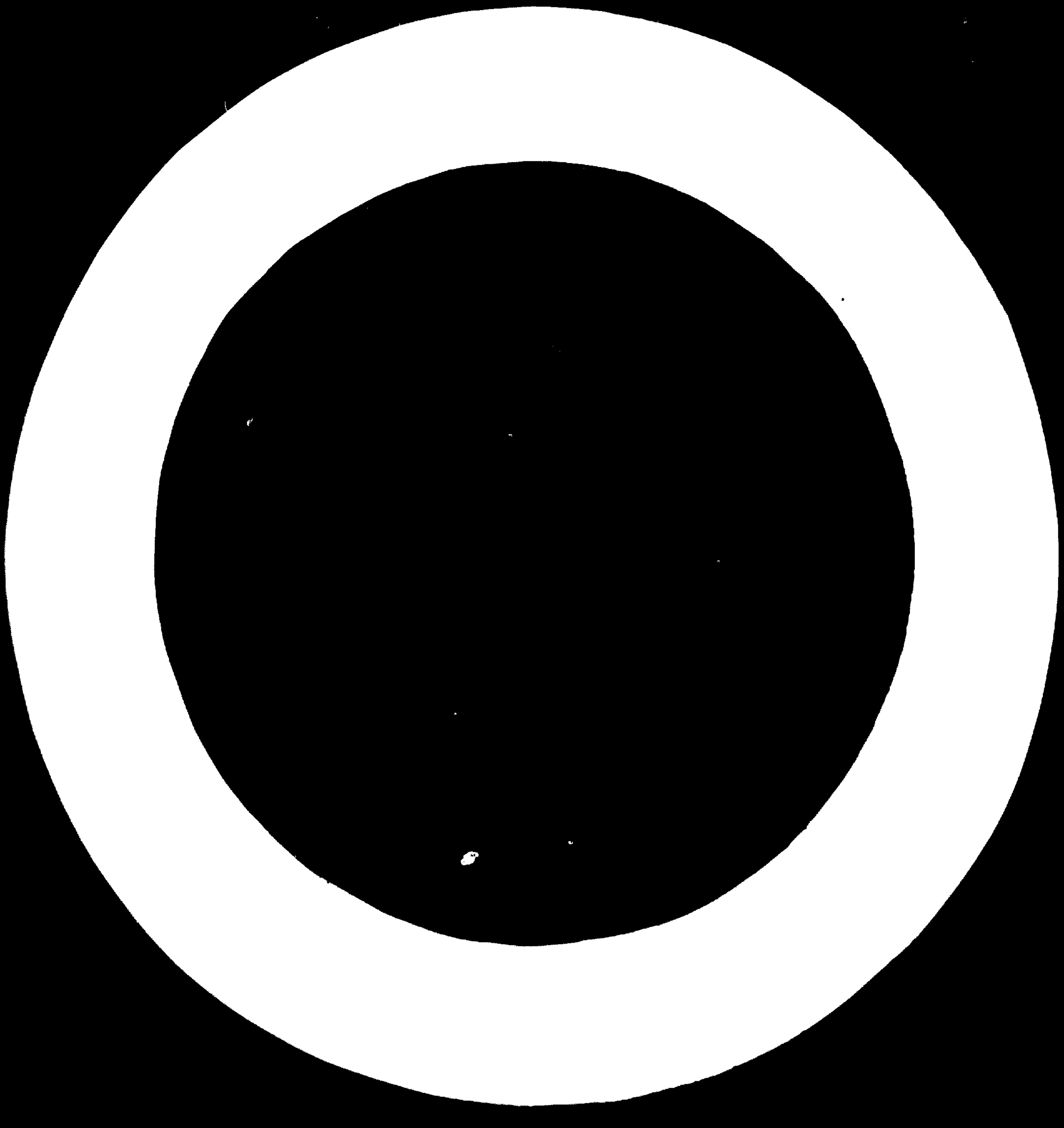
Part Three



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XVII. LOCATION OF FERTILIZER PLANTS

A. GENERAL INFORMATION

During the present century, annual world consumption of fertilizers has grown from under 2 million tons (in terms of N, P_2O_5 and K_2O) to a current level of over 36 million tons. By 1980, it is estimated that annual world fertilizer needs will approach 70 million tons, of which about 40 million tons or 57 per cent will be required by Asia, the Near East, Africa and Latin America (1). On the premise that 6 million tons of primary nutrient production capacity is equivalent to $1,000 million of investment (2), this additional 40 million tons represents a future outlay of about $7,000 million for new fertilizer plants, at current values.

To ensure that this money shall be spent wisely, it is essential that a location is found for each plant which will reduce to a minimum the delivered price of the fertilizer produced. In most industries, failure to select an optimum location usually generates excess costs which no amount of commercial or technical skill is able to overcome, and these additional charges may seriously handicap an otherwise successful enterprise, especially if competition is intense.

B. ECONOMIC FACTORS AFFECTING PLANT LOCATION

1. *Definition of terms*

The fertilizer industry is world-wide in scope and is becoming increasingly complex. Therefore, a single, broad consideration of location factors would be inadequate and even misleading. Perhaps the simplest approach is in terms of function and geographical location, on the following lines:

(*a*) Function: e.g., primary producer, secondary producer, mixer and/or distributor;

(*b*) Geographical location: as defined by country, region, area and site.

For the purpose of this chapter, a primary producer will be one who manufactures from such raw materials as air, fuels and minerals, such products as ammonia, ammonium nitrate, phosphoric acid, triple superphosphate and potash, i.e., products containing one primary plant nutrient, N, P_2O_5 or K_2O. A secondary producer will be one who uses such products to make multinutrient mixtures containing two or more primary nutrients, which can range from a chemical compound like ammonium phosphate, to a wide range of N-P-K granulated compounds or mixed fertilizers. Mixers and/or distributors will be those undertaking simple blending of bulk solids or liquids and/or storage and distribution to the farmer, since these functions are frequently combined and undertaken at locations near to the points of use.

In some cases, primary producers also undertake secondary-fertilizer production, e.g., the manufacture of diammonium phosphate or N-P-K granulated formulations and even (but much less frequently) simple bulk-mixing and distribution to local markets. However, the same economic factors apply to combined operations as for primary-fertilizer manufacture, although their relative influences on optimum plant location change according to circumstances. For example, to a primary producer, major requirements might be proximity to an ocean port and ample process water, whereas the principal concerns of a blender/distributor might be access to several reliable sources of supply and proximity to a prospering local farm community.

Similarly, the interpretation of location differs according to function. The primary producer must usually choose a region or even a country in terms of available raw materials, shipping, politics, financing and markets, and then select a site on the basis of more tangible factors — soil characteristics, process water and other utilities, local labour and transport. The secondary producer and distributor may only be concerned with relatively simple technical problems and local agricultural considerations. This does not mean, however, that location factors and associated economic problems are of less importance to him. On the contrary, the pressure of competition and sensitive customer demand often intensify the initial need for a judicious site selection, with regard not only to consumers, but also to the location of competitors, in order to capture the maximum sales volume from a given area and to stay in business.

2. *Relating economic and location factors*

The relationship between major economic factors and the optimum location of a plant or enterprise has been studied since the mid-nineteenth century, and an extensive literature is available on this subject (3, 4, 5, 6, 7, 8). Some locations are still chosen on a simple basis of personal preference or experience, while in other cases, detailed studies and comparisons are made, using linear programming and other operational research techniques, perhaps with the aid of a computer, before the optimum location and site are ultimately selected.

More frequently, locations and sites are established on the basis of progressively detailed comparisons and studies, based on weighted check-lists and on an intimate knowledge of a specific industry. This method is still strongly favoured by the fertilizer industry, at primary, secondary and also mixer and/or distributor levels. However, theoretical methods continue to become less generalized and more specific, and, simultaneously, computer techniques have been developed which permit numerous input variables to be handled more easily than was possible a few years ago. Hence, the time is approaching when a theoretical analysis and a practical study based on check-lists and detailed field-work can be used to cross-check each other in the search for an optimum plant location, prior to making firm commitments.

(a) *Location choice by personal preference*

The correct selection of a plant site has virtually become a science based on experience and currently is a specialized function of industry, often undertaken by consultants (9) and others with an intimate knowledge of specific needs and local conditions, e.g., railroad and state development agencies or experienced company executives. Nevertheless, a few locations are still chosen on the basis of personal preference on the part of the plant owner, who may have little more than aesthetic or "psychic" reasons for wishing to live and work in a particular community.

Alternatively, the owner may have sound, practical reasons for choosing a specific location, based on experience of far-sightedness rather than purely personal considerations (10). Indeed, numerous instances can be found today where large and long-established plants owe much of their success to the earlier vision of one man, who chose a favourable location in which to grow and prosper. However, apart from small blending or distributing units of a private enterprise nature, the magnitude of investment required for a typical fertilizer plant demands a detailed study of several alternative locations in order to make sure that the best use will be made of both fixed and working capital, and that the criteria of least cost manufacture and maximum profit sales can be met.

The effect of personal or "psychic" factors on plant site selection can be very real and, as is realized by those with experience in this field, these influences must be recognized and resisted, if complete objectivity is to be maintained during a location study. This particularly applies to favourable (or unfavourable) encounters with local people, attractive surroundings and buildings etc., whereas the true basis for site location can only be in terms of a thorough and impartial study, preferably embracing several possible alternatives which may initially have a limited appeal.

(b) *Location and economic theory*

"Knowledge insufficient for prediction", said John Stuart Mill, "may be most valuable for guidance". This reflection epitomizes the contribution of economic theory during the last hundred years to plant location, which, in more recent times, has been the subject of intensive study by operational research specialists and economists.

Least cost theories

It is perhaps fitting that one of the earliest theoretical investigations into location theory was undertaken in terms of agricultural product supply and demand. This study was made in Germany by Von Thunen who developed relationships between transportation costs, land rental, labour and production charges (1, pp. 5-8; 11). The best plant site on this basis could be found by balancing various combinations of land cost (and its equivalent value as regards labour and other factors) with transportation charges until the least cost combination resulted. Alternatively, for a given location, the preferred crops and corresponding concentric zones of cultivation could be depicted graphically, with and without interference from external factors. Another German economist, Wilhelm Launhardt, endeavoured to define the optimum location of industry on the basis of equilibria between cost and demand of materials at various places, but his theories have not found wide acceptance.

A notable advance in location theory was made in 1909 by Weber; who recognized the fact that, in many circumstances, transport costs are theoretically the most fundamental element in determining the optimum point (3). He established that the location of an industry is often ideally determined by the ratio between the weight of localized raw material and weight of the product. Furthermore, when labour costs are varied, an industry tends to deviate from its ideal location (in terms of transport), in proportion to the size of its labour coefficient. An additional influence is the effect of the local industrial agglomeration (or deglomeration) with attendant cost advantages and disadvantages.

Weber conceived these influences as exerting a series of pulls on the location centre and, in fact, used a mechanical device -- the Varignon — to demonstrate and resolve the various polygons of forces set up in analogy with typical industrial conditions. He showed that, in general, industries which had a high material-index and which were weight-losing in character were pulled towards raw material and fuel sources, whereas those industries which had a low material-index and which were not weight-losing to an appreciable degree tended to be pulled towards areas of consumption.

According to Weber, pure materials can never bind production to their origin, because they enter without loss of weight into the product; hence, the sum of the component weights of their deposits is always, at most, equal to the product weight, and the material index they create is never more than unity. Industries with high labour costs per ton of product, according to Weber's analysis, will concentrate at favourable points in terms of labour markets and other variables.

On these theoretical lines, primary fertilizer producers will tend to concentrate near raw material sources, since they are weight-losing in nature, whereas secondary producers and mixers, blenders and distributors (having a material index of the order of unity) will tend to locate near their markets. In either case, the labour coefficient is relatively low and the influence of high or low labour costs from other areas is not great. Such theoretical Weberian location patterns for the fertilizer industry are often found to be borne out in practice, especially regarding phosphate and potash materials.

Nitrogen fertilizer plants based on natural gas are accorded some locational flexibility if pipelines permit closer proximity to market areas; furthermore, they are not large weight-losing operations. Naphtha-consuming nitrogen fertilizer plants are also in this category and are usually found at a port or refinery site as near as possible to the market area served. However, the forthcoming availability of large, refrigerated ocean-going tankers for bulk shipments of liquid ammonia may de-emphasize the transport cost factor in favour of low cost production in huge centralized plants located near sources of gaseous or liquid feed stocks in distant countries, instead of smaller scale production based on imported feed stocks.

Theories of interdependent locations and maximum profit

Earlier location theories based on principles of least cost assumed that demand was situated at a particular point and remained unaffected by a least cost site selection. The locational interdependence of producers and consumers in a group situation was also largely disregarded. However, a changing world brought an increasing awareness of other major factors influencing optimum site selection, particularly the competitive forces in a given market area.

The introduction of freight equalization, in-transit privileges and more efficient freight-handling methods further de-emphasized transport as the principal location factor. As a result, Palander (12), Hoover (13) and others studied market areas and demand factors in relation to least cost locations. In turn, this work was followed by investigations into the relation between location and maximum profit in competitive markets, as well as the corresponding development of complex land-use patterns and market networks, as pioneered by Lösch (4).

Further work in this field has been undertaken by Isard (6, 14, 15), Lefeber (5), Greenhut (7) and others, who not only have attempted to refine and integrate the earlier least cost principles with maximum profit interdependent location theories, but have developed new approaches of their own. In some of these cases, linear and non-linear programmes capable of handling numerous input variables have been outlined, and these lend themselves to solution by computer means.

Despite conflicts between the various theories of location and a frequent inability to meet specific cases, they can often promise valuable guidance regarding the objectives of a proposed or existing plant and the selection of an optimum site. For reasons of space, however, it has only been possible here to make a brief reference to the principal theories believed to be of practical application, together with the appropriate literature sources.

In general, it can be deduced from the considerable data available that producers selling to one or two points, or to consumers only, tend to choose the respective least cost location and are not fundamentally concerned by the location of competitors. However, when numerous customers exist in a given market area, the location of competitors greatly influences the optimum site selection. Consequently, dispersion of production facilities may become necessary in order to maintain an adequate share of the market, in accordance with maximum profit location principles.

In numerous instances, the fertilizer industries in the United States of America, and various other countries have anticipated these theoretical deductions. Primary production units are often to be found adjacent to phosphate rock deposits or to large ports, while such secondary producers as granulated mixed fertilizer manufacturers tend to locate near to large agricultural areas.

Bulk blenders and liquid fertilizer mixer distributors often establish themselves as strategically as possible entirely within a given market area, which may be limited to a radius of only a few miles. This is because such factors as freight equalization, intense local competition and personal relationships reduce the relative importance of the least cost transport location factor and intensify locational interdependence between producers, consumers and competitors in terms of maximum profit location principles.

Large vertically integrated fertilizer producers therefore tend to establish their primary production units near mineral deposits or ports and to transport semi-finished material (of a non-weight-losing nature) to their satellite mixing and finishing plants strategically located in or near the principal farming areas, instead of undertaking all operations in one main plant and attempting to move numerous types and grades of product to scattered markets by long distance transportation.

3. *Practical considerations in fertilizer plant location*

The foregoing theoretical considerations show that the fertilizer industry is, to a large extent, oriented in two directions: first towards raw material sources on the part of primary producers, and secondly, towards the consumer, in increasing degrees, on the part of secondary producers, blenders and distributors. Consequently, location factors vary in intensity, if not in principle, between the different groups; hence, they are preferably reviewed in separate order, on the following lines.

(a) *Primary producers*

Location of markets

The major raw materials for producing the three primary fertilizer nutrients, N, P_2O_5 and K_2O, are natural gas or petroleum (and solid fuels, to a limited degree), plus phosphate rock and various potassium minerals. Unfortunately, these materials are not distributed evenly throughout the world; some countries possess all three classes of materials, while others have none at all. Some primary producers are thus able to view the world as their market, in addition to domestic demands. This even applies to producers in countries which do not have indigenous raw materials (e.g., Japan, the Netherlands and the United Kingdom of Great Britain and Northern Ireland), but which are favourably situated as regards shipping, utilities and advanced technology. Conversely, several areas of the world possess ample supplies of one or more sources of primary plant nutrients, but as yet have no large-scale fertilizer plants, because of transport, technological or other limitations. For example, phosphate rock is shipped from North Africa and processed in many parts of the world, and huge reserves of natural gas await conversion and use in Chile and parts of the Middle East.

However, the recent development of techniques for concentrating phosphoric acid to about 80 per cent P_2O_5 (compared with some 35 per cent in phosphate rock) and the erection of large ammonia plants adjacent to overseas feed-stock sources (together with the forthcoming availability of large ocean-going tankers) will cause a radical change in established production and marketing patterns. Considerable quantities of phosphoric acid and ammonia will be made in plants adjacent to raw material sources, and the world will become the market area to primary producers to a much greater degree than it currently is, limited only, perhaps, by currency or political restrictions and other man-made impedimenta.

In those cases where primary fertilizer production is undertaken for domestic consumers, the weight-losing nature of these operations also necessitates location near raw material sources or adjacent to such low-cost transportation as a seaport or a canal. At the same time, access to one or more markets must be possible, *via* road, rail or water-borne transportation, which may impose a reduced degree of freedom as regards choice of location. The cost of transportation to the secondary producer, the blender or the distributor must also be considered and the most favourable method adopted. This may also affect the plant location with respect to the market and further reduce the degree of freedom allowable.

Location of raw materials

As previously indicated, primary fertilizer plant location is strongly influenced by raw material availability because of the weight-losing nature of most processes in this category and the relatively high transportation costs. Raw material location thus plays a major part in the selection of an optimum site, either directly, in terms of a plant adjacent to the source of material, or indirectly, by locating near to a seaport if in a distant land. Furthermore, to prevent transportation costs from becoming prohibitive, phosphate and potash minerals are invariably upgraded at the mine before use.

Such petroleum products as naphtha and refinery gas also act as location-influencing forces for ammonia plants, which are often built near a refinery or a port capable of receiving bulk shipments. Since the production of high-analysis phosphate fertilizer requires large quantities of sulphur, this raw material will have an influence on the location of phosphate fertilizer plants. In areas where sulphur or by-product sulphuric acid is available, phosphate rock is transported to the source of sulphur. In areas where these raw materials must be imported, optimum plant location tends to be where there is access to water transportation or a source of nitrogen, if multi-nutrient fertilizers are to be manufactured.

Influence of transportation

Raw materials. Primary fertilizer plants are, in most cases, sensitive to the transportation factor, especially regarding raw material supplies and, to a lesser extent, as affecting delivered costs of products to secondary producers or blenders and distributors.

This particularly applies to the weight-losing processes in the industry, e.g., the production of concentrated phosphates from phosphate rock, the manufacture of agricultural potash from potassium-bearing minerals and the production of ammonia from petroleum crudes *via* refinery products. In fact, when circumstances permit, it is often advantageous to eliminate raw material transportation costs by locating the primary fertilizer plant at the source of phosphate rock or feed-stock. When dependent on imported materials, the least cost location is usually near a deep-water port or harbour, to eliminate additional transportation and handling charges.

Transportation costs, plus loading, unloading and port charges, represent a substantial portion of the delivered cost of raw materials to a primary-fertilizer producer. For example, the ex-mine cost of phosphate rock is sometimes less than one-half of the delivered cost to producers located overseas or across a continent, and the production cost of ammonia from projected large plants operating on low-cost natural gas in various countries is estimated to be little more than the cost of intercontinental refrigerated-tanker shipment (e.g., $15 to $20 per short ton).

Thus, experience in securing the lowest cost transportation and improvements in bulk shipping and cargo handling are no less important than skill in production and new developments in process technology. Similarly, changes in overseas and inland transportation rates can transform an economic plant location into an uneconomic one, or *vice versa*. Therefore, it becomes imperative for primary fertilizer producers to reduce and stabilize transportation cost variables to the greatest possible degree, by making appropriate agreements with suppliers and shippers, and by being continually on the alert for new ways of reducing these charges.

Finished goods. Transportation factors regarding finished goods are also of considerable significance in determining the optimum location of a primary fertilizer producer (unless freight equalization is predominant in the market area). The influence of lower delivered costs to consumers, on the part of competitors, makes it imperative to select a location which permits minimum cost deliveries to be made, with additional emphasis on reliability and efficiency. Ability to make bulk shipments and deliveries is also becoming important. Some producers regard the availability of alternative transportation, e.g., road and/or rail, and barge, or two competing railroads, as an absolute necessity for reasons of transport-cost reduction and assured deliveries to customers.

Weighted transportation. One simple way of determining the optimum area of location in terms of transportation distances for potential or actual raw material sources and customers is to use the weighted distribution method. First, a map of the country or region under consideration is drawn on graph paper between X and Y axes, and all major supply and delivery points are marked. Their X and Y values and the tonnage weights, W, from and to each point are respectively tabulated. The tonnage weights are each multiplied by the corresponding X and Y values, and these extensions are also tabulated. Each column is totalled and the weighted averages for X and Y found by appropriate division. The weighted X and Y distances from each axis are intersected on the map to indicate the optimum location point in terms of least cost transportation. A search within a reasonable radius for a suitable site would be the next step, followed by a detailed comparison of actual needs and available facilities.

When using this method, adjustments must be made for differences in freight rates and associated items, for example, changes in bulk densities or revisions in commodity classification for processing. Although this method is empirical, it can provide a rapid initial guide to the major effects of transportation costs on an optimum plant location and also may reveal a number of unsuspected alternative possibilities when developed in conjunction with detailed area maps.

Seasonal demand. In many areas of the world, fertilizer demands are seasonal and unless transportation facilities both for raw materials and finished goods are adequate to meet these requirements, the large storage facilities and inventories required to meet peak production and deliveries may seriously reduce the return on investment. Therefore, the regularity and reliability of inward and outward transportation can be a factor of considerable significance in determining optimum plant location because of the corresponding relation to storage needs.

Availability of utilities and labour

In general, the availability of power is not a major factor in deciding upon the location of a primary-fertilizer plant since, if necessary, a self-contained generating unit driven by a gas or steam turbine can be installed. Moreover, in some processes, e.g., sulphuric acid, nitric acid and ammonia manufacture, sufficient steam can often be generated to provide a good deal of the energy needed.

When necessary, supplementary energy can readily be produced by diesel, gas or steam-driven equipment at reasonable cost. In fact, it is preferable in some locations to make the plant totally independent of outside power, for reasons of lower unit energy costs and greater reliability. In extreme cases, the plant power-station can also be designed to supply or supplement local electrical needs. In a few areas of the world, where ample hydro-electric energy is available, power costs may be as low as 3 mills ($0.003) per kWh, whereas in some countries which are dependent on imported fossil fuels, the local power rate may be between 10 and 20 mills per kWh. Consequently, other factors being equal, the availability of low-cost power, even if it is not a major factor can exert a favourable influence on plant location for processes whose net energy requirements are appreciable. For example, an ammonia plant might require about 700 kWh per ton of product, and a difference of 5 mills between local power rates would mean a corresponding cost reduction of $3.50 per ton of ammonia if the area having the lower rate were chosen. An alternative choice might be to produce power within the plant, if this would result in lower energy costs; however, an additional capital investment would be required, which would have to be taken into account when studying the economics of the project.

Water. Without adequate supplies of water for process needs, cooling requirements, power and other purposes, primary fertilizer plants could neither be conceived nor operated. Therefore, the availability of water is a key factor in influencing plant location. However, considerable flexibility exists regarding water requirements since, if not initially present at the preferred site, it can usually be brought in *via* pipeline, provided it exists or can be found in the region. In many locations, water can also be obtained by sinking appropriate wells in the plant area or vicinity.

Where fresh-water supplies are inadequate, sea-water is often used for cooling purposes; alternatively, air-cooled heat exchangers are sometimes installed. When climatic circumstances permit, cooling towers offer means of reducing cooling-water needs. Treated brackish water, sewage-plant effluents and other wastes are also possible cooling media in extreme instances.

Water for process purposes, boiler feed and human consumption necessitates relatively high purity standards, which can usually be met in a number of ways if local fresh-water supplies are insufficient, e.g., by ion exchange, condensate recovery or steam distillation. Experienced process design often permits considerable economies to be achieved in process water requirements, which in many cases are only a fraction of cooling-water needs. For example, in ammonia manufacture, some 50,000 gallons of water per ton of ammonia might be specified for cooling purposes, compared with 10,000 gallons for boiler feed, which could yield about 8,000 gallons of condensate for re-use in the boiler or other parts of the plant.

Hence, except in extremely arid regions, such as the centre of a large desert devoid of any sources of water, flexibility in plant and process design, plus modern equipment, can, in many cases, permit the solution of water problems in an otherwise desirable area and site, provided costs are not prohibitive.

Because some primary-fertilizer plants, for example, ammonia and wet-process phosphoric acid installations, use substantial volumes of water for cooling and scrubbing needs, the unit water-cost for such purposes must be kept to a minimum. When river-water is available, the cost is usually little more than pumping charges; alternatively, sea-water might be employed at shore locations, at very low expense, although an additional capital cost may be necessary for corrosion-resistant alloys or linings.

In some developed areas, there are available industrial water-supplies, which, although high in *B. coli* and other organisms, may be suitable for cooling, scrubbing and wash-down needs. Costs may range from about $0.03 to $0.30 per 1,000 gallons, plus any expenses for chlorination to minimize troubles from algae growth. Purified water for process purposes and human needs, obtained from public-supply organizations, may cost between $0.30 to $0.60 per 1,000 gallons, or even higher in some dry areas. Potable water from salt-water conversion units and distillation plants may cost $1.00 or more, per 1,000 gallons, according to daily volume and other circumstances. Some large projected conversion installations with capacities of over 1 million gallons per day are expected to yield potable water ideal for process purposes at costs between $0.50 and $1.00 per 1,000 gallons.

It can be seen, therefore, that if available water-supplies for cooling and process purposes are unreliable or costly, this situation may be a decisive factor in selecting another site (other factors being equal), even though modern technology could solve local water problems.

Fuels. In some countries, solid fuels are still used for feed-stock, heat and energy purposes in ammonia plants; consequently, location near the source of fuel permits appreciable savings to be made in transportation costs. When solid or liquid fuels are needed for energy and heating needs in other types of fertilizer plants, these are normally brought in by the same transport services used to ship the product, e.g., water, road or rail. Hence, fuel requirements do not normally become a major location factor, except for ammonia plants using solid feed-stocks and fuels.

Waste disposal. The upgrading of phosphate, potash and sulphur-containing ores is usually undertaken near the pit or mine, where sufficient space for gangue disposal can be found, either as spread or back-fill. Wet-process phosphoric acid plants generate substantial volumes of waste gypsum, of the order of 2 tons of wet gypsum per ton of rock used, which frequently creates disposal problems, especially in built-up industrial areas. Cases have been known where the proposed dumping of waste gypsum either on land or in rivers and shore-water has been refused by local authorities, and alternative sites have had to be found. Similarly, the disposal of acidic effluents containing fluorides may not be permitted; in addition, fumes from sulphuric, nitric and phosphoric acid plants may be subject to rigid local by-laws. Additional capital and operating costs for the treatment and disposal of solid, liquid and gaseous wastes can thus rise to prohibitive levels, necessitating the selection of a more favourable plant site. Therefore, waste disposal can be another major factor in the location of a primary-fertilizer plant, especially those producing phosphates. The former carbon-black problems associated with ammonia manufacture from liquid fuels have been virtually overcome.

Site conditions. Capital costs and operating expenses may be considerably increased by adverse site conditions, which, in extreme cases, may compel the selection of another site. Major features to be checked include freedom from flooding, earthquakes, typhoons and other catastrophes. Soil-bearing conditions, rights of way, titles, expansion provisions, neighbouring plants and numerous other items, for which check-lists are available (9, 16), are additional considerations which may prove to be major physical and/or economical factors with regard to the ultimate site selection.

Site development and plant construction. The problems encountered in plant construction are often severe. They include transportation and site difficulties, weather hazards and labour recruitment. However, experienced contractors are not daunted by construction problems and, in most cases, will accept the most challenging project, even if it involves considerable financial risk. Therefore, construction difficulties do not normally become major factors in plant location and site selection, unless the costs of overcoming local adverse factors would be prohibitive, e.g., for extensive piling or an unusual degree of land reclamation,

Labour. Modern primary-fertilizer plants are highly automated on a fail-safe basis and the labour content is very low per unit of output. Provided training and supervision are adequate, local labour in many parts of the world has proved able to undertake most plant maintenance and operating duties with reliability and efficiency. Indeed, the use of local labour often minimizes off-site costs for housing, transportation and other amenities. Supervision and management may have to be recruited from outside areas, but the number of personnel required is normally small and presents little difficulty, except in areas of extreme climate or political unrest. Therefore, labour requirements, although a major consideration, usually have only a minor influence on primary-fertilizer plant location.

Labour relations, however, are a major factor to be considered in primary-fertilizer plant location, both domestically and overseas. An area with an unhappy record of unrest and strikes is best avoided, at least for a time, however promising in other ways, since prosperity cannot result from strife.

Political taxation and corporate factors

The foregoing sections have reviewed economic factors affecting primary-fertilizer plant location as regards a least cost product. Of equal importance are those factors which have a major influence on plant location in terms of capital investment and profit protection. Large primary-fertilizer plants represent capital expenditures in the range $10 to $50 million, and unless investors can be assured that their capital will be secure and will also provide a reasonable rate of return, it becomes difficult to attract sufficient funds to finance a large (or small) project, either domestically or overseas.

Political factors. A prerequisite to the establishment of a large fertilizer plant overseas is a stable political situation, free from threats of revolution, expropriation, devaluation and associated troubles. In some cases, insurance against possible disasters of this nature can be obtained from government agencies or other sources as a means of offsetting, at least partially, most risks in this category.

Another political consideration is the relationship between the respective countries in which raw material suppliers, processors, consumers and plant owners are located. Such relationships may fluctuate from strong friendship to a state of war, with unfortunate results to the investor. Thus, national histories, existing treaties and trade agreements, patriotic fervour and the policies of political incumbents can be considered factors of major importance in a plant-location study.

Taxation factors. Another major influence on plant location is taxation, which may be applied to raw material supplies, payrolls, capital expenditures, earnings, sales and unsuspected items. The modest rates of return generated by many primary-fertilizer operations can be reduced to unfeasible proportions by the numerous taxes imposed by some countries and states. Hence, every possible aspect of taxation for several alternative locations should be anticipated, studied and compared by corporate and local experts, and checked with government authorities prior to making a location decision.

For example, locating a fertilizer plant within the boundaries of a refinery may affect the net taxation figure advantageously or adversely, according to prevailing law.

Some countries or states offer tax holidays and depreciation concessions; others not only apply heavy wage burdens for social benefits, but collect a payroll tax as well. The increasing popularity of common market areas and reciprocal trade agreements may justify locating (or even relocating) in another country altogether. Another item of importance is the net taxation imposed on incomes of expatriates, as well as on corporate royalties, fees and earnings, which may seriously hamper the spirit and growth of the whole project, if too severe. A thorough pre-investment check may show an alternative location to be justified. Export-import quotas and currency restrictions are other vital factors affecting optimum plant location, among many others of a national and local nature (9).

Corporate and other factors. Some countries restrict the participation of foreign investors to less than 50 per cent, the majority holding being retained by local public, private or government interest. This may not be acceptable to some foreign investors who wish to retain control of policies and operations. In other cases, compulsory transferral of ownership to local shareholders may be mandatory after a stated period of time. In some areas, land may only be made available on leasehold terms, under which buildings and certain other assets pass to the private leaseholder or to the Government on expiration of the lease, which may range from about twenty years to ninety-nine years or longer.

Occasionally, an insistence on joint corporate management, in conjunction with local private or government directors, may arise. Some investors in overseas projects welcome a local participation or merger, in the interests of greater local stability and increased sales. In certain cases, this may also offer some tax advantages. In addition to equity considerations, the necessity to obtain loan capital may restrict operations to certain countries or regions covered by various international lending and insurance agencies.

It is evident that the influence and effect of fundamental corporate, fiscal and financial considerations on plant location can be even more decisive than compliance with economic theory or site requirements. Therefore, a thorough study of these items for several different possible locations by corporate and local specialists, and written confirmation of agreed terms from the authorities concerned, are essential before irrevocable decisions regarding a site selection are made.

(b) *Secondary producers*

As defined at the outset, secondary-fertilizer producers manufacture multinutrient fertilizers from such primary materials as ammonia, phosphoric acid and potash. In some cases, production of both primary and secondary fertilizers is undertaken at the same site, in others, the primary materials are transported considerable distances prior to use. Although the economic principles defined in the previous section also apply to secondary-fertilizer production, their effects on plant location differ in degree and in accordance with an increasing emphasis on locational interdependence (i.e., the influences of competitors and customers in a given market area).

Location of markets

Secondary-fertilizer plants are largely concerned with domestic markets, although products of a "standard" formula nature — diammonium phosphate (18-46-0), "ammophos" (16-20-0) and some nitrophosphates (e.g., 15-15-15) — are exported in appreciable quantities for direct application or for incorporation in simple mixed goods and granulated fertilizers.

An important market location factor arises from the seasonal demands of some areas. To maintain balanced production schedules and to minimize off-season storage, both primary and secondary producers may wish to have access to markets which have differing seasonal requirements and which may be distant from the plant and each other. As a result, the optimum location may be the resultant of several opposing material-supply and marketing forces. Consequently, the significant locations of the various potential and actual markets (both domestic and overseas) are affected by market accessibility, competition, custom, specific technical features of the products and other non-geographical considerations.

In general, because of transportation costs, competition, close customer relationships and regional or local identification, secondary-fertilizer plants tend to locate nearer to the market area than to raw material supplies. Moreover, since secondary fertilizers are not weight-losing in character, no one plant would secure a corresponding cost advantage by locating nearer to the source of raw material supply. However, the production of primary and secondary fertilizers in adjacent units, when market and other factors permit, may lead to significant savings in storage, handling and general overhead (8, case 96, p. 645).

Location of raw materials

In many areas of the world, the fertilizer industry is subjected to large seasonal demands. Therefore, as for primary producers, accessibility of raw materials is of major importance to secondary-fertilizer manufacturers. If remote from suppliers, large inventories of primary materials may have to be carried to ensure reliability of supplies and to meet peak customer demands. Consequently, the additional fixed and working capital needed, compared with the relatively small investment for some secondary-fertilizer plants, may reduce the return on investment to unacceptable levels. This may especially apply to satellite or secondary-fertilizer plants separated by long intercontinental or overseas distances from supply sources. In such cases, economies from large bulk shipments at less frequent periods may not be realized, because of the correspondingly greater storage and inventory requirements needed to keep the plant operating between longer raw material delivery schedules.

Ready accessibility to primary fertilizer materials may thus be a determining factor in secondary fertilizer plant location. This particularly applies if several sources can be made available, which not only increases the reliability of supply but may offer price reduction advantages and better service as well.

In most cases, a secondary-fertilizer producer must obtain supplies of all three primary nutrients, plus secondary materials and bags. Locational "pulls" from phosphate sources, ammonia plants, potash producers and bag manufacturers will exist, which must be evaluated on the bases of reliability and delivered costs, for each location under review.

In cases where the market demand in an area will support several secondary fertilizer plants, it is sometimes possible to take advantage of "locational agglomeration" by arranging large bulk material deliveries to the area, sufficient for the needs of all producers and at less cost than for separate, smaller shipments. Joint savings of this nature have led to the formation of local "co-operatives" in several countries.

Influence of transportation

Raw materials. As previously indicated, the non-weight-losing nature of typical secondary-fertilizer processes may result in little or no transportation savings by locating nearer to primary fertilizer sources. However, particular circumstances may justify a joint primary-secondary operation, e.g., where local markets also exist and/or where significant savings can be made by sharing some of the fixed costs. The additional economies resulting from the elimination of handling and transportation charges for some (or all) of the primary material may lead to extremely favourable price levels for a considerable area around the plant.

More usually, however, raw materials for secondary-fertilizer production are transported appreciable distances, in which case reliability of supply and transport rates become principal factors. Location in terms of area and even site may also be determined by the availability of more than one means of transportation, in order to provide better reliability and some competitive element, i.e., canal or river *versus* road and/or rail.

Finished goods. The influence of transportation on secondary plant location, as regards finished goods, is significant in terms of minimum delivery costs to the distributor or farmer, especially if competition is strong. Reliability and customer service are other important transportation factors. When freight equalization on the part of public transportation and other carriers is permitted, increased emphasis is placed on the indirect factors. As a result, some secondary producers prefer to operate their own delivery vehicles and offer door-to-door service for liquids, as well as solids in bulk and bagged form, not only to give better customer service, but also to make some savings in delivery costs.

The tendency for secondary-fertilizer plants to agglomerate nearer to each other and to farming areas may offer additional transportation advantages in the form of back-haul loads and the ability to lease local transportation and even to institute co-operative networks during peak periods.

The effect of transportation variables in multiple supplier-consumer frameworks can sometimes be examined with benefit on the lines of the Launhardt-Palander approach (12, 14) and by the weighted transportation method previously described, in order to investigate the effect of competition and to find the optimum locational centre.

Availability of utilities and labour

Power, water and fuel. Utility requirements for secondary-fertilizer plants are relatively moderate and can usually be accommodated by local resources. Major power needs are normally for operating rotary granulators, driers, coolers and fans, and often total only a few hundred horsepower. Process-water requirements are kept to a minimum, in order to save drying costs, and other water needs are often limited to scrubbing dust from exhaust gases in the spray type of units prior to release to atmosphere. Drying operations are usually confined to the removal of a few per cent of water from granulated products and can readily be met by any locally available fuel in almost all cases. Thus, the availability of utilities cannot be said to constitute a major location factor for secondary-fertilizer plants.

Waste disposal, site conditions and plant construction. As indicated, secondary-fertilizer processes are not in the weight losing category; moreover, every effort is made (or should be) to avoid material losses of all types. Therefore, waste-disposal problems do not normally arise. Nor do site conditions and plant construction problems prove insurmountable in the majority of cases. Of course, other factors being equal, the choice of a firm, level site is to be preferred because of the savings in piling and land-preparation costs. Hence, waste disposal, site conditions and plant construction problems cannot be regarded as major influences affecting the location of secondary-fertilizer plants, except in most unusual instances.

Labour. As in the case of primary-fertilizer plants, secondary production processes are highly automated and the relative labour content is low. The use of local operators is to be preferred, when possible, to minimize housing and transportation expenses, as well as to foster local goodwill. Hence, labour needs are normally not a major influence on plant location, although they are certainly a major consideration. As previously emphasized, however, labour relations are both a major consideration and a possible major influence on plant location, since it is preferable to avoid an area of unrest, until the situation improves, however promising the other factors may be.

Political taxation and corporate factors

In most instances, secondary-fertilizer plants involve appreciably less investment than primary installations. Nevertheless, the same principles apply regarding the necessity for a stable political environment, the absence of iniquitous taxation and freedom from interference in corporate affairs, as regards both domestic operations and associated production units overseas. Thus, these factors can be considered, once again, to exert a major influence on plant location, on the lines previously discussed.

(c) *Mixers, blenders and distributors*

Location of markets

To the typical mixer, blender or distributor of secondary-fertilizer materials, the market usually means a number of individual farmers or cultivators located within accessible distance of the mixing and/or distribution centre. This can range from several hundred miles in sparsely populated countries to as little as five miles for bulk blenders and mixers in closely agglomerated farming areas (14, p. 254).

Direct contact with the final consumer places particular emphasis on customer-service features: prompt deliveries, individual packaging requirements, odd-sized shipments, specific formulations, special credit terms and possible back-haul arrangements. These services can be furnished more easily when supplier and customer are within easy reach; therefore, location should preferably be within the weighted centre of gravity of the market served, in the absence of competitive forces. Usually, however, strong competition exists, or will arise, in a given market area, possibly from more than one source. As a result, the strategic location point may shift from the weighted transportation centre of gravity to a site which permits the producer to operate on an effective competitive basis and which, at the same time, permits the maintenance of good customer service and profitable distribution.

It is of interest to examine cases of this nature with the aid of the graphical constructions developed by Lösch (4) Launhardt-Palander (12; 14, p. 254) and others.

An analysis of the actual and potential markets may show that about 80 per cent of the volume is represented by only some 20 per cent of the total number of customers, as is often the case. Accordingly, an attempt to serve the entire area from its centre of gravity may be unwise, and a location near to one or two large consumers may prove much more expedient. At the same time, some thought should be given to the possibility of new customers entering the market elsewhere and also to probable expansion of the market area. A future bipolar operation of several satellite mixing and/or distribution centres might form a satisfactory growth pattern in such instances.

Location of raw materials

The tendency for mixing and blending plants in the United States of America (and, to an increasing extent, elsewhere) is to use such primary raw materials as urea, diammonium phosphate, triple superphosphate and potash supplied in granular bulk form, and also to distribute the liquid or solid mixed fertilizer on a bulk basis. Therefore, ready access to primary-fertilizer producers is much more important than close proximity to secondary-fertilizer plants. In fact, bulk-mixers and blenders are, in many cases, strong competitors of secondary-fertilizer manufacturers, and in many areas, the future for small producers of bagged mixed and granulated goods is limited.

Therefore, the location of bulk raw-material suppliers can be of strategic importance to mixers and blenders, as regards minimum delivered costs, reliability, ability to meet seasonal demands (to avoid large inventories) and access to several sources of supply. This may, in turn, mean locating near to a port, if the plant is dependent on water-borne supplies, or adjacent to reliable rail and road services. The same requirements apply to distributors, but most probably also embrace good accessibility to secondary-fertilizer producers and to other agricultural material sources as well.

Because of the seasonal requirements of most fertilizer consumers and the inability of small mixers and distributors to carry large inventories, it can be seen that they must locate where it is readily possible to obtain large supplies of material at regular intervals, without uncertainties due to weather, shipping, politics, currency problems and other causes. Possible interruption in supply resulting from any of these factors may enforce relocation and/or the use of more costly materials from alternative and more distant sources, with a resulting loss of profits.

Influence of transportation

Raw materials. As is evident, reliability of raw material deliveries and least cost transportation are imperative to mixers, blenders and distributors, who cannot maintain large stocks and whose principal assets are often a reputation for service and dependability. Consequently, location is conditional on the availability of good, reliable transportation for raw materials and/or finished products for distribution and sale. Possibilities of interruptions due to weather, strikes, currency problems and other difficulties must be anticipated, and the availability of alternative means of transportation is regarded as imperative by some mixers and distributors.

In certain countries, freight equalization and in-transit privileges apply to fertilizers and/or agricultural goods. Nevertheless, cost-saving opportunities may still exist regarding transportation, and linear programming (11) or other techniques may reveal an optimum combination of location and least cost shipping programmes. Additional sources of possible savings in costs, which may have a bearing on location, include: back-haul arrangements with suppliers, consumers and others; less-than-carload-lot shipments in conjunction with local firms; the availability of leased or contracted facilities; and, of course, the delivery services offered by the raw material suppliers.

Finished goods. Many bulk-mixing and blending operators offer associated spreading and application services, whereby the farmer purchases fertilizer in place, rather than in the bag. This means using specially designed vehicles which are more suited for short hauls and field-work than for highway operation. Hence, bulk mixers and blenders must locate within a few miles of their principal customers; otherwise, transportation time and costs become prohibitive. Distributors of bagged materials usually have a greater degree of freedom regarding location and delivery to consumers, who may have access to several alternative types of transportation, e.g., road, rail, public or private services, or their own pick-up facilities.

Availability of utilities and labour

Utility requirements for mixing and blending units are not large and should not be a major influence on location. Similarly, operator needs are modest and, provided local labour relations are good, manpower considerations should not be a major location factor, either for mixers and blenders or for distributors. Neither should site conditions and construction details constitute major location factors because of the relatively small sizes of the units involved.

Political, taxation and corporate factors

As for primary- and secondary-fertilizer producers, political stability is essential for the encouragement of investment, and taxation levels must be reasonable to permit mixing, blending and distribution operations to flourish and provide reasonable rates of return. Therefore these factors can again be considered major items influencing location. This may especially apply to cases where relatively large units operating overseas on imported bulk primary material are envisaged, since local authorities may discourage a satellite operation in favour of a more basic, but unfeasible, project having greater prestige.

Because of the direct relationships with farmers and other cultivators, the availability of extended credit, insurance against various types of loss and assistance with promotional and demonstration programmes are other important local considerations in operating mixing, blending and distribution units. Therefore, they should also be regarded as factors which may determine the success or failure of an investment and, accordingly may, have a major influence on optimum regional or area location.

C. LOCATION STUDIES

In addition to a review of the major factors influencing optimum plant location, a brief mention of the fundamentally important principles of locational studies is of value. The numerous items to be closely examined prior to undertaking a relocation or a new investment will not be detailed here, as this material is available in numerous check-lists (2, 3, 4, 18, 19).

First, a list of objectives should be prepared, which justify the need for a new investment or relocation, and, secondly, the method which will be used to undertake the study should be selected, e.g., by consultant, by a company executive or by an internal study team. Thirdly, a precise list of requirements relating to company policies, production needs and future plans should be compiled and used as a screening device, when investigating potential investment opportunities and plant sites.

When conducting location searches, it may be possible to save considerable time and effort by discussing the detailed needs with such specialists as consultants, state, regional and area officials, port, railroad and utility companies, and realtors. The availability of, and adherence to, a well-prepared check-list of requirements

TABLE 103. TYPICAL FACTORS AFFECTING OPTIMUM PLANT LOCATION

Factor	*Probable degree of influence on optimum location*		
	Primary-fertilizer producer	*Secondary-fertilizer producer*	*Mixer, blender, distributor*
Market			
Distance	Med-minor	Major-med.	Major
Accessibility	Major-med.	Major-med.	Major
Raw materials			
Distance	Major	Major-med.	Major
Cost, availability	Major	Major	Major
Transportation			
Raw materials	Major	Major-med.	Major
Products	Medium	Major-med	Major
Utilities			
Water	Major-med.	Med.-minor	Minor
Power, fuel	Med.-minor	Med.-minor	Minor
Labour			
Availability	Medium	Med.-minor	Minor
Local policies	Major	Major	Major
Site			
Shape, conditions	Medium	Med.-minor	Minor
Waste disposal, expansion	Major	Medium	Minor
Political			
Stability	Major	Major-med.	Medium
Risk coverage	Major	Major-med.	Med.-minor
Taxation			
Benefits	Major-med.	Medium	Med.-minor
Future increases	Major	Major-med.	Medium
Corporate			
Local control	Major	Major-med.	Med.-minor
Local participation	Med.-minor	Minor	Minor
Environmental			
Loans and assistance	Med.-minor	Minor	Minor
Local goodwill	Minor	Medium	Major

will, in turn, save wasted energy on the part of all. The general screening sequence should normally be in terms of country, state, region, area and site. The apparent advantages of an attractive local situation or existing premises should not be allowed to influence an over-all unfavourable investment. Nor should a rising number of investigations lead to discouragement and the premature selection of a mediocre location. In one analysis of site-selection studies, an average number of visits between twelve and twenty-four was indicated, with a range from one to 175.

D. CONCLUSION

To conclude, when undertaking location studies, it is essential that the final area and site selections be made in accordance with all the fundamentally important factors and not on the basis of isolated advantages or hunches. An impartial investigation by experienced personnel, aided by a well-organized approach and detailed checklists of requirements, is indispensable. A theoretical analysis may provide additional useful information and can be recommended, when sufficient input data and the specialist skills are available.

As a guide, table 103 shows, for typical situations, the influence of each major factor on optimum plant location for the various operating categories.

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XVIII. PLANNING FOR DEVELOPMENT OF THE FERTILIZER INDUSTRY

A. GENERAL INFORMATION

In countries seeking to accelerate agricultural development, a national fertilizer industrial development programme is necessary. This is to ensure that the industry shall develop along optimum lines from the national viewpoint and to ensure the optimum use of available or externally raised capital and foreign exchange. These factors cannot be effectively handled on a local or unplanned basis.

The securing of financial aid from other countries or the attraction of private capital to a country would be contingent upon the presentation of a thought-out, organized plan for the development of the industry.

Many factors not directly related to the production and use of fertilizers must be taken into consideration to provide a workable plan for the development of a fertilizer industry. Every country presents its own unique set of problems and requirements. In the case of large countries, it would probably be necessary to develop the plan on a regional basis, fitting the parts into the whole and making modifications to suit the over-all economy.

In some countries, many of the factors needed have already been developed. In others, very little information would be available and each case would have to be considered a separate problem in the selection of personnel for the task of planning. The number required in each technical discipline would vary with the requirements for the specific area under consideration, but some types of technical personnel would be common to all. Trained and experienced agronomists, engineers, economists and marketing specialists would always be needed to form the hard core of the planning team. In addition, geologists and specialists in the mining and processing of minerals would be required where phosphate and/or potash were to be developed from sources within the country. Transportation specialists might be required, as well as operations research personnel, depending upon the specifics of the area under study.

The complexities of the problems involved are enormous. Such broad influences as the social structure, political development, general level of education, national traditions and world markets all exert checks and balances which must be carefully evaluated. These are in addition to the more tangible factors of logistics, climate, soil, water, yields, markets, raw materials and finance. It would therefore be essential for the planners to take advantage of the management planning methods which have been developed and have been proved successful in dealing with extremely complex problems in other fields of human endeavour.

An experienced planning group must be assembled, which could develop the logic of the over-all plan and break it down into manageable components. A relatively new tool, the "critical path technique", could then be applied to assure that the project was completed on a specified time schedule with a minimum of delay and to provide co-operation between all the contributors to the plan.

Experienced specialists would be needed to fit suitable computer programmes into the planning, with the modifications required for the specifics of the country and its special factors. Demographic, transportation, profit-projection and market-projection models are readily available from the Governments of developed countries, from computer manufacturers and from the major corporations and specialists in this field.

Technical and economic assistance from sources outside the country should be used as determined by the particular circumstances of the country developing the agricultural plan, but no group of citizens of one nation can do more than advance partial answers to the problems of another nation. The task would require that the Government and people of the country make difficult choices and heroic efforts. Other countries could help in various ways, but the decisions and impetus must come from within the country itself.

This chapter attempts to provide a check-list to outline the many factors which must be considered in the formulation of a fertilizer plan and includes those both directly and indirectly related to the fertilizer industry.

B. DEFINING THE OBJECTIVES

It is assumed that the ultimate purpose of any plan for the development of a fertilizer industry in a given country is to increase agricultural productivity to meet the country's needs for food and fibre.

In order to translate this deceptively simple statement of the over-all objective into a fertilizer plan containing plant-nutrient requirements, a great deal of information must be developed. The objectives can be restated as follows:

(*a*) To provide an adequate diet for the population;

(*b*) To provide for the national requirements of agricultural products other than food;

(*c*) To provide for the production and export of agricultural products for which the country has a comparatively good advantage in production.

To attain the first objective, feeding the population, it would be necessary to obtain statistics on the population and projections for the period of the plan. The projections and the plan should cover a fairly short span of time, five or ten years for practicality, but this factor can vary with the country under study. The average composition of the diet would have to be constructed, giving due consideration to necessary national and regional preferences. The projection should provide for improvement of the average diet over the period of the plan, as well as for changes from anticipated improvements in living standards. Family consumption requirements and the marketed portion of crops must be determined. The total food requirements derived could then be translated into tons of various agricultural products. The total food requirements must be further broken down by sections of the country, according to the current and projected density of the population.

Estimating the non-food requirements for agricultural products would require population projections, density projections and consideration of improvements in the standard of living. Projections of general industrial requirements for fibres, oils and other non-food agricultural products must be converted to tons of raw products at the field level.

Export demand for agricultural products in which the country has a comparative advantage in production must be determined. For the plan to be useful in this area, there must be a major effort, involving market and demand studies on a regional or world basis, transportation and port projects, foreign exchange considerations etc. It would be necessary to know the types and qualities of agricultural products most salable to other countries. Future expected prices, as well as improvements in production techniques in competing countries, would affect the tonnages which could be sold. When this information had been developed, the product requirements for export could be converted to tons at the field level. All three segments of the market for agricultural products should be subdivided into totals for each region of the country.

C. DETERMINING THE AGRICULTURAL ASSETS AND LIABILITIES

A major portion of the preliminary planning effort would be needed to determine the agricultural assets and liabilities of the country. The assets would assist in attaining the over-all objectives, while serious liabilities must be delineated, in addition to providing a definite plan and time table for finding solutions. There must be sufficient arable land, water and a suitable climate to meet the objectives for agricultural products with a reasonably high productive efficiency, or the objectives would have to be modified downwards. There must also be an over-all transportation plan capable of delivering the agricultural products to the market areas from the land in production. Transportation, while beyond the scope of this chapter, could exert a major influence on the agricultural plan and thus the development of fertilizer production. It does no good to produce at the farm level if the products cannot reach the consumer.

An inventory of the agricultural assets and liabilities should include the land areas currently being cultivated and the available additional land together with an estimate of the magnitude of effort necessary for the conversion of this land to its required place in the plan. The soil types, pH, mineral content and tilth should be estimated from data available for the country or from soil surveys.

Technical agronomical studies and research should be evaluated by experienced agronomists and compared with studies on similar crops in other parts of the world in which conditions of growth were most comparable to the country under study. This would help to fill in gaps in the available information and would provide a basis for estimating yield responses from fertilizer treatments. Due care must be taken to allow for variety differences in yield response from fertilizer treatments. It might be important to consider in the plan the importation or development of special seed better suited to the country's environmental conditions.

Agricultural research data are limited in developing countries. It would be necessary to have a strong, well-operated effort along these lines as a part of any massive agricultural operation. Such a programme takes many years to be effective, and when people are hungry, there is not enough time to wait for the results of a research programme. Therefore, average nutrient requirements and yields would have to be estimated to move the plan forward. The uptake of nutrients in crops could provide some guidance in making the estimate of fertilizer requirements, but this method alone is not reliable, as it often provides astronomically high demands. Modifications must be added to cover virgin *versus* farmed-out soils, the mineral content of the soils, the differences between types of plants in the same species, luxury consumption and other factors. Lacking reliable research data on yields *versus* treatment on the soils of the country, it would be necessary to estimate on the basis of the nearest technically similar data available from other countries. Such estimates could be modified in later years as the research results become available.

If the analysis and evaluation were valid, the following information should be available:

(*a*) Tons of agricultural products required;

(*b*) Market location for these products;

(*c*) Transportation facilities, existent or planned;

(*d*) The land area required for production and its properties with regard to soil type, pH, general mineral content etc.;

(*e*) An estimate of the tonnages of major nutrients needed to obtain the required agricultural production, as well as an estimated fertilizer distribution pattern.

D. FERTILIZER RAW MATERIALS

With an estimate of fertilizer requirements, the actual work on the production part of the plan could get under way. The current fertilizer industry, if any, should be studied in order to utilize the facilities already available. Information as to types of products, methods of distribution, credit, farmer profiles, the effect of government regulation and taxes should be obtained from the local industry and should be evaluated.

A study of the sources of the major raw materials for fertilizer production should be undertaken. National sources of natural gas, refinery off-gas, naphtha, oil, coal or inexpensive power should be evaluated. If imports were necessary, the importation of both raw materials and the final product should be studied. The problems of foreign exchange must be considered, as well as trade relations involving the barter of raw materials for exportable agricultural or other commodities. These might modify the requirements for the materials imported. It might be more advantageous to begin with imported solid nitrogen products, phasing these out when, and if, national production was provided.

Unless there are known workable phosphate deposits, it will be necessary to resort to geological investigation or to provide imports. Since the development of a major phosphate reserve takes time, it would likely be necessary to begin with the importation of rock or finished fertilizers. There are enough world suppliers to make the possibility of export-import trade or monetary considerations worthy of study.

Potash, like phosphate, requires a deposit of a suitable salt from which potash can be recovered economically. Development of a new national resource would take time and money. The practical alternative would be importation, at least in the early years of the plan. There are enough world suppliers to provide some flexibility in choice, from the trade and monetary standpoints.

Depending upon soil acidity and alkalinity, calcium might or might not be of importance. Limestone is widely distributed throughout the world, and deposits might be available, although not developed. Often, there are available dolomitic limestone deposits, which can supply magnesium if this is needed. While calcium may not be a part of the fertilizer industry in many developed countries, it can be very important in obtaining optimum yields from lower applications of N-P-K and therefore would be well worth inclusion in any over-all plan where the soils require it.

Sulphuric acid is required for the solubilization of phosphates in most of the common processes for the manufacture of fertilizers. It is also one of the cornerstones of the heavy chemical industry. The possibilities for national sources of sulphur should be evaluated. Sulphuric acid is commonly produced from a variety of raw materials. With some loss in flexibility, phosphate can be solubilized with nitric or hydrochloric acids if sulphuric acid is undesirable or unavailable. If sulphur is required in the soils, ammonium sulphate, normal superphosphate and gypsum are the most common sources, and agronomical data should be checked for the extent of this requirement. If highly saline soils were a problem, there might be a large requirement for gypsum or sulphur to reduce the sodium or other salts to reasonable limits.

Unless there were large minor-element problems revealed in the agronomical data or specific areas with recognizable single-element deficiencies, these materials would not need to be considered in the early plans. In future years, when needed and as required, these minor elements could be determined by an agronomical research programme and could be included in the fertilizer plan at that time.

E. FERTILIZER PRODUCTION

The next step in the development of the fertilizer plan consists of matching the total demand by regions for N-P-K with the raw material supply and the agronomical input data on the type of products most suitable for each region. Agronomical data should suggest the type of nitrogen, whether ammoniacal or nitrate, and the quantity of each, as well as the importance of water solubility in P_2O_5. The latter can be important if even modest quantities of phosphate can be applied directly as rock. Agronomists would have to supply the plant planning-group with the special needs for non-chloride potash, sulphur and magnesium. All these factors can affect the type of process selected and the raw materials required. Alternative production plans would have to be prepared in order to achieve a balance between the most economic raw materials, processes and agronomical requirements.

Plant locations, transportation, power, fuel, water, waste disposal, labour availability and the distribution and application system for the products would all exert their modifying influence on the processes to be used. Possible by-products, for example, gypsum for wallboard or fluorine products, should receive attention, as should the production of feed phosphates if needed. The potential for producing detergent or feed phosphates with fertilizers could significantly change the process selected for fertilizer production.

F. MARKETING

Formulation of a sound marketing plan is extremely important to the development of a fertilizer industry. Informational feedback to the production planners from a marketing system would supply the needed definition of the products, whether bagged or bulk, and the proportion of each, as well as the physical properties needed for the distribution and application systems involved. To some extent, the actual ratios of N-P-K in the various products would be dependent on whether single or multiple applications were to be practised on the farms.

The level of the farmer's sophistication, literacy and current practices, and even his likes and dislikes, would need evaluation. Studies of methods of sales promotion, educational programmes and sales personnel requirements and their costs must be provided. The necessary distribution facilities, storage warehouses, dealers or other factors in the chain from plant to farm would require a finite plan of time, manpower and money requirements. The possibility of farmer co-operatives or other group activities, as well as the selection of key farmers for the educational programme, should be considered.

Pricing policies and the economic value of fertilizer to the farmer, together with credit problems, would need to be worked out to the point that sales prices and plant profits could be determined. Where needed, plans for government assistance in the early stages, or throughout the plan, should be formulated, based on the most feasible methods for the particular country under study. The plans previously developed for marketing and distribution of the agricultural products should be reviewed for possible use in the back-haul of fertilizers, storage or the combination of personnel or financing.

Methods of application should be co-ordinated with agronomists and production engineers for the effect on product specification. Of course, the availability of the required equipment for the farms should also be keyed into the programme with whatever modification this factor might bring about in the product specification. A plan for the supply of the needed farm equipment should also be part of the effort.

While perhaps beyond the scope of this chapter, it would also be desirable to look into the need for such agricultural chemicals as pesticides and herbicides. These are an important part of the whole agricultural picture and are often sold with fertilizers or through the same outlets.

G. GOVERNMENT ACTION

Many requirements of a sound agricultural programme of national stature are beyond the means or reasonable interests of the fertilizer industry, and government action and support would be necessary. The derivation and implementation of the basic plan outlined in this chapter would almost certainly require government action, with participation by industry to the degree that circumstances permitted. When the plan was ready for action, sectors could be set up for bids by private industry, with direct government action filling in the gaps where necessary.

Since the basic motivation for private industry is profit, the Government must provide a suitable financial climate for the growth of a fertilizer industry. There must be reasonable confidence in the Government's general stability and future plans for the control of inflation, reasonable taxation, expropriation policies and similar unsettling business factors. Industry must be able to plan ahead with confidence, or it will not participate. The industry need not be private, but could be entirely or partly Government controlled or operated. Even in a Government-controlled operation, stability and the ability to plan ahead with confidence are necessary for reasonable efficiency and economy of operation. Exportable products would face stiff competition in the world markets from countries with well-developed and economical agricultural systems if price and quality, rather than subsidy or surplus, rule. To a great degree, the same efficiency and economy of operation should be expected within developing countries.

Among the many large and continuing programmes which are beyond the scope of a fertilizer industry and essential to the total agricultural programme are the following:

(*a*) Scientific training of agricultural technicians in schools and universities;

(*b*) Field and laboratory research in agriculture on a regional and national basis;

(*c*) A regional system of dissemination of information, training and assistance to the farmers, i.e., an extension service;

(*d*) A statistical service to provide measures of agriculture on a regional basis: cultivated areas by crops, yields, fertilizer consumed, crop prices etc.

There are many fine training institutions and experimental stations in the world to provide a guide as to how the job should be done. There are also excellent international foundations operated by charitable or industrial organizations [illegible] consultants in [illegible] extension services [illegible] of the countries [illegible] these [illegible] manner are [illegible] ment sphere. They [illegible] the [illegible] improvement of a national agricultural programme.

Direct or indirect assistance and guidance of the agricultural programme might also require governmental participation in the form of [illegible] fertilizer subsidies, credit plans or other forms of financial subsidy. The value of a nation's currency is to some extent dependent on the balance of trade, and the Government might need to exercise a measure of control through duties or subsidies.

A fertilizer-control law on a national basis is a means of getting industry, the Government and the farmer on a uniform basis. Such a law protects the farmer and industry against unscrupulous practices. Methods of analysis, labelling, guarantees as to content and weights, types of nutrients, minimum grades and other pertinent items can be included. A workable inspection and penalty system must accompany and complement the law, and this could be financed, at least in part, by a registration fee system, licences and/or a tonnage tax. The law should be kept workable by revisions and should be subject to fairly frequent reviews by Government and industry as the agricultural plans mature.

Finally, the Government, with the help of industry, should maintain an adequate planning group with reasonable continuity of personnel to review the goals of the initial plan and to keep abreast of the development and growth of the country. A one-shot initial plan, no matter how good, could profitably be modified by future factors as they develop.

H. SOURCES OF CAPITAL FUNDS

There are available to the developers of soundly conceived and practical projects a number of different sources from which capital funds may be obtained.

Most countries have banking facilities that, although not as sophisticated as those in Europe and the United States of America, can furnish both financial and local aid in dealing with government bureaux. Several countries have also set up development corporations to encourage investment in the country through the provision of long-term loans and equity participation. For example, India has the Industrial Finance Corporation of India and the Industrial Credit and Investment Corporation of India, and is in the process of setting up a new development bank. Analogous organizations, which have available to them the resources of the major foreign financial institutions, can be found in most countries.

In addition, there are local institutions which are not strictly financial, but are capable of, and interested in, participation in local ventures. In this category, there are insurance companies, both public and private, investment trusts and investment bankers. There are also large family accumulations of capital, which become available if a venture is attractive.

A further source of capital is available from suppliers of both equipment and raw materials, and from engineering firms who wish to participate in a venture either as a partner or as a supplier of goods or services to the venture.

There are a number of international private sources of financing available. Many of the larger banks in the United States of America have Edge Act Corporations which are willing to lend significant amounts for investment in foreign ventures provided the Edge Act Corporation is able to obtain equity participation if it so desires. Usually, if the amount required is very large several Edge Act Corporations will act together to lend the money.

The International Bank for Reconstruction and Development, the International Finance Corporation, the International Development Association, the Inter-American Development Bank and the European Investment Bank all have funds available, and there are many other such international institutions, which are specifically set up to encourage the type of investment under discussion.

When the investment is to be in a developing country, large sums of money are available from many sources. The Agency for International Development has both the "Cooley Fund" (i.e. local currency, so-called "counterpart funds") and unrestricted funds, which it can lend to ventures which have been set up with the participation of the United States of America. The Export-Import Bank of Washington is a second large source of such funds, if the funds are to be used to purchase goods and services for the foreign project from the United States. Similar institutions have been set up by the Governments of other countries to encourage such projects as a fertilizer industry. Generally, to use these resources, a national of the country which has set up the financial institution must be a participant, or there must be some form of trade which the proposed fertilizer project will have with the sponsoring country.

Joint ventures between experienced international corporations and the local fertilizer companies are a possibility, particularly where an attractive investment atmosphere exists. This has the advantage of providing the foreign partner with a participant knowledgeable in the local market area and conversant with the Government and customs of the nation. It provides the national partner with a source of new funds, a reliable source of raw materials and greater experience in manufacturing and marketing.

A major problem in the world today is one of foreign exchange, and any project, to be attractive to a country with this problem, must be able to demonstrate that: (*a*) it saves foreign exchange by cutting down imports from without the country, and (*b*) that it possibly will generate foreign exchange by producing exports.

I. Reporting

With a task as complex as this, voluminous sets of reports would be required. There should be sufficient detail in the plan to eliminate the necessity for users of the reports to do research in order to evaluate the plans and proposals. The use of statistical and data appendix volumes and of foot-notes keyed to references could serve to simplify the reports and to make the evaluation easier for those who needed more information.

Alternatives should be included because changes in any of the factors might make the alternatives more suitable than the routes chosen. As the plan developed, they might offer a solution to unforeseen problems.

A reasonable number of graphs, bar charts and flow sheets should be included in the reports to provide clarity. Modern business management has made considerable progress in recent years towards the increase in effectiveness of visual aids for the summation of complex relationships. Specialists to assist in visual development could be readily obtained if needed.

The reports or over-all plan should contain, among other things:

(*a*) A statement of the agricultural objectives for a five-to-ten-years period, with an indicated plan for accomplishing progress towards these objectives;

(*b*) The summary of the agricultural assets and liabilities of the country, with the broad outlines of the plans and schedules for the action necessary to attain the agricultural objectives;

(*c*) Recommended specific quantities of nutrients and suggested means of supply, including: those to be produced internally, with the mining and manufacturing facilities required with their location, and those to be imported, with the probable sources, suggested means of financing, trade or barter. A schedule for phasing out initial quantities of imported fertilizers utilized to establish markets while national plants are being constructed would also be needed;

(*d*) A summary of the distribution plan for both agricultural production and plant nutrients with the scheduling of the transportation network development and facilities;

(*e*) Recommended procedures for developing the market for fertilizer; farmer education; methods of providing buying power to the farmer; continued research on the value of fertilizer in increasing yields and the role of the extension service in getting results to the farmer; mechanical aids for the farmer; and a summary of plans for the use of pesticides, herbicides etc.;

(*f*) A summary of the financial requirements of the programme with priorities and suggested timing to meet the over-all plan. Suggestions on methods of financing and estimates of costs should be included;

(*g*) A plan for executing the programme, including: approval of programmes for private domestic firms; projects to be handled by the Government; projects for participation by foreign private companies; and the creation of a permanent organization to monitor execution of the plan and to update it periodically;

(*h*) The over-all feasibility of the plan and its meaning to the country in both financial and social growth;

(*i*) The legislative action required by the Government, with suggested forms for the various laws and acts needed.[7]

XIX. GENERAL PROBLEMS OF FERTILIZER PROJECTS IN DEVELOPING COUNTRIES

A. General information

Chemical fertilizer projects and similar industrial undertakings proceed in accordance with a well-defined sequence of phases and activities along the following lines:

Phase	*Activities*
1	Conception and organization
2	Promotion and financing
3	Contract awarding and plant construction
4	Administrative planning and personnel training
5	Plant operation and future growth

To ensure that a project will evolve into a successful enterprise and yield the maximum return for a given outlay, it is essential that each step be carefully planned and competently executed. Failure to meet the scheduled start-up time and/or plant performance, in terms of design capacity and product specifications, inevitably leads to loss of earnings on invested capital and possible legal actions between producer and contractor, and also between customer and producer in some cases. In developing countries, the consequences of a delay in a fertilizer project may be even more serious, since crop failure and even hunger can result. Accordingly, this chapter reviews some typical problems associated with fertilizer projects in developing areas and suggests how these difficulties may be anticipated and overcome.

It should not be imagined, however, that problems are encountered with projects only in developing countries. Even in Europe, Japan and the United States of America, where ample resources and experience are available, there have been many instances of projects failing to start on schedule or not meeting production guarantees, with consequent heavy financial losses and costly lawsuits. Subsequent investigations have sometimes shown that only one of the activities defined above was inadequately planned or executed, or that possible complications were not anticipated. The need for realistic and thorough planning during every phase when undertaking projects in developing countries, and for foreseeing possible difficulties, thus becomes even more pronounced.

B. Project development and related problems

1. *Conception*

The idea of building a fertilizer plant in a particular area may originate in several ways, such as the need to grow more food locally, to save foreign exchange spent on imported materials or to generate foreign exchange by exporting fertilizers produced from indigenous skills and resources.

For a fertilizer project to be properly justified, however, it must be basically sound in principle as well as in practice. For example, the operation of a large nitrogen fertilizer plant based on domestically available solid fuel might save imports of liquid feed-stock, but, at the same time, it could involve a large additional capital outlay and extra production costs, which could result in extremely high fertilizer prices to the farmer. These high prices, in turn, might necessitate government subsidies or might lead to lower food production and a consequent reduction in national well-being. Conversely, the use of a suitable and readily available solid fuel in a specific location far from imported feed-stocks might be quite logical and beneficial to all concerned.

Similarly, the envisaged manufacture of fertilizers or fertilizer raw materials from indigenous sources for export purposes must be realistically considered in relation to competition, cost, transportation, customer specifications and many other factors. Although Government-owned plants can usually operate on longer return-on-investment periods than similar installations under other forms of ownership, an inability to show a reasonable rate of return is not in the public interest.

The conception of a fertilizer project must also be in conformity with technological developments, some of which are predictable. For example, there are over-all trends to high-analysis primary and secondary fertilizers, and regional preferences for various types of fertilizer and degrees of ammoniacal nitrogen or P_2O_5 water solubility. Bulk shipments of refrigerated ammonia and liquid phosphoric acid, and bulk deliveries of liquid and solid blended goods to the farmer on an in-place basis, are already established in the United States of America and will be adopted in other countries, with resulting radical changes in established customs. Bearing in mind that a period of several years often elapses between the conception of a fertilizer project and its initial operation, an envisaged plant must be thought of in terms of future technology and interrelated world practices, as well as future demand, and not merely on the basis of familiar, but dated, technology and imminent local needs.

2. *Organization*

(a) *The feasibility study*

However inspired the conception of a fertilizer plant may be, it becomes imperative to justify it as regards local and other needs, material availability, technology and the envisaged financial return. This necessitates a detailed feasibility study, for which funds must be provided and experienced personnel found. One way of undertaking such work is to employ reputable consultants in this field; another is to establish from within the organization a small team of marketing, technical and financial specialists who are familiar with the company's policies and aims.

When fertilizer (and other) projects are contemplated by government authorities, either alone or in conjunction with private investors, valuable assistance can also be rendered by consultants and industrial specialists in marketing, shipping, financing and other pertinent fields. In turn, many Governments, in both the developed and the developing areas of the world, employ state and regional experts for the purpose of assisting potential investors with needed information. Indispensable guidance can also be obtained from such organizations as the United Nations, the Ford Foundation and other trusts, as well as from the major banks and universities.

It is evident that the feasibility study must be completely objective and impartial, as well as accurate in its findings and recommendations. (For these reasons, the individual responsible for the conception of a project may not always be the most suitable to undertake responsibility for the study.) Failure to recognize possible difficulties and limitations (1), or a tendency to minimize financial requirements or to overestimate potential sales and profits may lead to unfortunate consequences in the future. Hence, the organization of a competent, objective study-team and clear definitions of the scope, depth, purpose and time schedules for the work to be undertaken by each individual are prerequisites for success.

3. *Promotion*

Following the conception of a project and proof of its feasibility, it must receive acceptance and approval, often by more than one authority. For example, in some countries, a fertilizer project developed and sponsored by one government body, such as the Ministry of Agriculture, may have to be supported by those ministries responsible for development and finance before final approval is given. Similarly, in a commercial organization, a project pioneered by the development group may have to pass a detailed investigation by the sales, legal and corporate finance divisions before authorization by the Board and possible approval by one or more government departments. Should outside financing be required, the scrutiny given to the envisaged project would likely be even more rigorous.

To pass such a series of close examinations, the feasibility study must be encouraging, yet, at the same time, accurate and even conservative. Furthermore, it would have to be read by specialists in different fields. Hence, suitable promotion and presentation of the project would be essential, perhaps supported by visual aids and brief speeches by experts. In particular, the following features should be emphasized and demonstrated:

(*a*) The basic need for the project and its products;

(*b*) Direct and indirect benefits to the community;

(*c*) Assurance of markets and sales;

(*d*) Assurance of raw material supplies;

(*e*) Suitability of the process, plus performance guarantees;

(*f*) Capabilities of the proposed senior management;

(*g*) Detailed projected earnings and financial statements over a suitable future period.

The feasibility study should, if at all possible, be supported by letters of intent from prospective customers and raw material suppliers, as well as by guaranteed maximum prices from contractors, licensors and others. An attractive format and binding would also encourage a favourable response, but if too lavish, the opposite effect might be induced, especially if some of the contents were open to question.

It has often been found that projects in developing areas tend to take much longer in preparation and approval than those of similar magnitude in Europe or the United States of America. An extended pre-financing or pre-construction period not only deprives consumers and others of the resultant benefits, but may also increase investment needs, owing to the continual rise in engineering, equipment and labour costs. A well-presented feasibility study, backed by detailed information sufficient to answer anticipated questions and requests for further data, would most probably save valuable time and money and thus expedite the entire project to a considerable degree.

However, should a feasibility study reveal a project to have limited justification, the outlay involved could still, in most cases, be regarded as a sound expenditure. Study costs for an envisaged project in the $10-million range might be of the order of $100,000 (or less), which could be regarded as only a 1 per cent insurance cost against possible future failure and, therefore, a wise investment.

4. *Financing*

The unique nature of most industrial projects often means that considerable study is needed to find the best way of providing the required fixed and working capital, in order that the cost of these funds, as for any other commodity, may be kept to a minimum and the greatest return on the total investment may be obtained. Provided that a project were supported by a realistic and well-presented feasibility study which also indicated a favourable profit margin after taxes, no difficulty should be experienced in securing the interest of potential investors who might wish to subscribe a large part, or all, of the needed investment. However, financing problems might still arise, owing to currency restrictions and doubts concerning the security of capital and earnings (2).

(a) *Foreign exchange difficulties*

Modern primary fertilizer plants for manufacturing ammonia, phosphoric acid and their derivatives necessitate expenditures of the order of millions of dollars, and, moreover, require many items that are unlikely to be available in developing countries, e.g., stainless-steel vessels, catalysts and complex instruments, in addition to engineering and process technology. The purchase of these facilities from other countries would be likely to make heavy demands on limited foreign exchange reserves, which, in turn, could lead to delays, increased capital costs and reduced earnings, or even abandonment of the entire project.

A practical way of surmounting foreign-exchange limitations, as well as of raising the large funds often required, might be to borrow money from one or more of the international lending agencies or banks specializing in these services. The major institutions of this type include the International Bank for Reconstruction and Development (IBRD), with its affiliates, the International Finance Corporation (IFC) and the International Development Association (IDA) and the Inter-American Development Bank (IDB). The United States Agency for International Development (AID), the Export-Import Bank of Washington (Eximbank) and similar agencies in other countries should also be considered.

(b) *International Bank for Reconstruction and Development*

This organization, also known as the World Bank, is currently owned by 102 member countries and makes loans to Governments, government agencies and private enterprises, mainly for the purpose of establishing basic undertakings: dams, utility services and large industrial or agricultural projects. Loans are made at the current cost of borrowed capital plus a 1 per cent annual charge, and more recent rates have been between 5 per cent and 6.25 per cent. The direct participation of private investors is encouraged and, normally, only the foreign-exchange costs of a project are financed.

(c) *International Finance Corporation*

The International Finance Corporation is owned by member Governments, and its aims are to stimulate the participation of private enterprise in the developing areas. The IFC share in the project is restricted to 50 per cent of the total, and it prefers to make investments of the order of $500,000 to $4 million. Interest rates vary in accordance with the respective risks and returns, and other factors. Equity positions, as well as loans, are adopted in association with nationals of the country in which the project is located, with foreign private investors or through a combination of the two. However, this does not apply to government undertakings. A prerequisite of investment is that the project must make a useful contribution to the economy of the member country in which the project will be established.

(d) *International Development Association*

IDA was created by the World Bank to assist developing countries in obtaining outside capital at much lower interest rates than are normally required. Typical credits are for fifty-year terms at no interest, although a service charge of 0.75 per cent *per annum* is made to cover operating costs. In certain cases, these funds may also be used for relending purposes, on terms that are customary in the country involved.

(e) *Inter-American Development Bank*

This organization includes every country in Latin America (except Cuba) and the United States of America. It offers assistance through its normal capital resources, a fund for special operations and a social progress trust fund, which finances development projects that are beneficial to the people's welfare. Ordinary loans to private enterprises and public utilities are repayable in the currencies lent, at 6 per cent *per annum*, for periods ranging from eight to twenty years, including grace periods. The special operation fund has interest rates of about 4 per cent *per annum* over ten to twenty years, including grace periods, and permits the world-wide procurement of equipment and services. The social progress trust fund makes loans in dollars, usually repayable in local currency at annual rates of 1.25 to 2.75 per cent, plus a service charge of 0.75 per cent over periods from fifteen to thirty years.

(f) *Agency for International Development*

AID was created in 1961 and superseded the former International Cooperation Administration (ICA) and the Development Loan Fund (DLF). It is empowered to help long-range growth in friendly developing countries by granting loans with maturities from fifteen to forty years, with grace periods of three to ten years, at rates varying from 5.75 per cent to zero, although the latter carries a credit fee of 0.75 per cent. In some cases, borrowers are permitted to repay their dollar obligations in local currencies within a relatively short period to their respective Governments, who reimburse AID over longer periods, which may amount to fifty years. To assist the balance of payments of the United States of America, AID endeavours, when possible, to support the purchase of United States goods and services with its loans (3). The Agency also grants loans in local currencies from funds resulting from the sale of surplus agricultural products of the United States, under United States Law 480, more popularly known as the Cooley Funds (4).

Under Section 201 of the Foreign Assistance Act of 1961, AID is authorized to make dollar loans to private and public enterprises in both the United States of America and other countries. Of course, such loans are made only where there are reasonable prospects of payment. In addition, the availability of financing from other public sources is taken into account before AID funds are made available. In turn, public financing agencies usually require that funds first be sought from private financial institutions and private investors before considering loan applications. The current principal terms and conditions of AID loans are as follows:

(*a*) The project must give reasonable promise of contributing to the development of economic resources and/or increasing the productive capacities of the country concerned;

(*b*) It must be consistent with the other development activities being undertaken or planned for that country;

(*c*) The project must be economically sound and technically feasible, with reasonable prospects that it will pay out satisfactorily;

(*d*) The project must not compete [within the meaning of Section 620(d) of the Foreign Assistance Act, 22nd United States Congress, Section 2370(d)] with enterprises in the United States of America;

(*e*) The proceeds of the loan must be used to finance the dollar costs of the project except where, for good cause, AID agrees otherwise;

(*f*) Procurement will be limited to goods and services originating in the United States, with few exceptions permitted;

(*g*) Loans are generally made directly by AID to the private borrower at an interest rate of 5.5 per cent. While principal and interest are owed in dollars, arrangements may be made for the repayment of principal and interest in local currency (dollar denominated) to the Government of the country concerned, which, in turn, arranges to pay AID in dollars;

(*h*) Borrowers must agree to follow normal commercially acceptable business practices to assure that the prices paid for goods financed under AID loans are reasonable and that contracts are awarded on an appropriate competitive basis (3).

AID also has a guarantee programme designed to protect new investments of the United States of America against political risks and, in some cases, part of the business risks, in accordance with treaties made between the United States and other Governments. The specific (political) risk-guarantee programme insures against currency inconvertability, confiscation and losses due to war, revolution or insurrection. Extended risk guarantees may cover up to 75 per cent of both business and political risks or up to 100 per cent of losses on pilot or demonstration private-housing projects. Fees for specific risks are currently 0.5 per cent of the amount of each of the three coverages in force during any given contract year plus an annual fee of 0.25 per cent of the amount of each stand-by coverage. For extended risk guarantees, an annual fee of up to 2 per cent of the insured portion of an investment is charged.

Encouragement of potential investors is also provided by AID in the form of a 50 per cent reimbursement of feasibility study costs if a project does not materialize. In addition, AID has compiled a catalogue of investment opportunities, which contains abstracts of hundreds of feasibility studies undertaken during recent years on investment opportunities in the developing countries. Detailed information on the loan services and other AID facilities available can be obtained from the Office of Development Finance and Private Enterprise, AID, Department of State, Washington D.C., United States of America.

(g) *Export-Import Bank of Washington*

This bank was established in 1934 and is the oldest financing agency of the Government of the United States of America. More than $13,000 million has been authorized for the overseas sale of products from the United States, particularly for industrial equipment and agricultural machinery and commodities. Loans are not available if private capital at reasonable rates can be obtained, but the participation of commercial banks or other private institutions is encouraged. Up to 100 per cent of the dollar cost of a loan to a private or public purchaser overseas may be financed at a current rate of 5.5 per cent annually, for periods ranging from five to twenty years.

Export credit insurance can be obtained from the Foreign Credit Insurance Association (FCIA) in conjunction with Eximbank, on medium-term and short-term conditions, and against various types ,of risk. Premium rates vary according to the respective country and terms of credit. FCIA is an unincorporated association of large marine, casualty and property insurers in the United States, in partnership with Eximbank.

(h) *Other foreign exchange needs*

In addition to United States dollars, developing areas require other currencies to purchase equipment, goods and services from sources other than the United States of America, at reasonable interest rates and on extended credit terms. To permit banks and financing institutions in developed countries to lend money to manufacturers and others for equipment and services needed for overseas projects, the Governments of such countries as the Federal Republic of Germany, France, Japan and the United Kingdom of Great Britain and Northern Ireland have also developed schemes for export credit and guarantee insurance. Interest and insurance rates are similar to those for loan agencies in the United States of America, and terms are normally for five years, although eight-year periods (or even longer) are becoming more common. Naturally, such arrangements are based on international treaties or other agreements, as well as on the anticipated ability of the country in which the customer is located to arrange payment in acceptable funds, or even by bartering appropriate commodities. Information on specific foreign exchange assistance and credit and insurance facilities may be obtained from the departments of commerce of most countries, as well as from affiliated members of IBRD and the major international loan agencies.

(i) *Regional and local financing sources*

Several of the developing regions have established their own development banks along the lines of the major international lending agencies, typical examples being the African Development Bank and the Central American Bank for Economic Integration. Special consideration is usually given to agricultural, transportation and utility projects. Other likely local sources of domestic (and occasionally foreign) funds include state, regional and area development boards, investment banks and trusts, in addition to public and private investors (5, 6). It may also be possible for these regions to limit immediate capital needs by adopting some form of lease-back or a similar type of arrangement.

(j) *Summary of financing*

It may be seen that there are several possible ways of overcoming foreign-exchange and capital-investment problems regarding projects in developing countries. This applies equally to the foreign investor who wishes to protect his investment and its earnings and to a Government or private enterprise which is desirous of maintaining a strong equity position and which needs long-term credit for overseas purchases. The essential requirement in all cases is a factual and properly presented feasibility study, supported, if possible, by the affirmative conclusions of independent authorities and letters of intent from prospective customers, suppliers and others who will play a vital part in the project. When foreign participation, in terms of equity and of technology management and marketing, is also required, a good, stable investment code (7) is of equal importance in helping to overcome foreign exchange and capitalization limitations.

5. *Awarding of contracts*

A critical phase of every project is the soliciting, awarding and undertaking of the plant construction. If insufficient attention were to be given to these functions, the project might be permanently handicapped by an excessively high installed cost, an inadequate plant (or, alternatively, over-elaborate facilities), or, perhaps, a process which was inflexible and not competitive. On the other hand, the fear of making such errors could lead to an unnecessary number of restudies and bid specification changes until the entire situation became increasingly perplexing, and a final decision would be made only after much wasted time and apprehension.

In view of the urgency and fundamental significance of fertilizer projects in developing countries, it is particularly important to achieve a proper balance between an over-hasty choice of the process and contractual services to be used and an unjustifiable amount of study work, negotiation and revisions in conjunction with numerous bidders. Undue apprehension in the pre-award period would be likely to result in serious delays to the programme and increased over-all costs. For projects in developing areas, there are several guiding principles which could help to reduce the time between preliminary bid invitations and the final awarding of the contract, as well as total project costs and the time needed to achieve anticipated production levels.

(a) *Choice of process*

Although, as mentioned previously, advantage should be taken of modern processes and improved technology when possible, the adoption of untried, new processes, equipment and methods should be avoided for projects in developing areas. Invariably, unforeseen troubles would arise, which, whether major or minor, would be likely to introduce a series of compounded delays. For example, a process which has demonstrated satisfactory performance on a pilot-plant scale may exhibit serious plugging or corrosion difficulties after a few weeks of full-scale operation, which could be disastrous in an area where replacement or repair facilities were non-existent. Similarly, minor changes in the design of compressors, or even seals, have resulted in costly delays to large nitrogen fertilizer projects overseas, owing to unsuspected troubles of a small but significant nature.

(b) *Process performance responsibility*

In some cases, a process owned by, or licensed to, a particular contractor might be selected, in which case the liability of the contractor to the customer for satisfactory performance could be clearly established. In other instances, the customer (or investor) might wish to use a process which had been developed by a producer or other party and which was not yet available through a licensed contractor. To avoid the pitfalls of split responsibility should subsequent troubles arise, it is often preferable to purchase the process and the plant on a "turn-key" basis through a mutually acceptable contractor, who then accepts full responsibility for both the process and the performance of the plant. In this way, a double-check on process and design engineering becomes possible and obligations between all three parties can be clearly defined.

(c) *Selection of contractor*

Although a contractor for a project in a developing country must have adequate financial resources and suitable construction facilities, special emphasis should be placed on previous successful experience of the process to be used and on the way it will work in the area in which the plant will be built. Such dual knowledge can be expected to increase substantially the probability of building a satisfactory plant within the anticipated construction schedule.

Various procedures for reducing the total plant cost and the erection period are available, according to specific circumstances. In many instances, competitive bidding is used, whereby several contractors submit firm prices for a plant to be built in conformity with a series of specified requirements. Although the more common tendency is to appoint a contractor on the basis of the lowest price for the plant, some sophisticated producers make their selections in accordance with the lowest cost of production, which also takes into account such factors as process efficiency, maintenance charges, and utility and labour needs. The ability to reduce construction time and to achieve full production more quickly are other factors to be considered when making the final selection of a contractor; hence, past experience and reputation must also be taken into account.

Construction time can often be shortened by means of contracts containing bonus-and-penalty clauses, whereby the constructor receives substantial benefits for every day that full production is reached ahead of schedule; conversely, a deduction from the contract sum is made for every day the project is delayed.

As is well known, labour productivity is affected by the type of contract under which a project is built (8). "Lump-sum" and "bonus-penalty" contracts offer incentives to shorten the construction period, whereas the cost-plus or fee type of arrangements tends to lengthen the time of erection and also to increase total costs. A compromise is to use a "fixed-fee plus guaranteed maximum cost" type of contract, which may offer some protection to both contractor and customer, when unknown factors are anticipated. Yet another arrangement that can be made between experienced constructors and knowledgeable producers is a "negotiated contract", which eliminates the time otherwise spent in soliciting and examining competitive bids. In the long run, this type of arrangement would tend to save much wasted time and effort, to the benefit of all, if adopted on a wider scale, and might lead to some significant reductions in plant prices.

(d) *Contract specifications and terms*

Contracts between constructors and producers should be prepared with great care. First, on the part of the customer, the duties of the required plant should be clearly defined, as well as the raw materials and utilities to be made available. Unless the producer is extremely knowledgeable about the process and technology to be used, he should not attempt to specify precisely how the plant should be built; otherwise, the process licensor and/or contractor might not be prepared to guarantee either the plant performance or its construction time and cost.

On the part of the contractor, plant performances, product specifications, utility requirements and other associated factors should also be clearly stated, together with the appropriate guarantees. Contractual responsibilities, third-party liabilities, bonuses, penalties, time factors and means of legal redress are other items which must be defined and mutually accepted, in addition to the terms and methods of payment. Project contracts should be prepared by experienced legal and technical personnel, in the interests of ensuring adherence to guaranteed plant performances and anticipated time and cost schedules. Standard forms of typical construction contracts can usually be obtained from the major engineering societies and associations in Europe, the United States of America and elsewhere, if guidance should be required.

It is particularly necessary for overseas projects to avoid in the contract all ambiguities caused by differences in custom or language and to detail exactly what is required and what will be furnished. Furthermore, it must be ensured that each party fully understands the details of the contract before signature and that implications do not become subsequent causes of dissent.

(e) *Reducing pre-contract review time*

A major cause of delay between project conception and contract award in any situation can be the time spent by the prospective customer in studying the technology involved and in reviewing the proposals received from several potential contractors. In turn, this may interfere with both the financing programme and such schedules as raw material supplies and equipment procurement, leading to a series of corresponding delays. Therefore, every effort should be made by the customer to reduce to reasonable levels the time and work spent on project study and contract review, since these efforts tend to become excessive, especially in large organizations comprising numerous departments.

This may especially apply to projects in developing areas, under both government and private auspices, where experienced professional personnel are likely to be in short supply and government departments are under great pressure from numerous ordinances and many projects claiming high priority. In such cases, specialists from the United Nations, the various foundations and international consulting organizations could provide invaluable guidance in simultaneously expediting urgent projects and training local personnel.

Much can be done also by reducing local administrative protocol to an absolute minimum and avoiding, when possible, the repeated circulation of important projects through numerous ministries, departments and committees on a chronological basis. Such basic projects as agricultural programmes and fertilizer plants usually merit a high priority status, but, at the same time, they need the support of the ablest executives and ministers, backed by a small team of energetic specialists, to ensure that time shall not be needlessly wasted in the pre-contract period.

6. *Plant construction*

In the case of a "turn-key" contract, all responsibility for adherence to the guaranteed plant performance, in terms of time, quantities and product specifications, would rest with the contractor. However, it would be advisable for the customer to appoint one or more members of his staff to follow the progress of the project, in close conjunction with the contractor's personnel. In this way, the tendency for a busy contractor to fall behind schedule because of pressure of other work would be lessened, and simultaneously, the customer might be able to assist the contractor in expediting deliveries and overcoming obstacles.

Occasionally, plants are built by several contractors and subcontractors under the co-ordination of the customer's engineering department. In such cases, extremely close control must be kept on each construction schedule; otherwise, the total time and costs of the project may increase alarmingly, since over-all responsibility rests with the customer.

One of the best ways of achieving minimum time and cost construction schedules and maintaining close control of each activity, as well as over the total project, is to use the "critical path method" of programming. This technique has been described by several authorities (9, 10, 11, 12) and is now extensively used by contractors, consultants and engineering departments. In addition, there are available standard computer programmes through which complex schedules may be optimized with speed and confidence. In such cases it is essential that extremely close adherence to the entire project be maintained and drastic steps may have to be taken by the customer (or the responsible contractor) to restore a lagging portion of the schedule; otherwise, the entire project programme may be jeopardized.

Construction time can also be shortened by assisting the contractor with such items as temporary utility supplies, transportation, housing, local labour and guidance in local government regulations, as well as customs clearance and similar sources of potential delay. A comprehensive critical path analysis will reveal many instances in which valuable time can be saved by collaboration on administrative and off-site needs, in addition to the development of a major construction schedule.

(a) *Use of local resources*

Although complex process equipment is not likely to be manufactured in a developing country, it is quite probable that adequate facilities would exist for undertaking site work, supplying construction materials and erecting buildings to designs approved by the prime contractor and the customer. Although actual costs of materials and labour differ for various countries, it might be possible to achieve an appreciable cost reduction by employing local resources to the maximum when building fertilizer plants, in view of the large storage requirements usually installed.

Similarly, the use of locally available pipe, hardware and other equipment of a non-critical nature should be explored as another possible way of reducing the installed-plant costs. Prior experience on the part of the contractor could be most helpful in assessing the suitability of local resources.

(b) *Plant acceptance*

Following the construction of the plant and its associated units, successful operation, in accordance with the duties specified in the contract, must be demonstrated. In developing countries, it is important that this trial run should not be limited to a brief test under exaggerated control conditions, whereby the plant is temporarily overstaffed with highly experienced contractor's technicians. Instead, a reasonable period of continuous operation under typical circumstances and with the normal number of control and operating personnel should be selected, after the inevitable minor corrections and adjustments had been made, and the operators had become thoroughly familiar with their routine (and emergency) duties.

If the plant were to be prematurely accepted by the customer, it is possible that after the departure of the contractor's specialists, output would decline rapidly for a considerable period and, in addition, damage or even accidents might arise. Moreover, it might be difficult to obtain prompt rectification of design or equipment troubles, or to obtain substitute parts quickly, after the contractor had left the site.

Because of unsuspected difficulties, it might be a good insurance to retain one or two key contractors' personnel on a previously agreed basis for a few weeks after plant acceptance, to make sure that full output would be maintained and the good relations between contractor and customer were not impaired by minor problems.

7. *Administrative planning*

While the plant was under design and construction, the administrative and personnel structures of the organization would have to be established. If the company were a new one, then a board of directors would have to be formed, experienced officers and managers appointed, and supervisors and operators engaged and trained. Insufficient attention to these vital functions would impair the entire project for a long time.

If the company were newly formed, it might be necessary to complete many corporate tasks — for example, further capitalization and negotiations with tax authorities and other government departments to obtain import and income-tax concessions — and, to make arrangements with suppliers, contractors and future customers. Raw materials must be purchased and paid for, and shipments arranged. Often, a sales pattern is established by purchasing the finished materials from others and repacking them in proprietary bags until the plant is on stream. Such departments as the personnel office, machine shop, laboratory and stores must be set up and operated, all of which would entail much pre-planning and administration, often in temporary buildings and handicapped by a shortage of facilities and trained people.

Therefore, in establishing administrative operations, a sequence based on the growth and needs of the project should be followed, in accordance with a pattern developed by Gant charts or critical path techniques. At the same time, allowances must be made for limited facilities and inexperienced personnel, to ensure that plant operations could commence as scheduled.

8. *Personnel training*

Following incorporation of the company responsible for establishing the project and operating the plant, experienced executives must be engaged to direct the sales, production, purchasing and other major divisions. In a developing country, it might be necessary to recruit some members of the management team from abroad until local personnel could be fully trained.

Similarly, experienced supervisors and operators might not be available locally, in which case suitable local personnel could perhaps be trained in a similar plant, by arrangement with the contractor or non-competitors. Training with the aid of models and process simulators is another way of helping to achieve rapid proficiency and safety when bringing new plants on stream. Another important feature regarding the establishment and training of a labour force for a new plant is the necessity to reach full accord with government labour departments and/or local trade unions well before the scheduled plant start-up date, to avoid the possibility of labour disputes delaying commencement of operations and, most probably, setting unfortunate precedents for excessive wage and employment demands.

C. PLANT OPERATION AND FUTURE GROWTH

1. *Plant operation*

After the project of organizing, building and starting up the plant had been completed, several operational problems might develop, which if not anticipated and corrected, could lead to high production costs and reduced output, as well as to a disappointing return on the total investment. Major problems in this category include:

(*a*) Inadequate and/or costly maintenance;

(*b*) Labour difficulties;

(*c*) Low output levels;

(*d*) Under-utilization of capacity;

(*e*) High costs of product.

Brief references to the probable causes of these problems and suggested methods of avoiding or overcoming them are accordingly given. It should be noted that some of the difficulties might have their origins in defective project development, as previously stressed.

(a) *Inadequate and/or costly maintenance*

Costly maintenance is a handicap in itself, but inadequate maintenance is much worse, as it reduces output and so causes unit overhead and losses to soar. A major reason is the lack of a planned inspection and repair programme and, instead, a resort to *ad hoc* plant first-aid whenever any item breaks down. Sometimes, it is argued that because of the apparently random nature of maintenance work, it cannot be planned, but this is not true;

a planned inspection and maintenance programme permits the reduction of unscheduled jobs to only a few per cent (13) and yields substantial savings in both maintenance charges and production costs.

Procedures for establishing preventive maintenance have been detailed by various authors and reveal that two main problems are involved (13, 14, 15, 16). The first is the programming of all routine jobs — inspection, greasing and chronological replacement or adjustment. The second and more difficult task is the scheduling of non-routine work — repairs, new installations and modifications. The key to successful scheduling and avoidance of lost maintenance and production time is "work simplification and measurement" (17), which makes it possible to find the best means of undertaking a task and also to determine the optimum time (18). As a result, forward work planning can be undertaken with confidence, and accurate cost controls can also be instituted, together with incentive payment for maintenance workers, if desired.

Another way of undertaking maintenance work is by contract with an outside firm of specialists. This method is increasingly used in several parts of the world for petroleum and heavy chemical plants and can be especially useful when major repair and maintenance programmes are undertaken at predetermined intervals (19, 20). Contract maintenance may be suitable for some large nitrogen fertilizer plants in areas where periodic demands for additional skilled craftsmen cannot be met from local sources.

(b) *Labour difficulties*

Unless the training of supervisors and key operators was adequately undertaken prior to start-up, the plant might very well be handicapped as regards product quality, output tonnages and production costs. As previously mentioned, the use of models, process simulators and in-plant training and refresher courses would help to rectify shortcomings in operator skills. To encourage operator productivity and output, as well as plant cleanliness and safety, various incentive payment plans could be developed, which, if properly designed, could result in substantial benefits to both operators and management.

It would be equally important to foster good labour relations as regards working conditions and rates of payment, whether or not the plant labour were organized into a trade union, since a fair labour policy is often reflected in high output standards and local good-will, which in turn helps to minimize labour problems. Hence, an alert, experienced personnel manager is advocated for all but the smallest plants, to ensure that operator skills and well-being shall be maintained at the highest levels.

(c) *Low output levels*

From time to time, fertilizer and other plants fail to achieve anticipated production targets — a malady by no means confined to developing areas — even though the process units themselves have been shown to be capable of reaching the capacities for which they were designed. This is particularly serious in the case of fertilizer manufacture, because of the essential need for the product and also in view of the large financial losses incurred should the ouput of a high capital cost installation like a primary-fertilizer plant fall below the break-even point.

Low output may be owing to one or more reasons, major causes sometimes being inadequate maintenance and insufficiently trained operators, as previously reviewed. Ineffective supervision and poor process control are other contributors to low output. For example, failure to ensure that filter cloths and screens are regularly cleaned, that condensers and pipes are descaled or that instruments are checked for accuracy and plant logs are properly kept, will soon be reflected in lost production.

Administrative short-comings can also result in failure to achieve planned output levels. Temporary shortages of maintenance spares, catalysts and other materials, bags, transportation, storage space and labour may arise through oversight. Over a period, such interruptions can cause significant losses in production that may be difficult to make good.

External factors can also create production difficulties which may reduce output unless anticipated and thoroughly understood. Variations in ammonia plant feedstocks, phosphate rock composition when making phosphate fertilizers or caking troubles with primary materials when producing mixed goods are typical examples, as well as non-adherence to shipping schedules on the part of suppliers and customers. Such variations in external factors and their adverse influence on production point to the necessity for very close collaboration between suppliers and producers, as well as producers and customers.

The use of linear programming to supplement traditional methods of medium- and long-range planning has been advocated as a means of reducing production losses (21). For plants having a multiproduct mix, attempts to meet numerous small orders having widely different specifications will result in lost production owing to frequent clean-outs and change-overs. This situation may have to be corrected by rationalizing the product range and simplifying the production schedule. The provision of additional product storage facilities may also help to achieve a higher annual production level by permitting the accumulation of finished goods which can later be shipped during peak-demand periods at rates above average production capacities. However, this will necessitate additional fixed and working capital, which may offset the benefits from the increased sales, if considerables extra storage is needed.

(d) *Under-utilization of capacity*

Provided a plant has been designed and built in accordance with a realistic market study, excess capacity should not arise in relation to foreseen demand. However, circumstances may change and lead to an under-utilization of production facilities, resulting in diminished profits, or even losses. Therefore, during market investigations, should any doubts arise regarding changing future circumstances or an inability to achieve the anticipated sales targets, precautions should be taken to avoid installing an oversized and inflexible plant.

Consultations with potential contractors might reveal that production units capable of easy expansion at reasonable costs and in accordance with actual future needs could be installed in preference to an initially oversized unit. Although it is realized that the total capital cost of an expanded plant is likely to be higher than one initially built to the largest capacity ultimately anticipated, the incremental production cost of the additional output is relatively low and, therefore, caution in building a plant capable of easy expansion could be entirely justified. Furthermore, any losses induced by operating at reduced levels during the earlier years could entirely cancel the anticipated capital savings resulting from building a larger unit.

Another possible reason for under-utilization of capacity could be the inherent over-design of the plant on the part of a conservative contractor, perhaps coupled with first-class management and high operating skill. Occasionally, a fortuitous combination of these circumstances can lead to an additional capacity of 25 per cent or even 50 per cent over the design rating. The incremental cost of such extra production should be sufficiently low to permit the sale of the entire additional output without difficulty in either domestic or export markets, once the management and sales departments had realized the advantageous circumstances and had taken steps in advance to market the surplus material.

Other factors contributing to under-utilization of plant capacity include insufficient storage (particularly for product), uncertainties in shipping and transportation, and exceptionally large differences between seasonal and off-season requirements, which could lead to long periods of reduced output or even occasional shut-downs. Possible remedies might be the offering of attractive price discounts during off-season periods, the provision of extra storage and the generation of new markets. Perhaps the production of different materials or grades might also assist to increase plant utilization between the customary periods of peak demand.

(e) *High costs of product*

High product costs reduce profits and may also reduce sales, which, in the case of fertilizers in developing areas, would lead to diminished food supplies. These serious consequences would make it imperative that every source of excess should be discovered and that losses should be reduced to a minimum, which, at the same time, would help in obtaining the maximum benefits from the foreign exchange and other capital invested in the plant.

High product costs can result from increased delivered prices of raw materials, from material waste, from excess production costs and from high sales and distribution charges. A review of all material requirements and alternative sources of supply and delivery might indicate that lower cost materials and better shipping and payment terms could be obtained from other sources. An analysis of inplant material losses and conversion efficiency ratios might show that wastage and production losses were excessive and indicate likely sources of savings. The establishment of standard cost control for production and maintenance, and the daily analysis of excess costs would most probably reveal several sources of potential savings and indicate where prompt remedial action was essential. Similarly, an investigation of sales and distribution costs, and the institution of cost-control procedures would permit the measurement and curtailment of rising expenses in this category also, if they were found to be unwarranted.

2. *Future growth*

Attention to future growth must be given to an undertaking, even when only in the early project planning stages. In some cases, the future pattern might be clear, and land, capital equipment and other facilities could be acquired or budgeted with confidence. In other instances, a growth pattern might not be immediately definable. However, in every successful enterprise, an expansion pattern of duplication or diversification inevitably emerges, for which land and capital will be needed. Therefore, since the cost of purchased or leased land is, in most cases, small in relation to other costs per unit of product, purchasing, leasing or taking options on an area at least equal to the space initially acquired is usually a wise safeguard for future needs.

The provision of capital out of earnings for part or all of future growth is a common procedure in many successful companies, as is the provision of funds for a small research and development group, perhaps to the extent of 2 or 3 per cent of sales revenue. In the fertilizer industry (particularly with regard to the developing areas), research need not imply the expenditure of huge sums on fundamental work, but, preferably, the study of new products and improvements made in other parts of the world, with reference to possible adoption or modification for local use by licensing or other arrangement. Failure to recognize the rapid advances in fertilizer technology could lead to early obsolescence and uncompetitive prices.

Future growth also requires that suitable young men and women be brought into the company and trained (perhaps locally and overseas) so that they can eventually help the organization to expand and prosper. In developing countries, this means that assistance with educational programmes, scholarships and perhaps part-time employment would be likely to be a good investment on the part of fertilizer companies and other industrial organizations.

D. SUMMARY AND CONCLUSION

It is evident that the full success of fertilizer projects in developing countries depends on realistic market surveys in terms of more immediate needs, on the use of the lowest cost available raw materials and on the availability of foreign exchange on reasonable terms. To convince potential investors, government departments and other participants that the project is sound, an accurate and well-prepared feasibility study would nearly always be essential; at the same time, it could ensure against future failure, should the concept be revealed as unattractive.

Internal factors contributing to efficient operation include the choice of a reliable process, planned maintenance, experienced management and properly trained labour, and an effective production and cost-control system to provide prompt feedback of excess cost data to management. Proper consideration must also be given to the establishment and continuance of sound labour

TABLE 104. RECOMMENDATIONS FOR AVOIDING OR OVERCOMING TYPICAL PROBLEMS OF FERTILIZER PROJECTS IN DEVELOPING COUNTRIES

Stage of project and problems	*Recommendations*
Conception	
Uncertainty of sales	Detailed market study
Over-optimism regarding results Under-emphasis of difficulties	Technical and financial feasibility study
Organization	
Lack of specialist skills	Assistance of United Nations and consultants
Insufficient objectivity	Use of consultants
Inadequate pre-project funds	Partnership with investors in the United States of America or other countries and assistance of Agency for International Development or similar agencies of other countries in financing study
Promotion	
Lack of private interest	Submit convincing feasibility study
Lack of public interest	Submit convincing feasibility study
Failure to obtain government support	Stress benefits to country and welfare of people, plus a convincing feasibility study
Financing	
Shortage of local funds	Show a good return on investment in a well-prepared feasibility study
Shortage of other capital	As noted above
Unavailability of foreign exchange	Apply to AID or similar agencies in other countries and/or international lending agencies, guaranteeing a good return on investment in a convincing feasibility study
Contract awarding	
Apprehension	Enlist assistance of United Nations and/or experienced consultant
Procrastination	Reduce interdepartmental handling. Appoint able task force headed by dynamic leader
Costly ambiguities	Enlist expert legal and technical help. Confirm that all mutually accepted points are really understood. Avoid implied responsibilities
Plant construction	
Excessive time and cost	Minimize by use of the penalty type of contract
Inadequate or lavish plant	Avoid by expert advice and competitive bidding
Prolonged start-up troubles	Avoid by adoption of well-proved process and use of experienced contractor
Administrative planning	
Shortage of experienced personnel	Employ experienced key staff from elsewhere. Send trainees to similar plant for experience
Inadequate subcontractor co-ordination	Purchase plant on a "turn-key" basis
Incomplete production and administrative procedures at start-up time	Use consultants and United Nations assistance. Employ experienced key staff from elsewhere
Personnel training	
Lack of training facilities	Train key people in similar plant elsewhere. Bring in models and simulators
Shortage of skilled local people	Set up training school
Poor labour relations	At outset of project, establish sound labour policies with local unions and seek advice of local industry

TABLE 104 (*continued*)

Stage of project and problems	*Recommendations*
Plant operation	
Low outputs	Improve plant maintenance. Raise conversion efficiencies. Improve production planning and control
Under-utilization of capacity	Do not overestimate sales during market study. Create new markets
High product costs	Obtain materials at lower delivered prices. Reduce material losses. Introduce effective standard cost control with prompt feedback. Employ experienced consultants or specialists to make impartial, thorough investigation of all activities
Future growth	
Insufficient space	Purchase or obtain options on at least 100 per cent extra adjacent land at project commencement
Lack of capital	Invest several per cent of earnings *via* applied research and development at earliest opportunity
Early obsolescence and lack of growth policy	Keep in close touch with world fertilizer industry with help of the United Nations, consultants, trade associations, trade magazines and international conferences

relations, as well as to future growth. Such inevitable changes in external factors as new raw material supplies, additional markets and improvements in technology must also be anticipated and used to advantage, whenever possible.

Provided, therefore, that these basic requirements were met, there would be every reason for fertilizer projects in developing areas to be as successful as their counterparts elsewhere, in supplying a basic need and simultaneously providing a sound financial return to local and other investors.

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XX. A CASE STUDY OF A NITROGENOUS FERTILIZER PROJECT IN A DEVELOPING COUNTRY

A. PROJECT OUTLINE

In 1957, the country referred to in this case study had three major fertilizer factories under production and several others in the planning stage. The planning body of the Federal Government had established national and regional requirements of fertilizers in terms of N, P_2O_5 and K_2O. The methods that could be adopted for determining the fertilizer requirements of a country are discussed in detail elsewhere. In this country the method followed was to determine the agricultural production targets at the end of every five years and then to determine the quantities of fertilizer required, along with other inputs needed to meet the agricultural production target. These estimates also gave consideration to the soil conditions, crops to be grown, area cultivated, rainfall, irrigation and optimum amounts of fertilizers to be applied, taking into account availability and economics of returns.

In the southern region of the country, in 1957, after five years of prospecting, a brown coal deposit of about 2,000 million tons, which could be economically worked, was discovered. The brown-coal seam was 50 feet thick and covered with an overburden of 300 feet. Mechanical removal of overburden and mining of coal was adopted. The brown coal had a low sulphur content, a medium ash content (7 per cent) and 50 per cent moisture, with a BTU content of 9,000 when dried. It was estimated that mined coal could be delivered to the thermal electric plant, fertilizer plant and the briquetting and carbonizing plant at $3 per ton.

Extensive studies were carried out to determine the extent of the coal deposit, to obtain representative samples of coal and to determine its characteristics. A trial pit was dug and 200 tons of coal were mined; 100 tons were sent abroad to coal-testing laboratories for analysis and pilot-plant work in burning, gasification and for briquetting and carbonizing trials. In the field, 200 trial holes were drilled and samples of coal taken at 5 foot intervals. These samples were composited to get representative samples at a vertical, as well as a horizontal, plane. The analyses were made to see whether there were any deviations from the analysis adopted as representative.

B. PROJECT REPORT

A foreign consulting firm, with wide experience in the mining of coal and the utilization of coal in various industries, was appointed to draw up a project report. This report was to cover the feasibility and costs of coal production, the methods of mining to be adopted and ways of controlling the aquifer water below the coal seams; and to indicate the capacities and investments needed to put up facilities for power production, fertilizer production and smokeless fuel production. As this was a project under the central Government, this report was studied and authorization was given to put up facilities to mine 3.5 million tons of coal *per annum* as a beginning, with plans for later expansion to 7.0 million tons. It was also decided to put up a 250,000-kilowatt thermal power-station, a fertilizer project to produce 70,000 tons of nitrogen and a plant to produce 300,000 tons of smokeless fuel *per annum*. The estimated cost of the whole project was $140 million initially, a figure which subsequently rose to $240 million.

A senior civil servant of the central Government was appointed officer in charge of the project. A planning call for the fertilizer project was established with an experienced chemical engineer as chief of the call. The duties were the following:

(*a*) To study the availability, quality and price of brown coal to be used for fertilizer production;

(*b*) To determine the end-products to be made;

(*c*) To make a detailed project report;

(*d*) To integrate the fertilizer plant with the other industrial units of the project with regard to location, supply of coal, supply of water and power.

The first matter to be decided was what fertilizer should be made. Originally, the idea was to make ammonium sulphate containing 21 per cent nitrogen, using gypsum ($CaSO_4 . 2H_2O$), which was to be found in small quantities at a distance of about 200 miles. The matter was studied, and it was felt that although ammonium sulphate had been a very popular fertilizer in the region, the low amount of plant nutrient in the fertilizer, namely, 21 per cent, would make it uneconomic for transport over long distances. The higher the percentage of plant food in a fertilizer, the lower the cost of transport and, hence, the price to be paid by the farmer. Furthermore, the deposits of gypsum were of an inferior quality and type. The experience of another fertilizer project using the gypsum process showed that the cost of winning gypsum by handpicking, washing and transport was high.

Therefore, the question of converting all the 70,000 tons of nitrogen (94,000 tons of ammonia *per annum*) into urea containing 46 per cent nitrogen was investigated. The region around the project had obtained good results by the use of urea fertilizer on such crops as sugar-cane and rice. Preliminary calculations also showed that the cost of production of urea could be reasonable and would be less compared with ammonium sulphate, on a nitrogen percentage basis. Hence, a decision was made to make urea as the end-product and to study the processes and costs of production of urea and related matters in the project report.

The project report studied in detail the following aspects:

(*a*) Integration of fertilizer production with other industrial units;

(*b*) Drying of lignite (brown coal);

(*c*) Gasification systems for production of ammonia synthesis gas;

(*d*) Purification systems for gas, carbon-monoxide conversion and final purification;

(*e*) Synthesis of ammonia;

(*f*) Synthesis of urea;

(*g*) Utilities: power, steam and water;

(*h*) Estimated capital costs and production costs;

(*i*) Schedule of execution of project;

(*j*) Personnel requirements and organization,

(*k*) Recommendations;

(*l*) Conclusions.

In addition, detailed information on the following was collected and included in the report:

(*a*) Comparisons of methods for drying lignite (brown coal);

(*b*) Gasification of lignite by different processes;

(*c*) Different processes for ammonia synthesis;

(*d*) Different processes for urea manufacture;

(*e*) Cost of plants and costs of production;

(*f*) Cost of raw materials and utilities;

(*g*) Investment costs for various process-combinations for gas, ammonia and urea;

(*h*) Total costs of off-site facilities;

(*i*) Cost of production (94,000 tons of ammonia *per annum*);

(*j*) Cost of production (152,000 tons of urea *per annum*);

(*k*) Personnel requirements — organization chart;

(*l*) Characteristics of lignite;

(*m*) Analysis and treatment of artesian water;

(*n*) Meteorological data for the site.

1. *Scope of the report*

A summary of the recommendations made in the project report is given below to show the scope of studies made.

(a) *Drying of lignite*

The report stated that the recommended method of drying the lignite for gasification would be that suggested by the successful gas-plant tenderer. If this method happened to be similar to the drying procedure subsequently recommended for the briquetting plant, more units of the same type could be provided and the lignite drying could be centralized. If it were different, then it would be obvious that the drying had to be separate for the fertilizer and briquetting plants.[1]

(b) *Gasification*

It was noted that although three processes, *viz.*, Winkler, Koppers-Totzek and Lurgi were commercially well established, the largest number of existing plants in the world for lignite gasification had adopted the Winkler process, which was the cheapest in capital cost and the oldest in technique. However, the other newer processes, e.g., Koppers-Totzek, Lurgi, Otto-Wesseling and Ruhrgas Demag, should also be considered for purposes of competitive tender. The Lurgi gasification process, though it involved more steps in processing the gas, had been shown to yield the cheapest ammonia, but some of the consumption figures, for example, of oxygen and power, and the capital costs of certain items of equipment for such processes CO-conversion and CO_2 removal, as estimated by them, appeared to be on the low side. Furthermore, the behaviour of unbriquetted dried lignite under pressure-gasification was not known and this uncertain factor was very important. It was noted that Lúrgi gasification involved output of such by-products as tar, oil and phenol, which required further processing.

The report stated that Process I gasification of lignite was a very efficient process although the capital cost was high. The greatest advantage in its favour was its versatility in using lignite tar, fuel oil, coal etc. as feed-material with slight modification in the burner nozzles. A high degree of instrumentation and a number of safety devices were required for this process.

Processes II and III were more recent developments and only large-sized pilot plants were operating. In these two processes, the ash was discharged in the molten state, resulting in high operating temperatures. It is a moot point whether these processes could be considered for adoption before commercial size plants were known to operate economically and efficiently elsewhere. But, as previously indicated in the report, for the purpose of competitive tender and in view of the fact that before the fertilizer factory began operation, data from commercial size plants under construction in Europe might become available, it was suggested that quotation might be obtained from these two firms also.

The report recommended that tenders should be invited for five gasifiers (one as spare) to supply the total quantity of 685,000 normal cubic metres of ($CO + H_2$) per day. However, if there were an appreciable saving in capital cost, the alternative of three gasifiers (one as spare), as had been suggested by some of the firms in their preliminary offers, might also be considered.

(c) *Air-fractionation plant*

It was noted that since air-fractionation plants were specialities of certain well-known firms — Air Liquide, Messer Linde, British Oxygen and Air-products, among others — it was felt desirable to obtain competitive quotations directly from these firms to suit requirements. The air-fractionation plants would supply the oxygen requirements of the gas plant and the nitrogen requirements of the ammonia plant, as well as being used for such general purposes as purging protective gas-supply.

The number of units recommended and for which quotation might be invited were: three units with one

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[1] If flue-gas drying were adopted for the lignite to be gasified, two units each were recommended to produce 20 tons per hour of dried lignite of 8 per cent moisture.

as spare, or two units each with 60 per cent of total capacity.

(d) *Ammonia plant*

The report stated that quotations should be obtained for the production of 285 tons of ammonia per day, all in liquid form, starting from raw synthesis gas in the gasholder. The process would include sulphur removal, CO-conversion under pressure, CO_2 removal, low temperature gas-fractionation followed by liquid nitrogen wash, ammonia synthesis and storage of liquid ammonia. The firms who could be asked to tender were, among others, Montecatini, Chemical Construction Corporation (CCC), Kellogg, Casale, Uhde, Foster-Wheeler, Hydrocarbon Inc. and St. Gobain.

The recommended number of streams for the purification step were two each, with 60 per cent of total capacity, and for ammonia synthesis, five compressors (one as spare) and four converters, each of 80-ton capacity.

(e) *Urea plant*

According to the report, the choice was to be one of four processes — Montecatini, CCC, Inventa and Pechiney — on the basis of capital and production costs, as well as quality of product and ease of operation and maintenance. It was recommended that competitive quotations should be obtained from the following firms: Montecatini or their licensee, Kellogg (United States of America); CCC; Inventa or their licensees, Vulcan Corporation (United States) and Uhde (Federal Republic of Germany); and Pechiney or their licensees, Foster-Wheeler (United States) and Toyo Koatsu (Japan). The quotations should be on the basis of a daily production of 465 tons of prilled urea of 46 per cent nitrogen content (from liquid ammonia and CO_2 gas of about 98 per cent purity), storage capacity for two months' output and the bagging of 500 tons in eight-hour shifts.

The report recommended that consideration should be given to four reactors, each of 125-ton capacity, for urea synthesis; and two streams, each with 60 per cent total capacity, for concentration, prilling and selective separation.

(f) *Back pressure turbines*

It was noted that after the tenders for gas, ammonia and urea plants were finalized, the exact requirements of steam for the fertilizer plants would be known. Tenders would then be issued for the boilers and the back pressure turbines. Whether the turbines would be located in the fertilizer plant area or in the power plant area had to be decided beforehand.

(g) *Water-treatment plant*

The water-treatment plant would handle all the water requirements of the fertilizer, and briquetting and carbonizing plants except the feed-water for waste-heat boilers in the fertilizer plant and that for the boilers of the back pressure turbines. These would be supplied by the thermal power-plant. The water-treatment plant would degasify, soften and filter the water for cooling-tower make-up and other process purposes. The report stated that the entire scheme of water purification and distribution might be done by the corporation or be allowed to be executed by a reputable water-treatment plant supplier on a competitive basis.

(h) *Off-site facilities*

The report stated that the general engineering of such off-site facilities as water, steam and power distribution might be left to one of the contractors supplying the fertilizer plants or to any other contracting firm in the country as a separate contract. As much as possible could also be done departmentally by the corporation.

The workshops, central laboratory and stores could be planned and executed by the corporation after ascertaining from the foreign contracting firms the service requirements and standards necessary for the efficient running of the different units.

(i) *Personnel training*

It was proposed to train about 200 graduate engineers for supervisory posts of chargemen and above, and about 250 diploma holders for posts at the operator grade. The training was to be for about two years and in two to three batches. Direct recruitment of experienced personnel from existing chemical and fertilizer factories was to be made in 1959. Technical personnel selected for some of the top positions would be sent abroad for training in plants similar to those to be erected.

(j) *Estimated capital and production costs*

The estimated capital cost and production cost data given in the report are discussed below:

Estimated capital cost of fertilizer plant and production cost of urea

In view of the number of commercially well-established and technically sound processes available for the gasification, ammonia and urea plants, it was not an easy task at that stage to recommend any particular combination of processes either from the technical or the purely cost point of view, this was even more the case because the country's experience of lignite gasification and urea manufacture by the total-recycle process had been practically nil, and the variation of estimated capital costs for the different gasification and urea processes was considerable. However, an attempt had been made to examine the capital cost of a few combinations of gas, ammonia and urea processes and to estimate the production cost of urea. The processes considered were: for gasification, Winkler, Koppers and Lurgi; for ammonia, Casale and Montecatini; and for urea, Inventa, Montecatini, Pechiney and Chemico. While the processes considered for gasification and urea were those likely to be adopted, it was noted that others (besides Casale and Montecatini) should also be considered for ammonia, for example, CCC, Kellogg and Uhde.

As had been mentioned earlier in the report, various alternatives existed in the gas purification methods, and in the schemes considered only the methods recommended by the firms who supplied the preliminary estimates had been adopted in the cost calculation.

The estimated capital costs, the details of off-site facilities and the production costs for ammonia and urea for the different combinations, as given in the report, are summarized below:

TABLE 105. SUMMARY OF COST DATA

Gas *Ammonia* *Urea*	*I*	*II*	*III*	*IV*	*V*	*VI*[a]
F.o.b. cost of plants (millions of rupees)	61.3	91.9	58.7	69.4	79.1	79.1
Erected cost (millions of rupees)	134.2	182.8	129.8	147.7	159.3	157.9
Ammonia cost (rupees per ton)	325	400	309	356	309	266
Urea cost (rupees per ton)	297	357	287	316	321	276.5

Note. $US 1 = Rs.4.8.

[a] Estimate of Powell Dufferien Technical Services.

The cost of ammonia had been originally estimated by the State Fertilizer Production Committee in June 1955 at Rs. 308/-, but with the latest figures for cost of lignite, power etc., it reached Rs. 330/- per ton. In the last two columns of table 105, the costs for the combination V and VI are shown, one based on the estimated costs for erection, buildings, freight etc., and the other as estimated by the consultants in their report. The differences in the production costs of ammonia and urea are accounted for by the higher capital investment, the labour and overhead costs, the interest rates and maintenance costs which have been assumed and the omission of any credit for the by-products, gas and liquor in the estimates. Furthermore, the consultant had calculated on the basis of a production of 162,000 tons of urea *per annum*, equivalent to 74,000 tons of nitrogen.

Cost of plant (f.o.b.) and erected cost

After a careful examination of the various estimated costs for freight, insurance, import duty, erection, foundation and buildings, the following figures were assumed for purposes of calculation, as percentages of the f.o.b. cost: freight, insurance and handling, 16 per cent; import duty, 6 per cent; erection and assembly, 16 per cent; and buildings and foundations, 14 per cent. Thus, the erected cost of plant came to 152 per cent of the f.o.b. cost.

Off-site facilities

An estimate of Rs. 22.8 million was made for the various off-site facilities for the fertilizer group plants. These included such items as power, steam distribution, water-treatment plant, workshop and laboratory.

Royalty

The royalty for a special process, e.g. urea, was indicated separately wherever such figures were available.

Engineering supervision charges

The costs for foreign technical personnel, at various stages of the project until full production was achieved, were taken at 10 per cent of erected plant cost.

Training costs

The cost of training operators and maintenance staff at home and abroad was estimated at about Rs. 2 million, and this was included in the total erected cost of the plant.

Colony for staff

It had been estimated that about 1,500 personnel of all categories would be required for the fertilizer group of plants. The cost of the colony had been estimated at Rs. 11.3 million, as that met the standards laid down by the central Government.

Back pressure turbine

The steam and part of the power requirements of the fertilizer factory were met from a back pressure turbine of about 10,000 kilowatt capacity, connected to two boilers. The erected cost of these was estimated at Rs. 20 million, pending confirmation by the planning department of the Central Water and Power Commission.

Working capital

This included: (*a*) spare parts at 4 per cent of erected cost of plant; (*b*) wages for six months; and (*c*) two months' stock of urea and bags.

Total investment

It may be seen that the total investment would vary between Rs. 166 million and Rs. 221 million.

Cost of raw materials and utilities

The latest available figures are those estimated by the consultants in their report, and the figures utilized for the cost estimate are shown in the tabulation given below:

TABLE 106. COST OF RAW MATERIALS AND UTILITIES

(Rupees)

Material	*Unit*	*Cost*
Raw lignite	Ton	9.59
Steam, low pressure	Ton	3.06
Steam, high pressure	Ton	3.37
Power	Thousands of kWh	38.01
Raw water	Cubic metres	0.055
Feed-water	Cubic metres	0.455

(k) *Foreign exchange*

Normally, about 20 per cent of the plant equipment involving tanks, vessels and gasholders might be fabricated domestically, provided sufficient capacity were available in workshops and the steel required were released by the Government. Similarly, 50 per cent of the cost of off-site facilities and 75 per cent of the freight,

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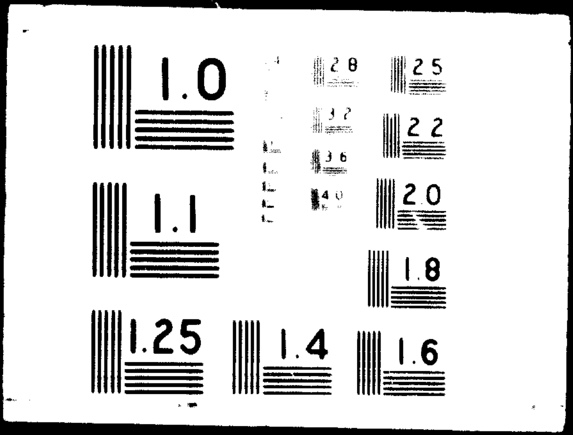

insurance, buildings, foundation and erection costs would be incurred in local currency. This would mean that, of a total investment of about Rs 210 million, foreign exchange requirements would be of the order of Rs 130 million.

C. TENTATIVE PROGRESS SCHEDULE

A rough indication of the schedule of work in planning, erecting and putting into commission the fertilizer group of plants is shown below. A more accurate picture of the schedule could be presented only after tenders had been received and orders placed.

1957

July	Submission of project report and broad specifications
August	Finalization of specification for tenders
September	Approval of Board and the Government
October	Issuance of tenders
November	Preliminary planning of off-site facilities, water treatment, laboratory, workshop etc.
December	Erection of Technical Cooperation Mission (United States of America) pilot plant for briquetting-carbonizing

1958

January	—
February	—
March	Receipt of tenders for fertilizer plants
April	Discussion and finalization of tenders
May	Placement of orders for fertilizer plants. Collection of data from Technical Co-operation Mission pilot plant
June	Issuance of tenders for back pressure turbines and electrical substations
July	Commencement of work on preparation of site
August	Receipt of tenders for back pressure turbines
September	Placement of orders for back pressure turbines and substations. Tenders for carbonizing and briquetting plant ready
October	Issuance of tenders for water-treatment plant and other off-site facilities
November	—
December	Receipt of tenders for above-mentioned items

1959

January	Placement of orders for water-treatment and off-site facilities
February	Commencement of work on foundations for the machines
March	Planning of laboratory and workshop
April	Planning of laboratory and workshop
May June July August	Beginning of deliveries of equipment for fertilizer factory
September	Beginning of deliveries of equipment for back pressure turbines
October	Commencement of erection of water-treatment plant and other off-site facilities
November	
December	

1960

January	
February	Erection of all fertilizer plant units, back pressure turbines, off-site facilities etc. in progress
March	
April	
May	
June	
July	
August	Completion of work on off-site facilities, water-treatment plant laboratory and workshop
September	Completion of erection of back pressure turbines
October	—
November	Completion of erection of fertilizer factory units completed
December	Commencement of trial production

D. DECISIONS OF BOARD OF DIRECTORS

The Board of Directors of the Corporation reviewed the project report, and decisions were taken along the lines discussed below.

It was decided that detailed tender specifications should be prepared for the following groups of plants within battery limits:

Groups

A.	Gasification
B.	Gas purification
C.	Air and gas fractionation
D.	Ammonia plant
E.	Urea plant
F.	Process-steam installation
G.	Electrical equipment
H.	Off-site and auxiliary facilities

Global tenders were then to be invited for f.o.b. supply of the plants. The tenders were to indicate deferred terms of payment, amount of equipment which could be manufactured in the country and an estimate of erection and start-up costs.

The project personnel were to design and install the power, water, steam and transport facilities, and also to tie up and provide connexions between plants. It was considered that the total cost of the fertilizer plant would be considerably less if done this way rather than given on a "turn-key" contract to a foreign bidder. The location and layout were to be worked out, and the workshop, stores, laboratories, safety and first-aid stations were to be designed by the project personnel themselves.

The project, as seen from the capital cost figures and production cost, was a viable one, and, therefore, it was decided that the Government should be requested to include it in its second and/or third Plans. The Government was also to be requested to provide the foreign exchange needed to execute the project.

E. TENDER SPECIFICATIONS PREPARED

Detailed tender specifications were prepared for the eight plant units. Each tender specification included, *inter alia*, the following:

(*a*) Capacity of the unit;

(*b*) Analyses of entering raw material;

(*c*) Analyses of the product;

(*d*) Main process steps;

(*e*) Number of "streams" desired.

Each tender was to give:

(*a*) The f.o.b. price of the unit under quotation;

(*b*) Delivery time;

(*c*) Variations from specifications;

(*d*) Guarantees and penalties in case the capacity or specification of the products were not met;

(*e*) Conditions for down payment, as well as terms for deferred payment;

(*f*) Complete description of process;

(*g*) Details of other plants which had been operating on similar processes;

(*h*) Details of requirements of raw materials, steam, power and water per unit of product.

F. TENDERS CONSIDERED

Global tenders were invited on 8 May 1958, and tenders were obtained by 4 November 1958. Detailed analyses of tenders were carried out by project personnel. Recommendations made regarding acceptance of tenders are given below:

1. *Tentative recommendations*

The tenders received for the fertilizer plant were carefully analysed. From the data available, summarized tables were compiled with regard to: (*a*) capital cost; (*b*) cost of production and installed cost per ton of urea; and (*c*) deliveries, deferred payment terms and financing charges (See tables 107, 108, 109.) The capital costs are tabulated on the basis of cash payment, to which the financing charges have to be added to show the capital costs, if the plant is bought on deferred payment terms.

In the following paragraphs the tenders received for each group of the plant, as well as the over all tenders for the whole plant, are considered from the point of view of:

(*a*) Technical aspect;

(*b*) Total foreign exchange cost of f.o.b. equipment;

(*c*) Cost of production and installed cost per ton;

(*d*) Deliveries, deferred payment terms and financing charges.

Tentative recommendations were then given, as noted below.

(a) *Group A: gas plant*

Oxygen gasification of lignite

The most elaborate and complete tenders and details were received for the oxygen gasification of lignite, i.e., for slagging-bed, fluidized-bed, entrained-bed and fixed-bed gasification. These four processes can be classified in another way into two types:

(*a*) Those which require sized lumps for gasification;

(*b*) Those which require extremely fine particles for gasification.

Under the first group must be mentioned the pressure gasification process, which requires 3-20 millimetre size and 30 per cent moisture, and the process which requires 0-10 millimetre size with 8 per cent moisture. Under the second group may be included the process requiring a particle size of 0-2 millimetre with 10 per cent moisture and the entrained bed requiring the finest particles, 10 per cent residue on sieve DIN. 70 (0.08 = 180 mesh), with 8 per cent moisture.

It was noted that in considering the gasification systems for lignite, the most important aspect to be considered was the property of the lignite, which has a tendency to

TABLE 107. COMPLETE PLANT: COMPARISON OF CAPITAL COST

(Millions of rupees)

	I	*II*	*III*	*IV*	*V*	*VI*
(*a*) Total f.o.b. foreign exchange	122.1	142.2	130.1	154.7	137.6 [a]	139.3 [b]
(*b*) Total foreign exchange	139.5	161.6	152.1	Details not given	Details not given	157.6
(*c*) Total excluding civil works	162.8	181.9	169.9	Details not given	Details not given	164.8
(*d*) Total including civil works [c]	185	211.5	192.5	Details not given	Details not given	183.5 [d]
(*e*) Freight	10.1	11.4	11	10.5	—	10.6
(*f*) Spares	10.928 [e]	12.613 [c]	12.106	7.143 [e]	—	Details not complete
(*g*) Total including freight and spares	206	235.6	215.6	—	—	—

Note: All prices given above are based on the cash mode of payment. Figures have been rounded to the nearest $100,000.

[a] Cost of parts that can be fabricated in the country itself has not been separated.

[b] Excluding groups G and H.

[c] Civil-works cost is only estimated.

[d] Including civil works of group A and Rs. 10 million for group E.

[e] Cost of spare parts has not been included in either f.o.b. cost or in total foreign exchange.

TABLE 108. PRODUCTION, COST OF PRODUCTION AND INSTALLED COST PER TON

	I	*II*	*III*	*IV*
1. Guaranteed minimum production (tons per day)				
Ammonia	285	285	285	285
Urea	465	465	465	465
2. Cost of production (rupees per ton of urea)				
Bulk	420.4 [a] (429.47) [c]	463	383 [b]	--
Bagged	447.4 [a] (456.4) [c]	490	410	--
3. Total installed cost per daily ton of urea (rupees)	443,094	506,600	482,970	

[a] Based on 565 tons of lignite per day.

[b] In the cost calculations, the f.o.b. costs of 33 kilovolt line transformers and pipelines to connect groups A + B + C outside the battery limits have not been included.

[c] Based on 732 tons of lignite per day.

TABLE 109. DELIVERY, DEFERRED TERMS AND FINANCING CHARGES

Delivery	*I*	*II*	*III*	*IV*	*V*	*VI*
1. Delivery (number of months after contract is signed):						
(*a*) Completion of erection	34	34	28	34	34	33
(*b*) Number of months for 50% production	—	—	—	34	—	—
(*c*) Number of montns for full production	38	38	29	36	38	36
2. Deferred terms:						
(*a*) Beginning date	Date of contract for all					
(*b*) Last payment (months from the date of contract)	66	66	Deferred payment details not given	84	66	—
3. Financing charges:						
(*a*) Credit insurance	No separate charge given; included in rate of interest					
(*b*) Rate of interest (percentage)	6	6	Not given	6.5	6.5	Not given
(*c*) Total financing charges (percentage) .	11.85	11.85	Not given	22.3	—	9.5 8.1

crumble into a very fine powder. The corporation had been running a very large-scale pilot plant for the crushing, drying, briquetting and carbonization of lignite. The crushing and drying section had capacities of 5 tons per hour and 2 tons per hour respectively. About 200 tons of lignite had been handled and it has been observed that it pulverized to very fine dust in both grinding and drying. For this pilot plant the greatest difficulty had been to obtain particles of larger size. From the crusher, which had a hammer mill, it had been very difficult to get particles of a size between 10 to 25 millimetres for drying in the fluidized system, whereby hot flue-gas flowed upwards concurrently with the lignite dust, thereby entraining it and drying the lignite from 56 per cent moisture to anything between 8 to 15 per cent. The flue-gas inlet temperature was about 300°-500° C, and the outlet was 100° C. The contact time was high. Even with this kind of drier, only with great difficulty was it possible to obtain 90 per cent of the dried product in 1-2 millimetre size. It may be stated that in most runs the dry product was below 1 millimetre, 50 per cent was of the 0.5 millimetre size and 35 per cent was 0.07 millimetre or lower.

From these figures, the purchaser was convinced that any process of drying lignite and then sizing it to 1-2 millimetre size would be an extremely difficult job. The only logical conclusion was that, for lignite, the gasification process should be that which gasifies the finest particles possible. Therefore, gasification processes using dried and sized lignite would be a difficult proposition. From this point of view, the gasification process which requires 90 per cent below 0.08 millimetre and 10 per cent above this size was the most suitable for gasifying lignite. Furthermore considering the friable nature of the lignite, the elaborate equipment provided by this process might not become necessary to reduce the particle size. If this were true, then the prices given by Process II could also be substantially reduced. Next came Process IV, which required 0.2 millimetre size. Here again, a large percentage of the undersized would have to be sent to the boiler plant. In the case of Processes I and III, although they had adopted the turbine type of Buttner drier, which does not allow the lignite to crumble to a large extent, a very high percentage of lignite from the drier would have to be sent as fines to the boiler plant.

Considering the data given above, one may compare the processes technically from other angles. From the point of view of fuel consumption per 1,000 normal cubic meters of CO + H_2 on the basis of bone-dry lignite, the consumption was lowest in the case of Process IV which was 609 kilogrammes followed by Process III with 654 kilogrammes. Process II with 732 kilogrammes, and Process I with the highest, 760 kilogrammes. From the point of view of oxygen consumption per 1,000 normal cubic metres of CO + H_2, Process III was the lowest with 214 normal cubic metres; next came Process I with 305, followed by Process IV with 320 and Process II, the highest, with 378. The normal cubic metres of CO + H_2 obtained per ton of bone-dry lignite was the highest in the case of Process IV with 1,671, followed by Process III with 1,526, Process II with 1,366 and Process I with 1,315. As regards the electric-power consumption, including power for lignite preparation and raw-gas compression, Process III was the lowest with 125 kilowatt hours per 1,000 normal cubic metres of CO + H_2, Process I was next with 230, followed by Process IV with 233; the highest was Process II with 316. In steam production, Process II produced the maximum, followed by Processes IV, III and I. In carbon efficiency, Process IV was the highest and Process I the lowest. In thermal efficiency, Process IV was the highest, followed by Process II, with I the lowest.

Foreign exchange

The total foreign exchange part of f.o.b. cost of equipment was the lowest in the case of Process I at Rs. 11.3 million, and the highest in the case of Process II, at Rs 29 million. It should be pointed out here that Process I provided only two gasifier units for a total capacity of 130 per cent, whereas Process II provided five units with 120 per cent total capacity. Process II had also provided for a lignite handling and bunker of 7,500-tons capacity, to take care of both the requirements of gasification and the boiler section. It should also be noted that the weight of the equipment supplied by Process II was 5,125 tons, against 2,795 tons supplied by Process I.

Gasification capacity

In the capacity provided for gasification, it may be noted that Process I had provided only two units each of 65 per cent capacity. Hence, if one were down, production would be only 65 per cent; Process II, on the other hand, had provided five units of 120 per cent capacity, and if one unit were down, 96 per cent production could still be obtained. Process IV had provided three units for 150 per cent capacity. If one were down, 100 per cent production could be achieved. Process III had provided three units with 110 per cent capacity. If one unit were down, only [illegible] per cent capacity could be obtained.

Considering the number of plants installed after 1945 based on the oxygen gasification of low-grade fuels for making ammonia synthesis gas, it should be noted that a number of plants were built with Process II one in Belgium, one in Finland, one in France, one in Japan and one each in Spain and Portugal, as well as one recently for the Greek lignite project. Compared with this, Process III had put up the gas plant for the supply of town gas in Australia and at Dorsten in the Federal Republic of Germany, as well as a very large plant for Fischer Tropsch synthesis in South Africa. Recently a Process III plant had been put up in the Republic of Korea for ammonia synthesis gas. Process I was the oldest of these processes, but it had the greatest drawback in the carry-over of dust with gas, which had to be burnt in a boiler. Process I generators had been working for the past thirty years in both Eastern Germany and the Federal Republic of Germany, and in Japan, in such famous plants as Leuna, Bohlen and BASF at Magdeburg. However, few Process I plants had been put up recently. A large size unit, based on Process III, was working at Wesseling, and another plant for lump coal had been put up at Sluiskill. Process IV was working on a semi-commercial scale at Wesseling.

Cost

The cost of production and installed cost per 1,000 normal cubic metres of CO + H_2 were stated to be as follows (in rupees):

	Cost of production of 1,000 normal cubic metres of CO + H_2 in raw gas	*Cost of production of 1,000 normal cubic meters of CO + H_2 in compressed raw gas (16-18 atmospheres*	*Cost of production of 1,000 normal cubic metres of synthesis gas (H_2 + N_2*
Process I	67.21	76.97	109.71
Process II . . .	88.18	97.93	124.51
Process III . . .	—	67.91	105.92
Process IV . . .	62.30	75.15	106.87

Terms

Delivery, deferred-payment terms and financing charges were nearly the same in the case of all the four tenderers, as shown in table 109.

Recommendation

After a careful consideration of the above points, it was recommended that for gasification, Processes I and II should be selected for further investigation. Process I was the lowest in price and was an old and established process, but it might have operating troubles and low efficiency. Process II was the highest in price, but would operate much more smoothly.

(b) *Group B: gas purification*

Quotations received

For this group, quotations had been received from five firms. One had been offered for the three gasifications, Processes I, II and IV. The purchaser prefered water wash, ammonia water wash or hot potash wash for initial H_2S removal from raw gas. During the study of the gas purification process it had been found that activated hot potash washing based on the Vetrocoke system had been adopted by many tenderers and was a very costly system, the make-up for the activated hot potash costing about Rs. 13,000 per ton. The consumption and cost had to be established exactly before a decision could be taken. If that system were adopted, guaranteed consumption figures would have to be given.

The purchaser was also of the opinion that the CO_2 gas going to urea synthesis plant must be completely purified of the H_2S and oxygen, either by activated carbon or iron oxide for H_2S and not by copper turnings for oxygen. Considering the process offered, it was believed that for the atmospheric gasification systems the most acceptable was Process I.

Cost

From the point of view of the cost on f.o.b. equipment, the preference was Process I.

Total production, cost of production and installed cost per ton

Process I was only offering three converters, each of 33 1/3 per cent capacity, for the CO conversion, which was not considered sufficient; therefore, the price would have to be increased for an additional CO converter of 33 1/3 per cent capacity.

Terms

Delivery, deferred-payment terms and financing charges were almost the same and were satisfactory.

Recommendation

On the basis of the considerations given above, Process I was recommended for further study.

(c) *Group C: air and gas fractionation*

Technically, all three offers — III, II and I — were acceptable. Unfortunately, one offer had not given any details beyond price.

Cost of equipment

On the basis of f.o.b. cost of equipment only, offer I was the lowest — Rs. 17.0 million; followed by offer III — Rs. 17.8 million; and offer II — Rs. 19.7 million. Since offer I had not provided any details, only offers II and III could be considered further.

Production facilities

Under production facilities it must be pointed out that offer III had provided each stream for a total capacity of 130 per cent, whereas offer II had provided only two streams with 50 per cent capacity each but with the provision that it could be pushed up to 65 per cent. On this basis, offer III was the better.

Terms

Delivery, deferred-payment terms and financing charges were the lowest in the case of offer II, and III was the highest.

Recommendation

On the basis of the above-mentioned factors, it was recommended that offers I and II should be selected for further consideration.

(d) *Group D: ammonia plant*

Quotations received

The offers for the ammonia plant received from companies I, II, III and IV were studied in detail. Firm I offered a medium-pressure system with ejectors; II offered the regular high-pressure system with ejectors; and III and IV offered the medium-pressure system with circulators. Although I offered a medium-pressure system with ejectors, a system which was not widely established, no difficulty was foreseen technically in the system working. Hence, technically, offers I, II and III were acceptable; IV was not considered, as details had not been given.

Cost

On the basis of the f.o.b. cost of equipment, offer I was the lowest, being Rs. 16.1 million, followed by II at Rs. 18.5 million and III at Rs. 21.3 million.

Production

The guaranteed consumption of synthesis gas was lowest in the case of II, being 2,703 per ton of ammonia, and higher in the case of I at 2,780. These figures would have to be confirmed as they would have a great significance in maximum production. Firm I gave the maximum quantity of steam being made, as 0.85 tons per ton of ammonia, and consumed the lowest power — 600 kWh per ton of ammonia.

Terms

Delivery, deferred-payment terms and financing charges were satisfactory for offers I, II and III.

Recommendation

On the basis of the considerations given above, provided that a guarantee would be obtained for the systems by firm I and also that the specific consumption of synthesis gas per ton of ammonia would be better, there was no hesitation in recommending I as the first choice, II as the second and III as the third.

(e) *Group E: urea plant*

Tenders received

Three processes had been offered for this plant: an oil-slurry recycle process by firm I, a total-liquid recycle of ammonium carbamate by II, and a total recycle of ammonium carbonate by company III. Company IV had not given any details. System I — the oil-slurry recycle — had given operational difficulties in plants in the United States of America. It is also pertinent to point out here that no company had offered the selective separation of ammonia and CO_2, which is a very costly and elaborate process. In urea synthesis, Process II had been most extensively used throughout the world and there was no hesitation in saying that this combination was technically the most favourable, followed by III.

Cost

The total foreign cost of the equipment was the lowest, Rs. 20.1 million, in the case of II, and it was Rs. 33.32 million in the case of III.

Production

With regard to guaranteed production etc., both II and III expected to produce 153,450 tons of prilled urea which was about 10 per cent above the target. Both had offered four autoclaves of 125 tons capacity each. However, it may be added here that II had offered four streams up to urea concentration and prilling, while III had offered better facilities for technical-grade urea and the air-conditioning of storage. It may also be noted that the total weight of equipment offered by III was 2,896 tons, whereas that offered by II was only 1,368 tons.

Terms

With regard to delivery, deferred-payment terms, financing charges and trial production, the trial production was expected in thirty-eight months, in the case of company II. Company III had not made a clear statement on this, whereas in the case of I, the hope was that 50 per cent production would be attained in thirty-four months, a factor of considerable importance.

Recommendation

From the above-mentioned considerations, it was felt that the processes offered by II and III should be given preference.

(f) *Groups F, G and H: process-steam installation, electrical equipment and off-site and auxiliary services*

For group F, offers had been received from four companies — I, II, III, IV. Of these, III had not given any details. In comparing this group only, the alternative given by I could be compared with IV, because I had given only a 5,000 kilowatt back pressure turbine. Furthermore, company I had not included part II under group F, i.e., electrical equipment. Technically speaking, the offers of I and IV were considered the best.

It was most difficult even to compare the f.o.b. cost of equipment in this group because companies I and IV had not followed the same pattern. Furthermore, taking the groups F, G and H together, offer I was preferable to II. Under group G, offer I had provided a transformer capacity of 58,900 kilowatt-amperes, whereas II had provided for only 40,000 kilowatt-amperes.

(g) *Total plant*

For the complete plant, it may be seen from the foregoing discussion that the alternatives preferred technically, financially and with respect to deliveries and deferred terms were the following:

(*a*) For groups D, E, F and H and for groups A, B, and C, offer I was the best. The foreign exchange involved was only Rs. 122.1 million.

(*b*) Technically speaking, offer I, in combination with a different gasification system, was superior to that selected, but it involved a foreign exchange of Rs. 142.2 million. Because of this factor, it was the second choice.

The recommendations were considered by the Board of Directors of the Corporation and by the Government, and on the basis of the lower f.o.b. cost of plant and equipment, offer I was accepted.

G. CONSTRUCTION PROBLEMS

The entire equipment for the project was then to be supplied by two foreign companies. Contracts were drawn up in November 1959 incorporating all details. The Government decided to pay for one firm on cash payment terms because credit was available at that time. In the case of the other firm deferred terms of payment were accepted.

It was stipulated in the contracts that about 3,000 tons of mild-steel equipment required by the firms would be manufactured in the country itself. These included:

(*a*) Gasholders;

(*b*) Tanks;

(*c*) Supporting structures and gratings;

(*d*) Conveyer systems;

(*e*) Low-pressure pipelines.

The Government was to release the necessary steel to the fabricating shops to which the contractors had given the subcontracts. Unfortunately, because of a shortage of steel in the country, the indigenous fabrication was delayed and, ultimately, the required steel had to be imported. Although delivery of the foreign-made equipment began at site in 1961 and was 90 per cent complete by 1962, the erection could not be begun before 1963, for the following reasons:

(*a*) The foundations and buildings were not ready. This was the responsibility of the Corporation;

(*b*) The indigenous fabricated equipment was not ready;

(*c*) The erection contract was not given in time, this being the responsibility of the Corporation, although the foreign contractors were to supply a large number of specialized erectors.

As a result, the foreign contractors who had a time limit for the supply of equipment and for the beginning of erection applied an "escalation" clause, as per the contract. It is estimated that, in addition to the loss of production for two years, a 20 per cent increase in the total cost of the project became inevitable. The erection was completed in 1965 and trial production was expected to begin during the year.

The Corporation authorities had to execute the following:

(*a*) Determine the exact location of the factory and make the layout;

(*b*) Survey soil conditions for foundations;

(*c*) Provide drainage, grading, road levelling and railway siding;

(*d*) Construct foundations and buildings;

(*e*) Provide lignite by a belt conveyer. Design and build the cooling- and process-water systems. Convey electrical power to the receiving station;

(*f*) Provide transport and storage of equipment;

(*g*) Provide erection of equipment;

(*h*) Arrange recruitment and training of personnel;

(*i*) Arrange for local fabrication;

(*j*) Arrange for all tools and tackle for erection, except for specialized items which were imported.

11 ACTUAL PROGRESS SCHEDULE

The time taken for the project to be completed from the date the contracts with the foreign companies were signed in 1960 was about four years. This was almost twice the time originally scheduled for the completion of the project. To a certain extent, this delay was beyond the control of the Corporation. It may also be stated that by ordering units of plants separately and by undertaking the interplant tie-up and the responsibilities listed above, a considerable saving in the total cost of the project was achieved. Members of the project personnel gained invaluable experience which could not be obtained in any other way.

Against this, it may be pointed out that the delay in earlier completion of the project cost the country foreign exchange for the importation of fertilizers and caused the Corporation loss in revenue. These factors have to be carefully weighed by developing countries in planning fertilizer projects. Similar undertakings are only possible in a developing country which already has experience in such projects and which has administrators, engineers and technicians who are capable of handling responsibilities. The easier and costlier way of executing such projects is to enter into "turn-key" contracts. Under such a contract, a competent foreign firm not only supplies processes and equipment, but assumes the entire responsibility up to trial production and handing over the plant after capacities and guarantees have been proved.

Many developing countries with established fertilizer projects are now designing component plants and fabricating most of the equipment themselves. For example, the following plants are being designed and built at least by a few developing countries:

(*a*) Sulphuric acid;
(*b*) Superphosphate;
(*c*) Ammonium sulphate;
(*d*) Nitric acid;
(*e*) Ammonium nitrate.

For the above-mentioned plants, most of the equipment can be manufactured locally, with the following exceptions:

(*a*) High-pressure compressors and blowers;
(*b*) Valves;
(*c*) Instruments;
(*d*) Special pumps;
(*e*) Catalysts;
(*f*) Stainless steel and special alloy steels.

Although this is a step in the right direction, it will be some years before many developing countries can undertake such a step. In the meantime, it is essential that every developing country building fertilizer plants take an active part in design, construction and erection so that the "know-how" can be utilized in future projects.

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XXI. PLANT INVESTMENT AND PRODUCTION COSTS

A. DESCRIPTION OF CHARTS

This chapter consists of a series of charts showing the investment required for building a plant to produce a specific fertilizer and the production cost of the fertilizer. One group of charts shows how the investment varies with the capacity of the plant. A second group shows how the production cost of a fertilizer varies with the capacity of the plant. In some cases, additional charts show how other variables — raw material and energy costs, for example — affect the total cost of producing a specific fertilizer material.

B. ASSUMPTIONS USED IN DEVELOPING CHARTS

1. *Charts showing production costs*

The same basic assumptions are used in developing all charts showing the production costs, with the exception of figure 64; the assumptions used in preparing that chart are listed thereon. The basic assumptions are listed below:

(*a*) Electric-power cost: $0.007 per kWh;

(*b*) Water cost: $0.03 per thousand gallons;

(*c*) Operating labour, $3.00 per hour;

(*d*) Maintenance: 5 per cent of investment *per annum*;

(*e*) Labour overhead: 30 per cent of operating labour and supervision;

(*f*) Plant overhead: 70 per cent of operating labour and supervision;

(*g*) Depreciation: 10 per cent of investment *per annum*;

(*h*) Taxes and insurance: 3 per cent of investment *per annum*;

(*i*) Interest on invested or working capital not included;

(*j*) Sales cost not included;

(*k*) Return on investment not included;

(*l*) Storage included only where specified (storage investment for solid materials can be assumed to be about $18 per ton of storage capacity in the United States of America);

(*m*) Bagging costs are included as part of the normal superphosphate plant cost, but not as part of any other;

(*n*) Plants to operate at 100 per cent of capacity;

(*o*) Plants to operate 330 days *per annum*, with the exception of that for normal superphosphate, which would operate 250 days *per annum*.

2. *Charts showing plant investment* versus *plant capacity*

The basic assumptions used in preparing all the charts showing the plant investment *versus* the capacity of the plant are listed below:

(*a*) Location in Gulf Coast area of United States of America;

(*b*) Battery limits plant, that is, supply and erection of process equipment required for manufacture of the products in plants of specified capacity;[1]

(*c*) All production units based on single-stream construction.

For all the various fertilizer products produced, the investment increases as the production capacity of the plant increases, and the cost of producing the fertilizer decreases as the production capacity of the plant increases.

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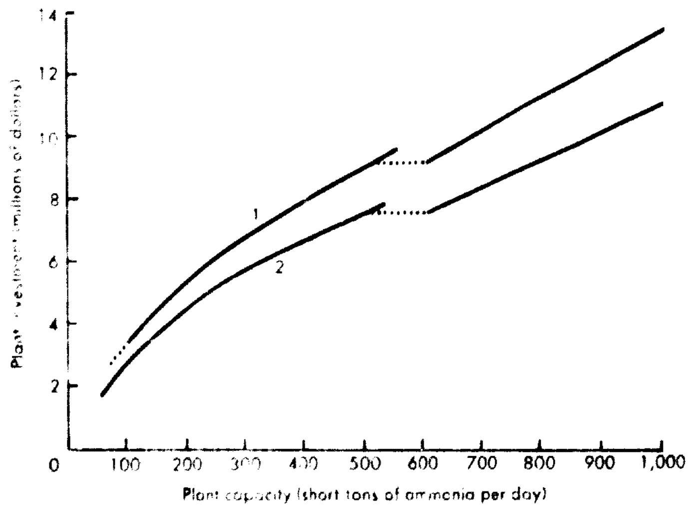
[1] For discussions of additional costs which must be faced, see United Nations, *Studies in Economics of Industry; vol. 1: Cement. Nitrogenous Fertilizers Based on Natural Gas* (United Nations publication: Sales No.: 63.II.B.3), pp. 34-39; chapter XII of this manual, "Production of phosphate fertilizers", pp. 117-136.

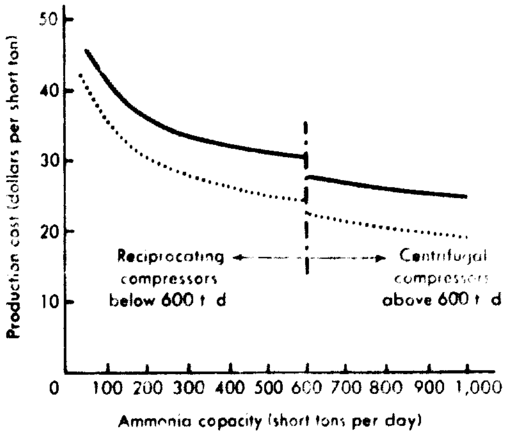
Figure 63. Anhydrous ammonia: plant investment versus *plant capacity*



Legend:

1 — Naphtha, steam reforming.
2 — Natural gas, steam reforming.
··· Indicates capacities at which shift to centrifugal compressors becomes feasible.

Figure 64. Anhydrous ammonia: production cost versus *plant capacity*



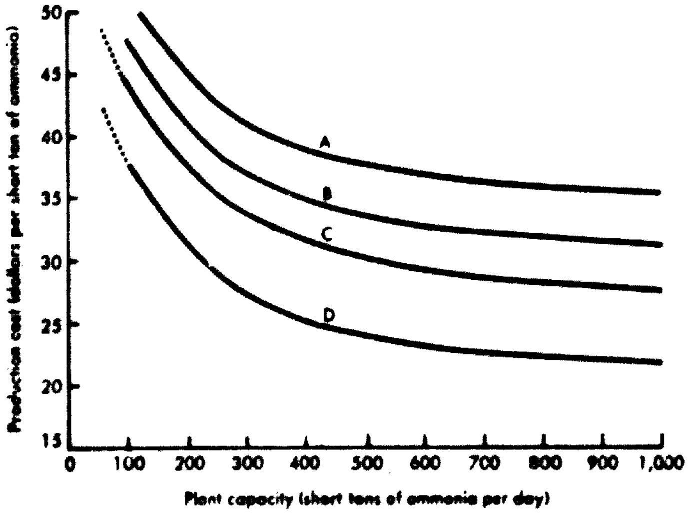
Basis:

Natural gas feed.
CO_2 removal by MEA scrubbing.
Cooling water at $0.02 per thousand gallons.
Boiler feed-water at $0.25 per thousand gallons.
Export steam at $0.50 per thousand pounds.
Maintenance and indirect costs at 20.5 per cent *per annum.*
Labour, five men per shift.

Legend:

—— Natural gas at $0.50 per million BTU; power at $0.010 per kWh.
···· Natural gas at $0.32 per million BTU; power at $0.009 per kWh.

Figure 65. Anhydrous ammonia: production cost versus *plant capacity, steam-reforming process*



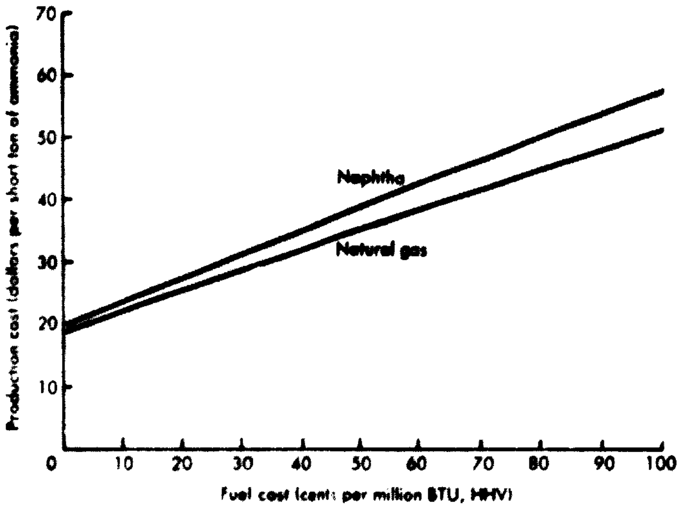
Assume:

1. Plants operate at 95 per cent of capacity.
2. Depreciation, 10 per cent *per annum*, battery limits.
3. Power cost, $0.007 per kWh.
4. Maintenance, 5 per cent of plant investment.
5. Taxes and insurance, 3 per cent of plant investment.
6. Cooling water, $0.03 per thousand gallons; boiler feed-water, $1.00 per thousand gallons; condensate credit, $0.30 per thousand gallons.
7. Plant and labour overhead, fringe benefits at 100 per cent of operating labour and supervision.
8. Wages, $3.00 per hour for operating labour.

Legend:

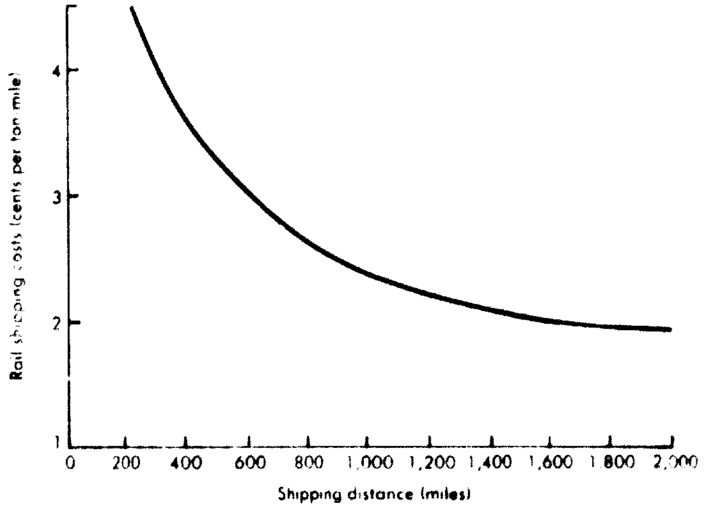
A : Naphtha, $0.01 per pound (20,000 BTU per pound).
B : Naphtha, $0.008 per pound (20,000 BTU per pound).
C : Natural gas, $0.40 per thousand cubic feet (1,000 BTU per cubic foot).
D : Natural gas, $0.20 per thousand cubic feet (1,000 BTU per cubic foot).

Figure 66. Anhydrous ammonia: production cost versus *energy cost*



Basis: Plant with capacity of 400 short tons per day, steam-reforming process.

Figure 67. Anhydrous ammonia: shipping cost versus *shipping distance,* via *rail*



Basis: **Shipments of 25 short tons or more.**

Note: **Truck rates will be about twice as much.**

Figure 69. Anhydrous ammonia: storage costs at atmospheric pressure; investment cost and production cost versus *capacity*

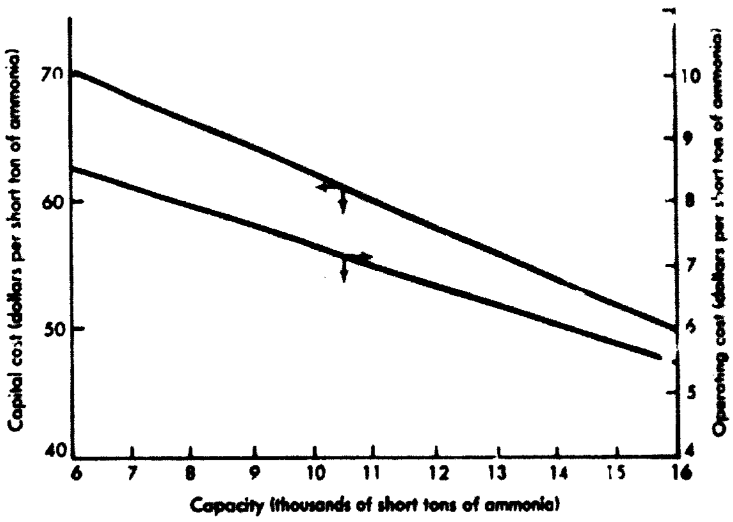


Figure 70. Urea, prilled (45 per cent N): plant investment versus *plant capacity, total-recycle process*

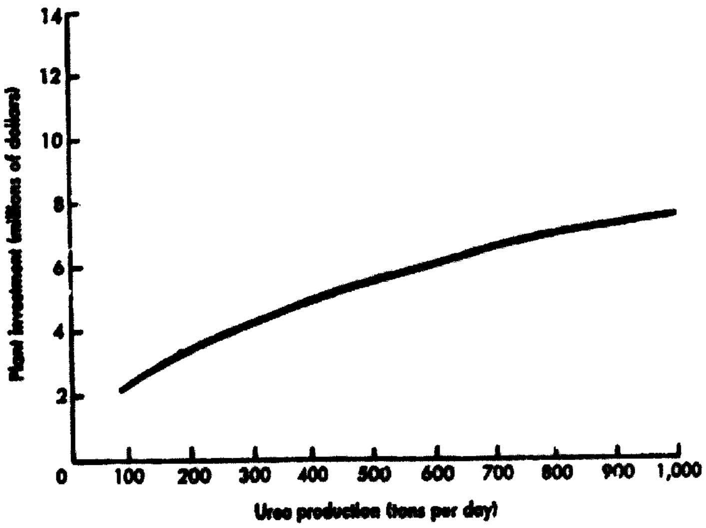
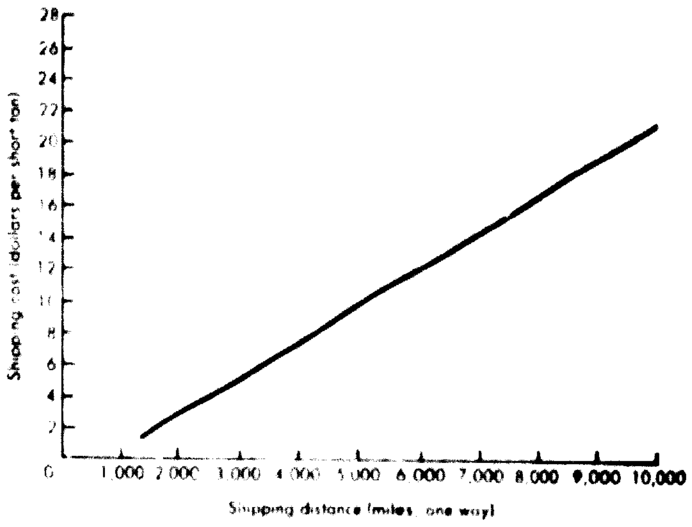


Figure 68. Anhydrous ammonia: shipping cost versus *shipping distance,* via *ocean-going ship*



Assume

New vessel at a cost of $6 million

Capacity of 8,000 short tons

Speed, 15 knots (17.3 mph)

Operation, 350 days *per annum*

Operating cost, $200 per day

Twenty-year amortization, 5 per cent interest

Loading and unloading, one day each

Maintenance and repairs at 2.5 per cent of investment

Figure 71. Urea, prilled (45 per cent N): production cost versus *plant capacity at various ammonia costs*

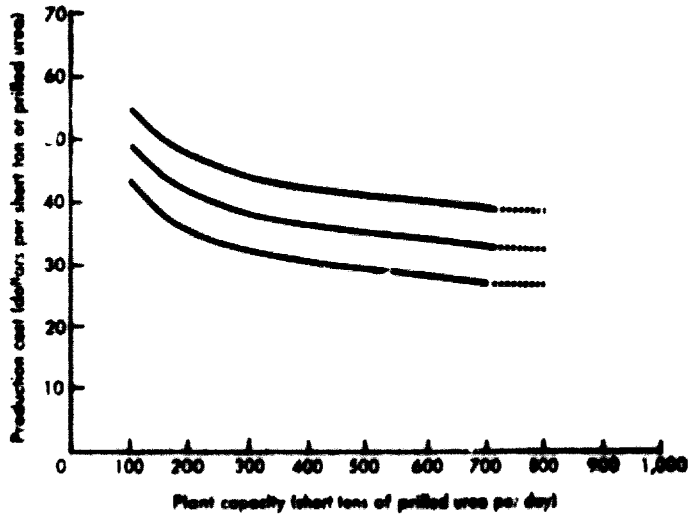
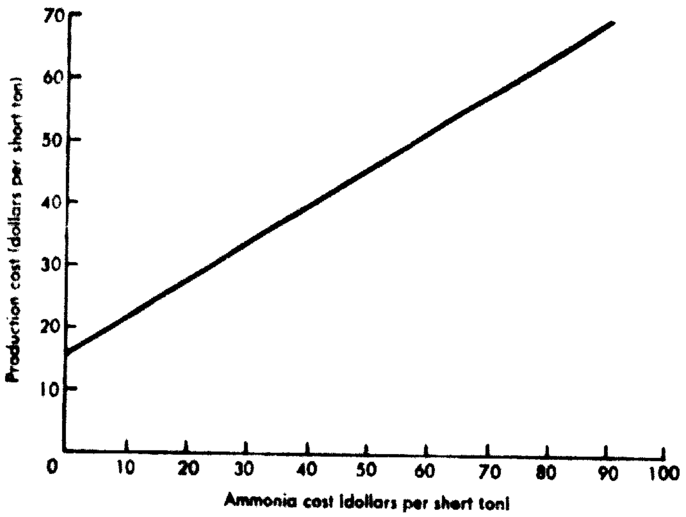
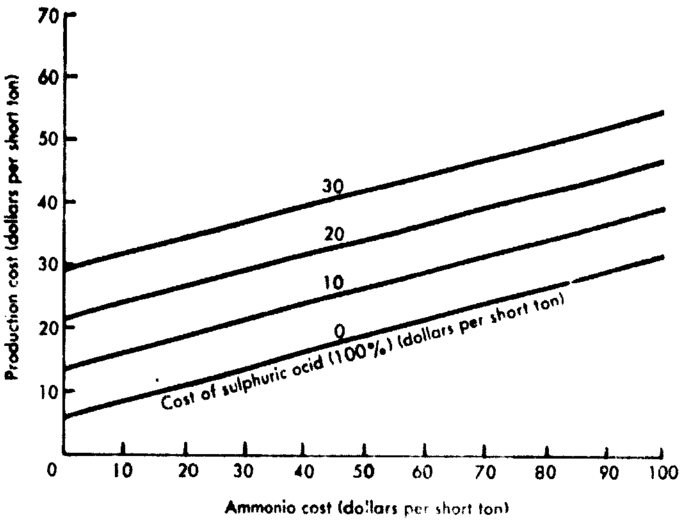


Figure 72. Urea, prilled (45 per cent N): production cost versus *ammonia cost*



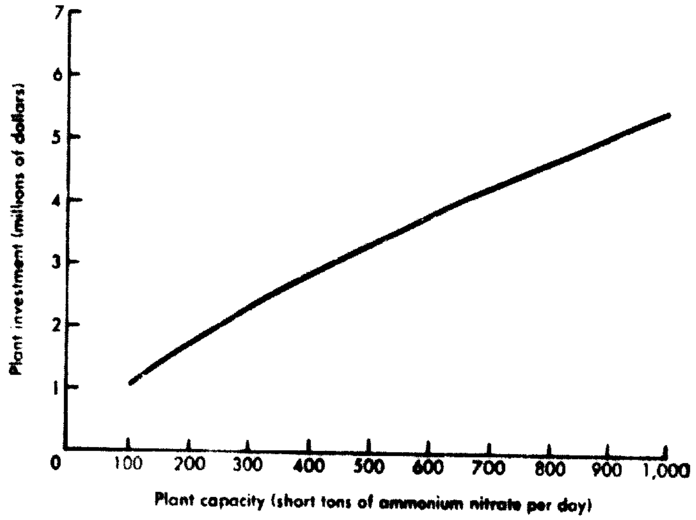
Basis: **Plant with capacity of 100,000 tons *per annum*.**

Figure 73. Ammonium sulphate, sulphuric acid process: production cost versus *ammonia cost at various sulphuric acid costs*



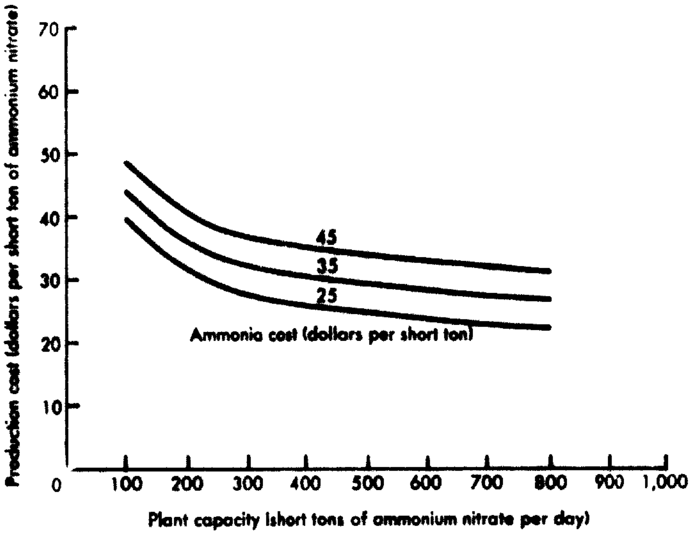
Basis: **Plant capacity of 100,000 tons *per annum*; plant investment, $1.8 million.**

Figure 74. Ammonium nitrate, prilled (33.5 per cent N): plant investment versus *plant capacity*



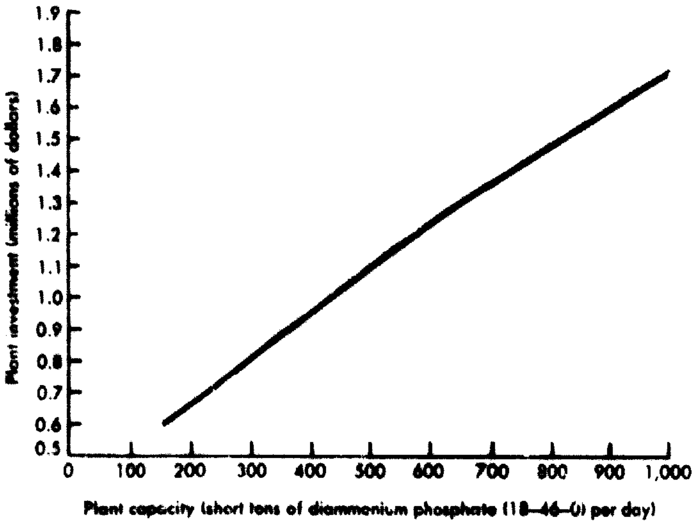
Note: Not including nitric acid plant.

Figure 75. Ammonium nitrate, prilled (33.5 per cent N): production cost versus *plant capacity at various ammonia costs*



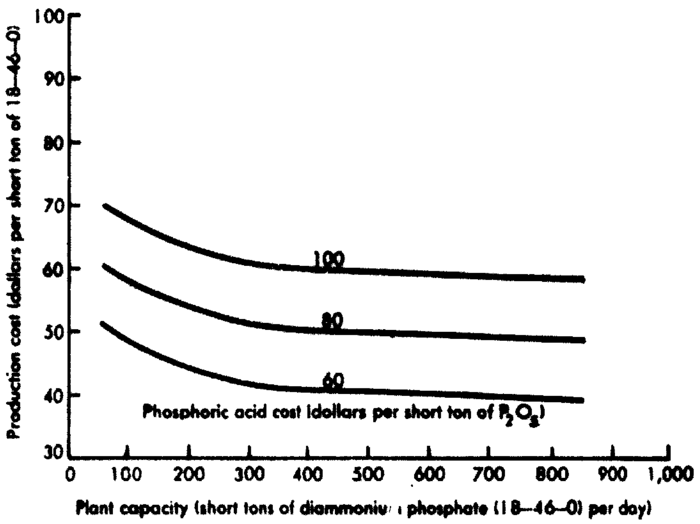
Note: **Including effect of ammonia cost on nitric acid cost.**

Figure 76. Diammonium phosphate (18-46-0): plant investment versus *plant capacity*



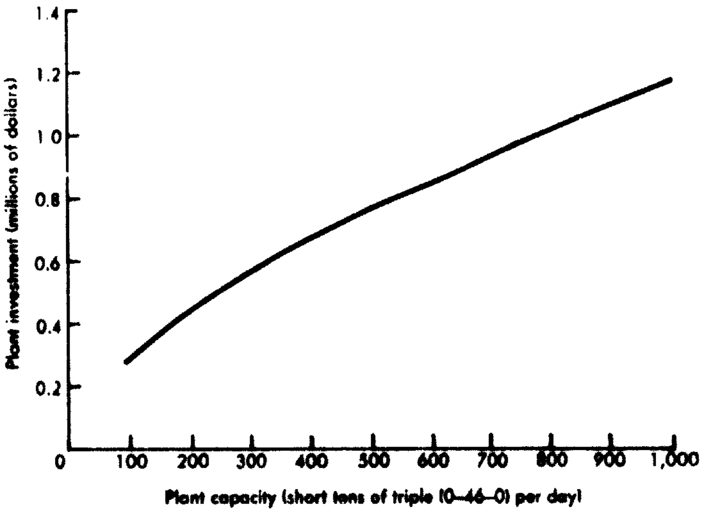
Note: **Excluding phosphoric acid or ammonia production units. Including storage for thirty days' production.**

Figure 77. Diammonium phosphate (18-46-0): production cost versus *plant capacity at various phosphoric acid costs*



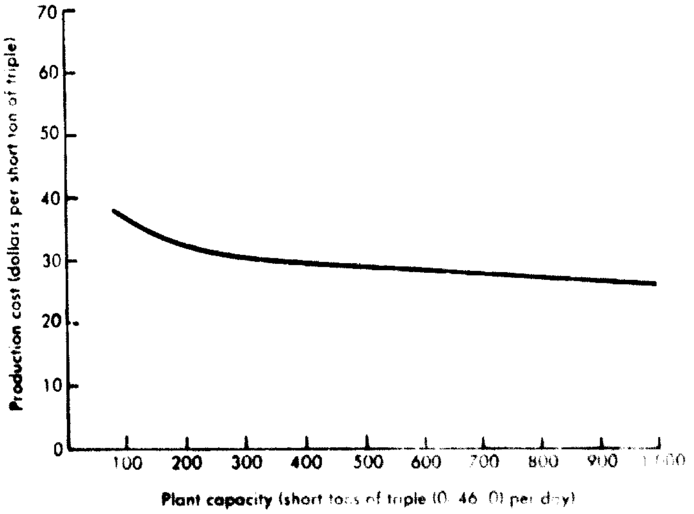
Note: **Assume an ammonia cost of $35 per short ton.**

Figure 78. Triple superphosphate (0-46-0): plant investment versus *plant capacity, cone process used by Tennessee Valley Authority*



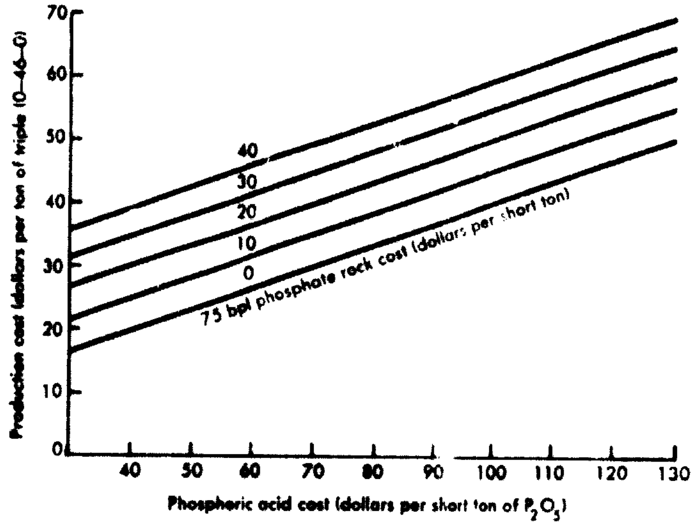
Note: Including storage for one month's production. Excluding rock-grinding capacity, for which allowance is made in costs for phosphoric acid plant.

Figure 79. Triple superphosphate (0-46-0): production cost versus *plant capacity*



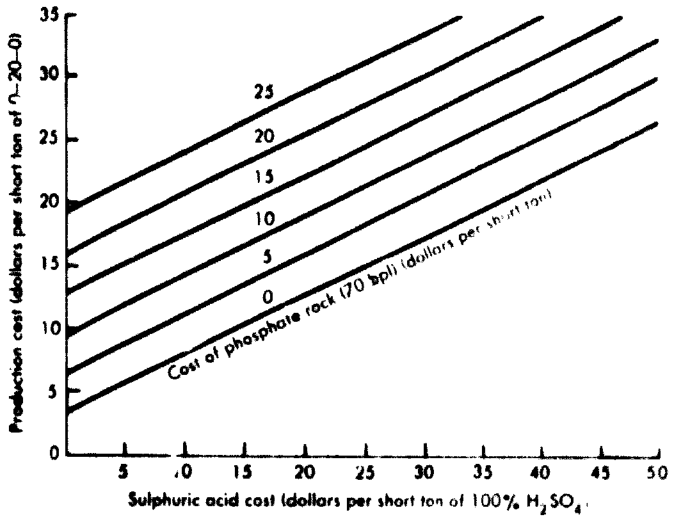
Basis: 75 bpl phosphate rock at $8.30 per short ton; phosphoric acid at $66 per ton P_2O_5.

Figure 80. Triple superphosphate (0-46-0): production cost versus *phosphoric acid cost at various phosphate rock costs*



Basis: Plant capacity of 450 tons of 0-46-0 per day.

Figure 81. Normal superphosphate (0-20-0): production cost versus *sulphuric acid cost at various phosphate rock costs*



Note: For plant with capacity of 37,500 tons *per annum* (150 tons per day) the cost per ton of 0-20-0 is increased about 16.5 per cent.

Assume: Plant capacity of 120,000 tons *per annum* (operations at 20 tons per hour, 250 days *per annum*). P_2O_5 basis: 24,000 tons *per annum* = 95 tons per day. Including rock grinding, 20,000-ton (six weeks) storage, and grinding and bagging of product.

Figure 82. Sulphuric acid: plant capacity versus *plant investment, sulphur-burning contact process*

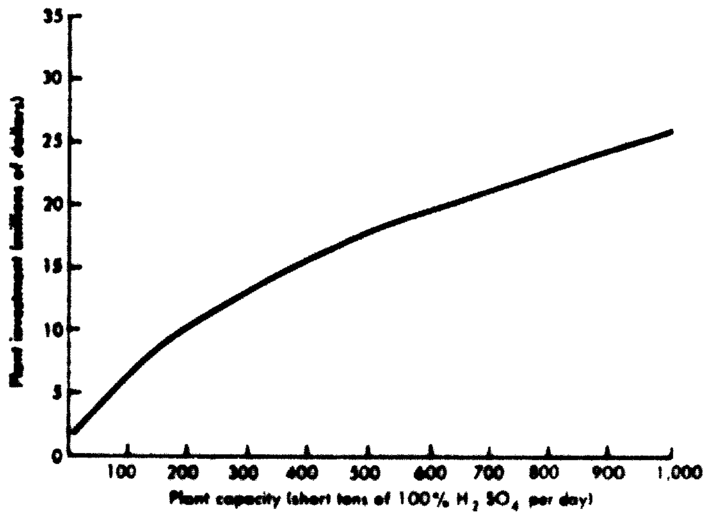
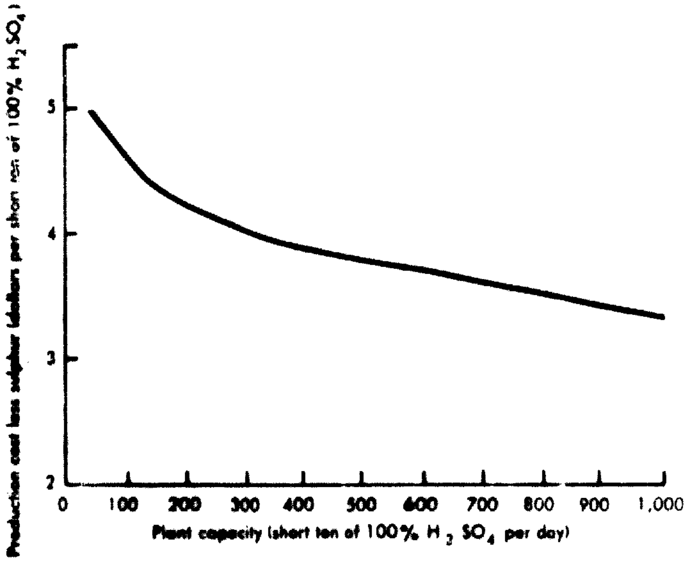
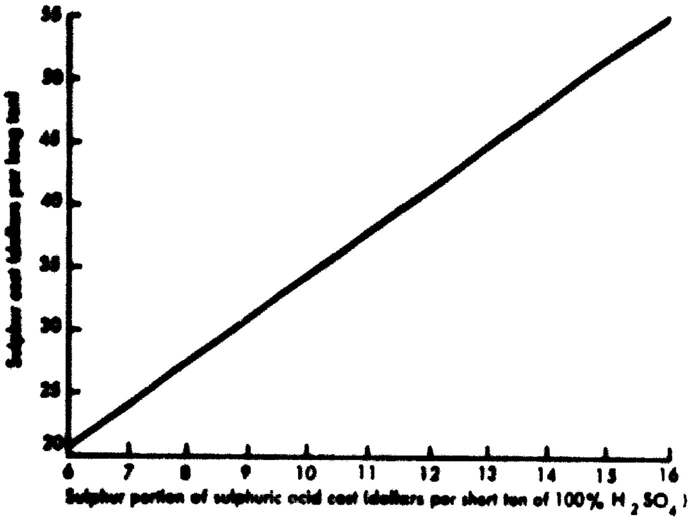


Figure 83. Sulphuric acid: production cost less sulphur cost versus *plant capacity*



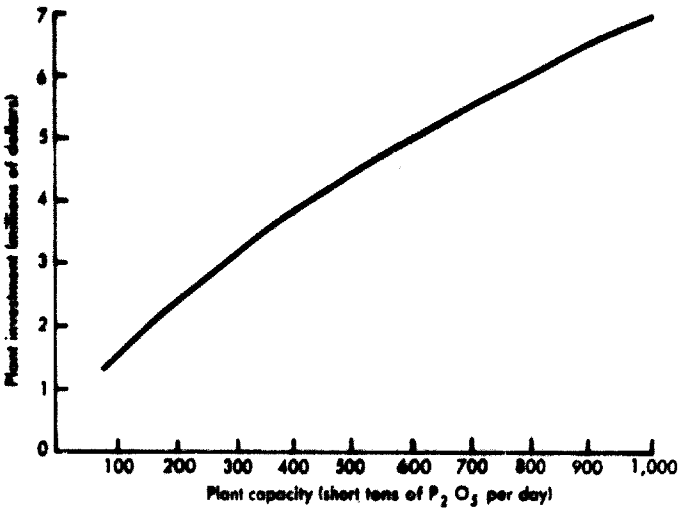
Note: For total acid production cost, add sulphur cost shown in figure 84.

Figure 84. Sulphuric acid: cost of sulphur in acid versus sulphur cost



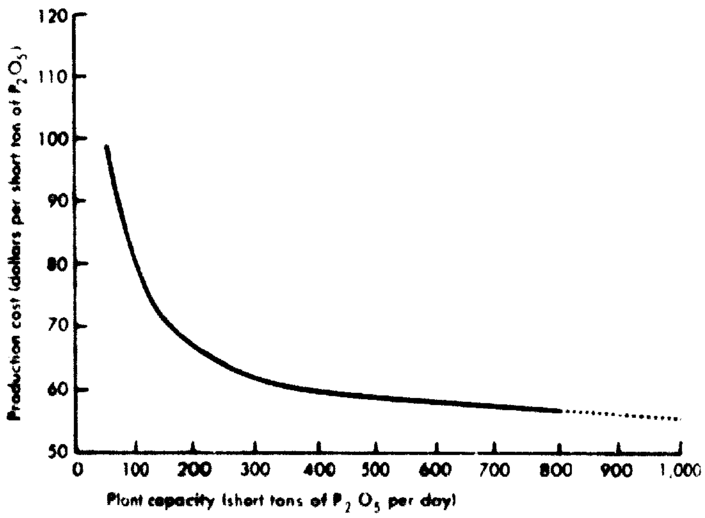
Note: For total acid production cost, add to cost obtained from figure 83.

Figure 85. Wet-process phosphoric acid (54 per cent P_2O_5): plant capacity versus *plant investment*



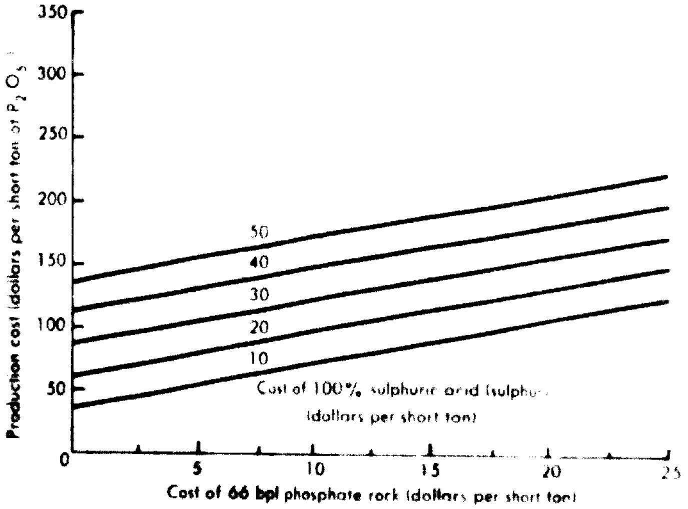
Note: Including rock storage, handling and grinding; and acid clarification and two weeks' storage. Excluding sulphuric acid plant and gypsum disposal.

Figure 86. Wet-process phosphoric acid (54 per cent P_2O_5): plant capacity versus production cost



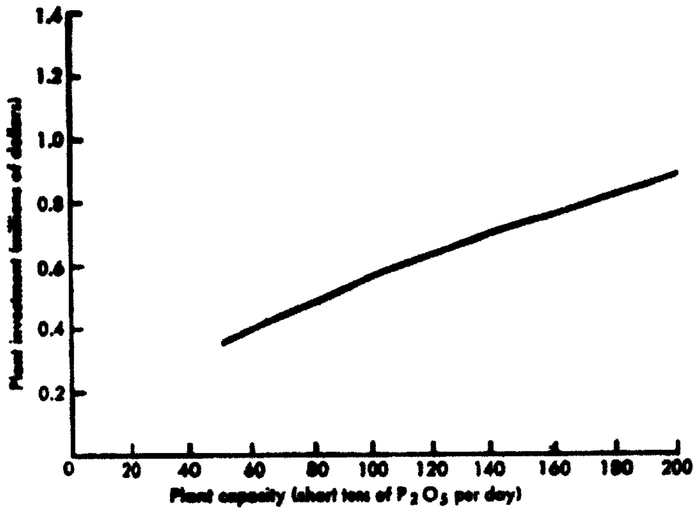
Basis: **66 bpl phosphate rock, \$6.00 per short ton; 100 per cent H_2SO_4, \$11.82 per short ton.**

Figure 87. Wet-process phosphoric acid (54 per cent P_2O_5): production cost versus cost of phosphate at various sulphuric acid costs



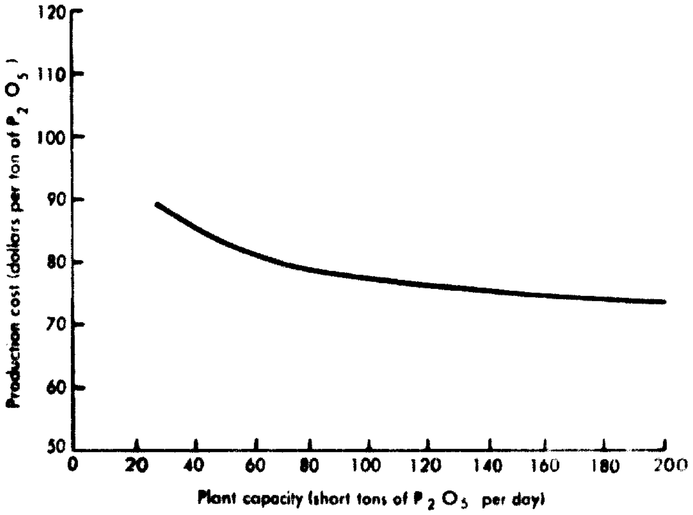
Note: **Plant capacity of 300 short tons P_2O_5 per day. Sulphur costs calculated by assuming production cost of \$3.55 per ton of 100 per cent H_2SO_4 in plant with capacity of 775 tons per day, the remainder being 32.7 per cent of the per ton cost of sulphur.**

Figure 88. Superphosphoric acid (70 per cent P_2O_5): plant investment versus plant capacity



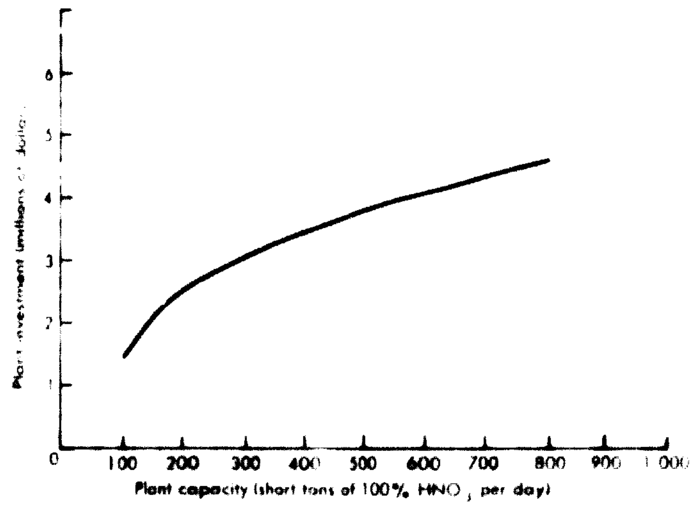
Note: **Vacuum evaporation of 54 per cent P_2O_5 wet-process acid. Including storage for thirty days' production and steam production facilities.**

Figure 89. Superphosphoric acid (70 per cent P_2O_5): production cost versus plant capacity



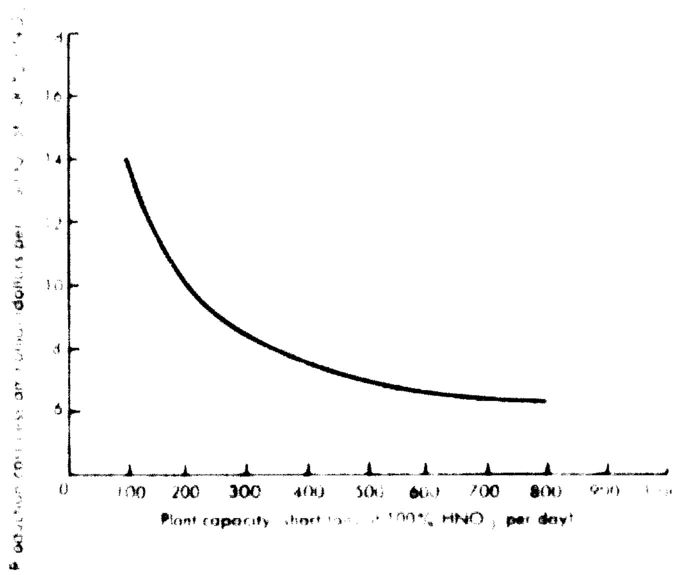
Note: **Phosphoric acid (54 per cent P_2O_5) at \$67.00 per short ton of P_2O_5.**

Figure 90. Nitric acid (50-60 per cent HNO_3) plant investment versus plant capacity, Uhde process



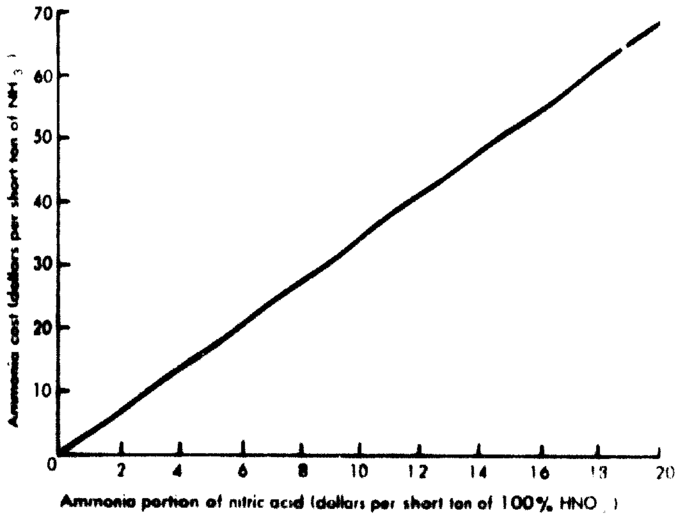
Note. **Takes account of design changes** as affected by size. **Battery limits plant with storage** for **800 tons, but with no services**

Figure 91. Nitric acid (50-60 per cent HNO_3): production cost less ammonia cost versus plant capacity



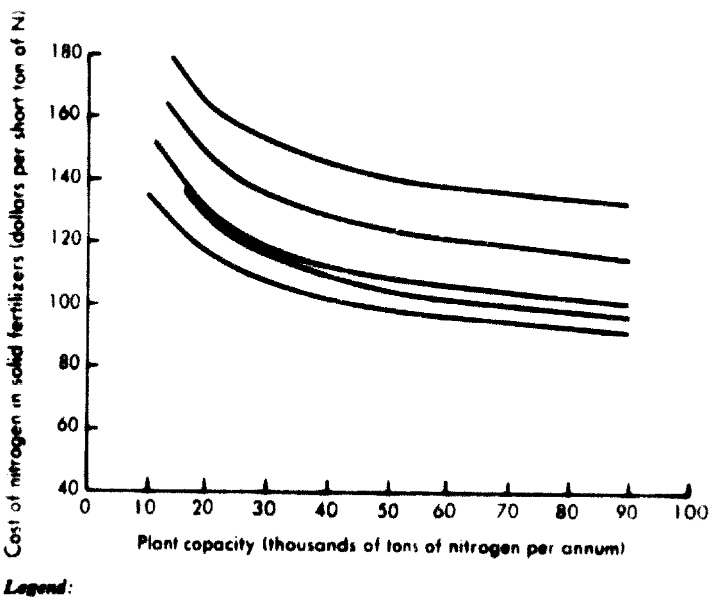
Note: **For total acid production cost, add ammonia cost obtained from figure 92**

Figure 92. Nitric acid (50-60 per cent HNO_3): cost of ammonia in acid versus ammonia cost



Note: **For total acid production cost, add** to cost **obtained from figure** 91.

Figure 93. Conversion of ammonia to solid fertilizers: cost of nitrogen in solid fertilizers versus plant capacity



Legend:

1 : **Ammonium sulphate: ammonia, $50 per ton; gypsum, $5 per ton $CaSO_4$.**

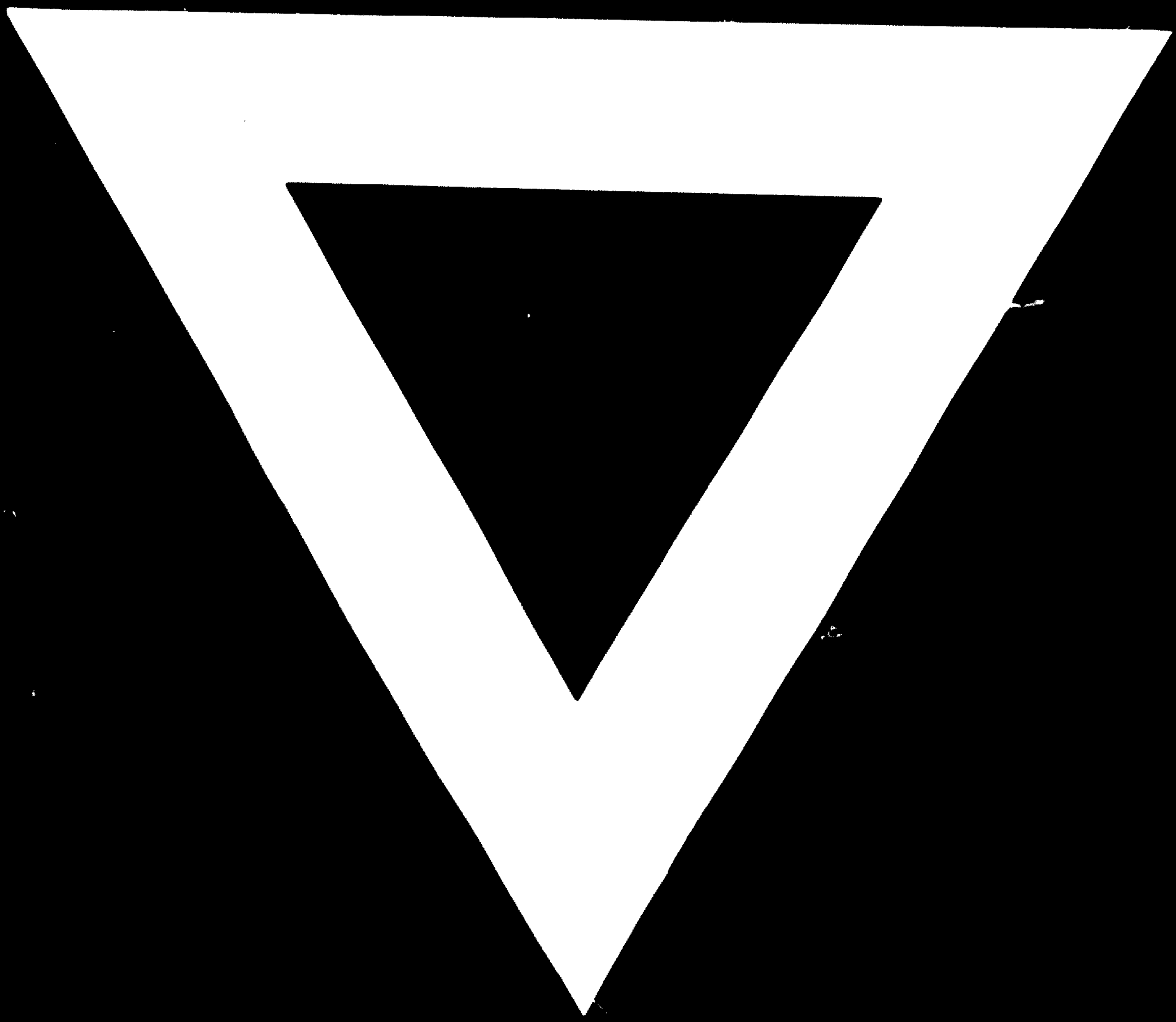
2 : **Ammonium sulphate: ammonia, $50 per ton; sulphuric acid, $20 per ton, 100 per cent.**

3 : **Ammonium sulphate: ammonia, $50 per ton; sulphuric acid, $15 per ton, 100 per cent.**

4 : **Ammonium nitrate (prilled): ammonia, $50 per ton; nitric acid priced accordingly.**

5 : **Ammonium sulphate: ammonia, $50 per ton; sulphuric acid, $10 per ton, 100 per cent.**

6 : **Urea (prilled): ammonia, $50 per ton; carbon dioxide, no cost.**



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