OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

DO 1434

Distribution
LIMITED

ID/WG.80/5
18 August 1970

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

UNIDO Meeting
on the Development of the Fertilizer and Pesticide
Industries in Latin America
(In Collaboration with ECLA and the Government of Brazil)

Rio de Janeiro, Brazil
15-19 September 1970

IMPORT OF NEW TECHNOLOGY ON THE DEVELOPMENT OF THE FERTILIZER INDUSTRY IN LATIN AMERICA [1]

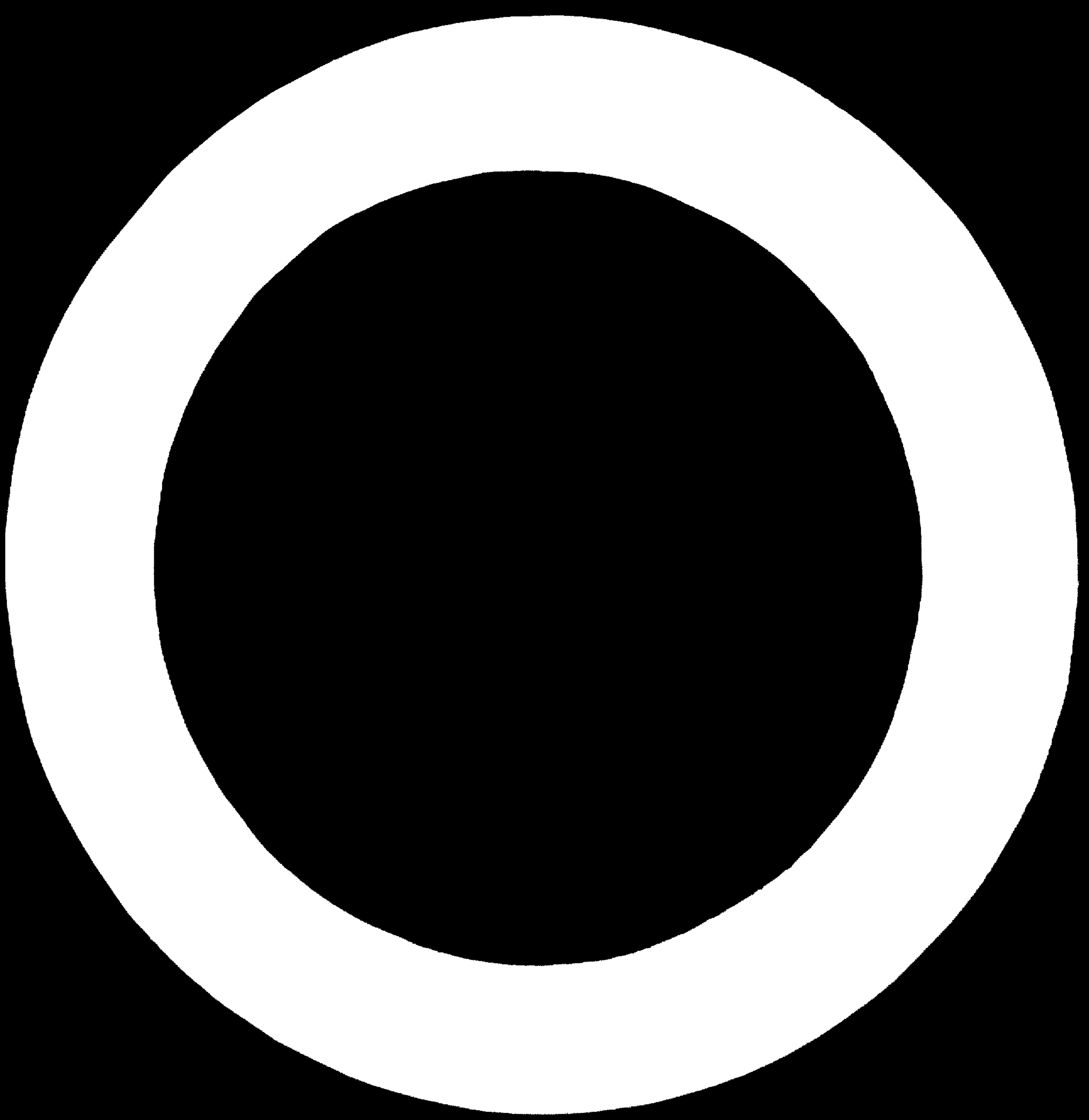
by

A.B. Phillips
Assistant Manager
Office of Agricultural and Chemical Development
Tennessee Valley Authority
Muscle Shoals, Alabama, USA

---

[1] The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.



It is natural and wise for a country in the early stages of developing a viable fertilizer industry for support of needed expansion in its agricultural base to look around at what the rest of the world has done and profit from this experience. Many Latin American countries are in this position. They have reached the point that the need for higher quality fertilizers in increasing quantities is apparent. They find that the search for the optimum in providing these needs is indeed a complicated process that involves consideration of many factors. Because of vast differences that exist, it is dangerous to assume that the optimum can be achieved by simple transfer of technology from one country to the next without careful consideration of these differences. Yet optimization is essential because even when the resource base is large, capital is usually limited and there is always severe competition for this capital for other phases of development.

Many decisions must be made in structuring projects that will fit into an optimum pattern for a fertilizer industry. Some of them are the scale of the operation, whether the higher analysis fertilizer made possible by newer technology will be advantageous, whether the import of certain intermediates is preferable, and what process routes should be considered. Also, the possible effect of new fertilizers being developed must be taken into consideration in present planning. The task assigned to this paper is to discuss in a general way some of the factors that must be taken into consideration in arriving at these decisions. It cannot make the decisions, of course, because they can be made only after intensive study of local situations.

The Effect of Scale

The question of how large to build a project is foremost in the planning process. Any engineer who is to become involved in chemical processing learns early in the course of his education that the investment cost in processing plants per unit of capacity generally decreases as the capacity of the plant increases. Thus, from the point of view of low unit investment cost there is an incentive to increase the size of plants to the greatest extent possible.

The general rule for the relationship between investment cost and capacity is that the investment cost increases exponentially as the 0.6 power of the capacity. A study by Guthrie (1) attests the validity of this old rule of thumb, giving data that averages 0.64 for 54 different chemical process plants. However, the range varied widely from 0.40 to 0.83, so the average is not very useful. These relationships for specific processes of interest to the fertilizer industry are available. A convenient compilation may be found in a manual published by the United Nations Industrial Development Organization (UNIDO) in 1967 (2). Several of these are reproduced in the charts, figures 1 and 2. They were prepared with the assumption that the plants would be located on the Gulf Coast of the United States of America and cover only "battery limits" costs. Since they were based on costs that prevailed in about 1964, they are subject to an escalation factor of about 1.2.[1/]

The relationship of investment cost to size is subject to influence by new technology and the state of development of the given process. The impact of new technology is seen most often in the availability of larger size units which permit the expansion of capacity in a single train rather than the generally more expensive option of multi-train design. The most dramatic example of this in the fertilizer industry of course is the adaptation of the centrifugal compressor to ammonia synthesis plants put into practice during the past few years. Use of these compressors made possible the design of much larger single-train plants than were possible with compressors of the reciprocating type. They require less floor space and piping and do not introduce oil into the gas stream. The effect on investment cost can be seen clearly in figure 1 in the form of a break in the curve at about 600 tons per day, the size at which centrifugal compressors become feasible. Work is under way to adapt centrifugal compressors to smaller size plants.

Other important technological advances also have been made to reduce the cost and improve the efficiency of ammonia plants. These include improved agents and simpler systems for gas purification and arrangements for a large increase in heat recovery (3).

[1/] Calculated from Chemical Engineering Index for Plant Costs.

Technical breakthroughs and process refinements also have permitted large-scale single-train phosphoric acid plants. But their development has taken place over a longer period of time, as shown in the following tabulation.

Period	Type plant	Capacity of largest single-train plant - tons P_2O_5/day
1920 - 1931	Multiple reactor	40
1932 - 1952	Multiple reactor	100
1952 - 1961	Multiple reactor	250
1962 - 1965	Single reactor	850
1966	Single reactor	1,000

The most important developments contributing to the feasibility and resulting economy of large single-train phosphoric acid plants were improved single-unit reactor systems and the very large tilting pan filters. The large number of wet-process acid plants built in recent years speeded these developments and lent the confidence needed to push the maximum size units higher.

Another fertilizer process influenced considerably by better technology that has permitted economy of size is urea manufacture. The most significant advances have been improvements in the design of reactors to give better heat removal and contact between reactants, developments in materials of construction to cope with corrosion problems, and refinements of methods of separation of reactants from product. Designs that feature internal stripping of reactants have made once through processes more attractive. As a consequence, the technology has advanced to the extent that the upper limit of single-train plant size has been pushed rapidly upward to about 1500 tons per day. Investment cost of these very large plants is as much as 50 percent lower per ton of capacity compared to plants of the maximum size available 10 to 20 years ago.

The same general rule holds for more modest projects as for the large complexes. An example that is of interest to many is the continuous ammoniation process for producing granular fertilizers using a rotary drum granulator. This process, which is discussed in more detail later, led to the wide spread of granular fertilizers throughout the United States during the 1950's and early 1960's by providing a route by which small manufacturers could supply the growing demand for high-analysis granular fertilizers in their local area. Since the process was introduced in about 1950, improvements in the design of the granulator and accessory equipment and in techniques for control of the process have led to at least a threefold increase in the maximum capacity of a single-train unit. Increasing the scale has substantially decreased the investment cost per unit of capacity as shown by the following tabulation which gives recent quotations for the f.o.b. price of the equipment only for three sizes of plants using the TVA continuous ammoniation process. The equipment includes a rotary drum ammoniator-granulator, a dryer, a cooler, and all the accessory equipment needed for the plants but does not include freight or erection.

Capacity, tons/hr.	Equipment cost, $	$1,000 per ton/hr.
10	149,000	14.9
20	187,000	9.3
30	237,000	7.8

Similar savings in cost per unit capacity no doubt would be realized in erection costs as the scale of the plant was increased.

The economic advantage of larger plants does not stop, of course, with investment costs. Some of the operating costs are fixed costs in the sense that they do not vary with the scale of the operation. Generally, labor costs do not increase in proportion to the size of a plant. Indeed, increasing the size of a single-train processing unit severalfold may not add any appreciable increment of labor costs. The same may be said in many cases for supervisory and overhead costs. Maintenance and utility costs may not rise in proportion to plant capacity; depreciation costs and the profit per ton of product needed for a given return on investment will decrease because the investment per unit of capacity is less in a large plant.

The magnitude of operating savings that will be accrued as the size of a plant is increased must be studied carefully for each individual case because wide variations in labor and raw material costs from one country to another cause large differences in the ratio of fixed to variable costs. However, charts applicable to the situation in the United States, showing the estimated variation of operating cost with plant size for several processes involved in fertilizer production, are shown in figures 3 and 4 to serve as examples.

As attractive as it may seem to design plants for the highest possible capacity in order to achieve economy of scale in investment and operating costs, extreme caution must be taken. It is most important to make sure that the capacity is supported by a realistic assessment of the market so that the plant can be operated at or near its design capacity. Otherwise, many of the same factors that make it advantageous to increase the size will work in reverse to cause far greater disadvantages when too large a plant is operated significantly below its intended rate.

The magnitude of these relationships can be seen from an illustration from a yet unpublished study made in a Latin American country. The study included estimation of the costs at various levels of operation in two different sizes of ammonia and urea plants.

Ammonia plants having capacities of 1,000 and 600 metric tons per day were compared. The capital costs were estimated to be $29.7 million for the total complex of the larger plant and $19.8 million for the smaller one. The purchase of 400 extra tons of capacity for less than $10 million incremental cost may appear to be economical, but obviously it is a loss if the capacity is not used. Furthermore, the majority of the loss would be in foreign exchange.

The relationship of operating costs to operating levels for the two ammonia plants is shown in figure 5. A study of these curves reveals a startling penalty for low operating levels. For example, the advantage due to scale of producing 1,000 metric tons per day over 600 when both plants are operating at 100 percent of capacity (B - A) is about $4 per ton. However, the disadvantage of producing 600 metric tons per day in the 1,000-ton plant (60% of design) rather than in the 600-ton plant (100% of design) would be about $13 per ton (D - B). If the demand should drop to 540 tons per day (90% of the 600-ton plant capacity), the penalty in operating cost in the smaller plant would be only about $1 per ton (C - B), but if this quantity were produced in the 1,000-ton per day plant (54% of capacity), the cost differential from 100 percent capacity would soar to $25 (E - A) or about $4-1/2 million per year.

Figure 6 shows the same sort of relationships for the urea complex. The operating cost in the 600 metric ton per day plant is about $3 per ton more (B - A) than in the 900-ton per day plant when both are operated at full capacity. However, when only 600 tons per day is made in the larger plant (67% of design), the cost is $5 per ton greater (C - B) than in the smaller plant and $8 per ton greater (C - A) than when the larger plant is operated at full capacity.

The foregoing example serves to illustrate the effect that over-building capacity can have on operating budgets. There are other disadvantages. In some cases, operating problems or processing inefficiencies are encountered when facilities are operated below full capacity. The "turndown ratio" of most plants will not permit operation below a certain percentage of design.

In large single-train ammonia plants the minimum turndown is usually about 60 percent of design capacity. In large urea plants it is in the order of 50 percent. Wet-process phosphoric acid plants have little turndown capacity and must be run on a stop and start basis, which is quite undesirable.

Overproduction, whether due to inability to turn down a plant or a desire to hold unit costs down, can be disastrous in a competitive situation when it leads to unrealistic price cutting among competitors as each tries to capture a larger share of the market. It was the root of the disaster that befell the U. S. fertilizer industry in the late 1960's when an overoptimistic projection of the fertilizer market led to gross overbuilding of capacity within the country.

In summary, advances in technology have created opportunities for substantial increases in the maximum size of plants, giving savings in both investment and operating costs. However, these opportunities can be abused. Severe risks can result from overbuilding capacity before a market for a substantial part of the capacity is assured. This is a lesson that can be learned clearly from experiences in North America during the past few years.

Higher Analysis Fertilizers

Another of the questions that faces planners of fertilizer production is how much emphasis to place on the grade of the product. Over the long range, perhaps the most effective contribution that improved technology has made toward lowering the cost of fertilizer to the farmer has been in increasing the plant food content. Because of the large portion of the total cost that is incurred in handling and transporting fertilizers, there are few greater opportunities to reduce costs than by adding more nutrients per unit of weight. In some countries where facilities for handling and transporting fertilizers are limiting factors, the response to fertilizers is high and the need for greater food production is large. Here, increases in analysis may mean that proportionately greater amounts of nutrients are applied and the total benefits may far exceed the savings in handling costs. In countries depending largely on imports of finished fertilizers, inadequate port facilities sometimes limit the amount of fertilizers used. Obviously, higher analysis can help alleviate this problem.

The average analysis of compound fertilizers produced in countries that are heavy producers of fertilizers has increased sharply. These increases, shown in figure 7, for a 10-year period have averaged 3/4 to 1-1/2 percent per year. The average concentration is now about 40 percent in both the United Kingdom and in the United States. Specific technological improvements that have contributed to these increases in analysis are well known. They began with improvements in processes for making wet-process acid followed by the development of continuous processes suited to large-scale production of triple superphosphate, making available more than a twofold increase in analysis over ordinary superphosphates. The development of the technology for production of diammonium phosphate from the increasing supply of wet-process acid added another 18 percentage points to the analysis. Large basic producers that had been marketing their phosphate as 0-46-0 TSP added 18-46-0 DAP to their line of products. The changes in fertilizer use that resulted can be seen by figure 8, which shows the dramatic increase in the production of more concentrated phosphate materials compared to ordinary superphosphate since 1950.

In nitrogen production and use, the most important technological advances toward higher analysis came first in the development of ammonium nitrate suitable for fertilizer use. This involved improvements in production, such as resulted in the widely used prilling method, and in methods for conditioning the material so that it could be readily and safely handled in fertilizer channels. This gave an opportunity to increase the N content to 33.5 percent compared to ammonium sulfate at 20 percent or nitrate of soda at 16 percent.

The next important advance came with a succession of improvements in the technology of producing urea. These, over a period of years, have made the cost of urea competitive with that of ammonium nitrate and yielded another substantial increase in the nitrogen content compared to ammonium nitrate. Between 1955 and 1968, ammonium nitrate production in the United States increased by a factor of about 2.5, while ammonium sulfate showed only a modest gain due to increased byproduct production. Between 1957 and 1968, urea production gained by a factor of almost 5.0 (4).

Undoubtedly the greatest technological development influencing the increase in analysis of mixed fertilizers has been granulation. Until satisfactory means for granulating mixed fertilizers were developed, it was not possible to achieve high analysis because the materials needed are too hydroscopic to be used in nongranular fertilizers. The much higher surface area of nongranular forms exposes these materials to rapid absorption of water from the atmosphere, causing caking in storage and many problems in distribution. The effect of the practice of granulation on the grade of compound fertilizer can be seen from examples in the following tabulation.

	Grades before granulation	Grades after granulation
	3-12-12	6-24-24
	5-10-10	10-20-20
	8-8-8	15-15-15
Average concentration	25%	47%

The economic advantage of increasing analysis can be illustrated by data from an unpublished study made at TVA to evaluate prospects for urea - ammonium phosphate, a new material of exceptionally high analysis under development on a pilot-plant scale.

In comparing the costs involved in producing and distributing this material rather than lower analysis materials, the following distribution costs that are independent of the grade of the material were estimated.

	$/ton of material
Storage and preparation for shipment	1.50
Bagging	4.00
Transportation	13.00
Retail distribution	4.28
Total	22.78

A simple calculation shows that these costs will vary from about $76 per ton of plant food if the total nutrient content (N and P_2O_5) is 30 percent to $38 per ton of nutrients if the grade is 60 percent. This would leave considerable margin for an increase in production cost to achieve the higher grade. However, in this case the estimated production cost also decreased about $11 per ton of nutrients as the grade was increased.

It must be realized, however, that while as a general rule increasing the analysis of fertilizers decreases their delivered costs, there are exceptions to this rule. In Latin American countries exceptions may occur, for example, where the cost of capital may make production of triple superphosphate exceptionally high and the availability of byproduct sulfuric acid suitable in quantity or quality only for ordinary superphosphate may make it exceptionally cheap. Then the higher cost of distributing the ordinary superphosphate may be more than offset by the lower cost of producing this material. Likewise, the availability of low-cost imported ammonium sulfate in some locations tends to lower the optimum grade of finished fertilizers when all costs are considered. In any case, it is most important to consider the overall system of producing the fertilizers and distributing them in order to be able to select the optimum alternate. Care should be taken to make such evaluation over a sufficiently long time span to allow for variations that often occur in the availability and cost of byproduct materials.

One of the disadvantages of higher analysis fertilizer is that in the process of reducing the impurities that dilute the nitrogen, phosphorus and potassium compounds, other nutrients essential to plant growth may be reduced or eliminated. An obvious example is the elimination of the secondary nutrient, sulfur, when triple superphosphate is used in place of ordinary. In the same manner, addition of a number of the micronutrients[1] might be eliminated by the change to higher analysis

---

[1] The elements, B, Cl, Cu, Mn, Fe, Mo, and Zn, are considered micronutrients; Ca, Mg, and S are classified as secondary nutrients.

fertilizers. Unfortunately, the need for addition of these elements is not often well delineated, even where the agriculture is reasonably well developed. It should be recognized, also, that alternative ways of supplying secondary and micronutrients might be a better choice than relying on low-analysis materials.

In some areas where the grade of fertilizers used traditionally is low, farmers are slow to accept fertilizers of increased analysis and, for this reason, manufacturers are reluctant to produce them. However, the benefits of higher analysis usually are so great that it pays to make every effort to educate farmers to their use.

Import of Intermediates

Another question very basic in planning to provide the fertilizer needs of a country is how much emphasis should be placed on importation and how much should be placed on manufacturing in the country itself. Among the many important factors that affect the answer are the availability of indigenous raw materials, the amount of foreign exchange available, and the amount of technical talent that is on hand or can be developed.

In situations where factors do not favor the development of a basic fertilizer industry there may be another alternative that is more attractive than importing finished fertilizers. This alternative is the importing of intermediates that will be used to produce finished fertilizers within the country. It may be the way to utilize limited resources of money and technical manpower to make the earliest strides toward developing an independent fertilizer supply. It can avoid what may be a premature commitment to the use of marginal indigenous materials that would not support a fully developed industry. It can provide a country with a stepwise approach that will permit the development of both the financial and technical ability needed for a fully integrated industry.

During the past few years, advances in technology have made the prospects for world trade in fertilizer intermediates much more feasible. Development of the technology of very large, efficient plants for the production of ammonia, phosphoric acid, and other products, as discussed earlier, has lowered costs because of the economy of scale. Location of such plants near the source of raw materials and water transportation has greatly enhanced the possibilities for world trade in intermediates. Technical advances in shipping, mainly the development of larger vessels and more efficient systems for loading and unloading, have made a contribution. Also, constantly improving technology for the production of finished fertilizers opens, and will continue to open, new possibilities for use of intermediates within the receiving country.

Some of the possibilities for fertilizer intermediates of immediate importance or that may have future potential are:

1. Ammonia (83% N)
2. Phosphoric acid (ortho or super - 54 to 83% P_2O_5)
3. Nitrogen solutions (32 to 37% N)
4. Elemental phosphorus (equivalent to 229% P_2O_5)

5. Ammonium phosphates or polyphosphates (12-50-0 to 15-61-0)
6. Ammonium polyphosphate solutions or suspensions (13-34-0 to 14-47-0)

Ammonia

Liquid anhydrous ammonia is the only fertilizer intermediate that is thoroughly proven in international trade. After some early problems, large plants located at the source of low-cost gas produce ammonia at very low cost. Shipment in ocean vessels is well established and dependable. Innovations are being made in barge and pipeline transport which might help distribution within the importing country. Storage of large quantities of anhydrous ammonia is relatively inexpensive and presents no difficult technical problems. Ammonia is, of course, the primary building block of all nitrogen fertilizers.

The main technical disadvantage of importation rather than local production of ammonia is that carbon dioxide, a byproduct of ammonia production, is not available for the production of urea, a particularly useful product in many instances. While alternative sources of carbon dioxide are possible, they are usually too expensive to be attractive. Imported ammonia would be useful in producing nitric acid, ammonium nitrate, and nitrogen solutions for the production of compound fertilizers or for direct application. It also would be useful for ammoniating phosphoric acid or superphosphate in the production of compound fertilizers.

In a study made last year at TVA for the Agency for International Development, the economics of manufacturing versus importing ammonia were compared for several countries, including one South American country--Uruguay--and at several levels of production (5). The results, summarized in table 1, indicated that in all locations and at all levels, ammonia could be imported at a lower cost than it could be manufactured, although the difference was not great when the capacity was large. However, the study also showed that this situation changes somewhat when the relative value of foreign exchange is considered. If foreign exchange is valued at more than about 1.2 to 1.6 times the value of local currency, it becomes more attractive to produce rather than import ammonia when the needs are from 1,000 to 600 MT/year, respectively, under the conditions assumed in the study.

Nitrogen Solutions

Although there have been no such shipments, nonpressure or low-pressure aqueous solutions of ammonia in combination with urea or ammonium nitrate or both might hold possibilities for ocean shipment. While the nitrogen content (32 to 37%) is comparatively low, progress has been made with corrosion inhibitors that permits shipping in low-cost containers. Solutions of this type for years have been shipped widely throughout the United States for use in formulating both solid and liquid mixed fertilizers. They are more useful for this purpose than anhydrous ammonia where the nitrogen content of the finished product requires more nitrogen than can be fixed by reacting ammonia with the acid ingredients of the formulation.

Phosphoric Acid

Phosphoric acid is the starting point for all phosphate fertilizers except ordinary superphosphate and some types of nitric phosphate. It may be ammoniated alone to produce ammonium phosphate or used in combination with other fertilizer materials to yield a wide variety of compound fertilizers.

Since phosphoric acid is produced in several different concentrations and degrees of purity, possibilities for import are varied. However, the most economical and prevalent acid production is in the form of 54 percent (P_2O_5) merchant-grade, wet-process acid and this is the only concentration that has thus far found a place in ocean transport. Even this has been rather limited and it must be recognized that there are problems remaining to be solved before it becomes as routine and trouble-free as ocean transport of anhydrous ammonia. Foremost among these problems is the presence of solid impurities in the acid and the further precipitation of solids during shipment. These create a difficult problem of residue deposits in the vessels. They also increase the viscosity of the acid and to some extent limit the uses to which the acid can be put--for example, in liquid fertilizers. The other problem is the corrosiveness of the acid, but this can be solved, of course, by the proper selection of materials of construction.

The problems involved in transport of wet-process acid are reduced by purification of the acid by settling or other means, by selection of the rock used in the manufacture, or by calcination of the rock. All of these tend to increase the cost of the acid, and purification by settling leaves a low-grade sludge that must be utilized by some means. However, much progress was made in techniques for producing cleaner wet-process acid during the last decade to support a greatly expanded commerce in the acid within the U. S. and elsewhere, and progress no doubt will continue with the prospects of expanded overseas shipment. Also, more economical corrosion resisting systems for acid-carrying vessels will be developed as more experience is gained.

The development of wet-process superphosphoric acid (70 to 74% P_2O_5) holds some promise of advantage for ocean shipment of the acid, but none of the schemes for producing it for the world trade have yet materialized. This acid is made by further concentration of merchant-grade acid. Starting at about 63 percent concentration, some combined water is removed forming polyphosphates, mainly pyrophosphate. The polyphosphates tend to sequester the impurities in the acid, preventing precipitation. However, a disadvantage that tends to counteract this benefit is a sharp increase in viscosity of the acid. While the viscosity, like sludge formation, can be controlled somewhat by controlling the impurities in the acid, it probably would be high enough in any event to require heating of the acid to facilitate unloading a vessel at a reasonable rate. Super acid is less corrosive than ortho acid, but the difference probably is not great enough to give it an advantage in ocean shipment since the risk of using anything less than corrosion resistant materials would be too great.

The cost of clarification of 54 percent wet-process acid is about \$5 per metric ton of P_2O_5, and concentrating the clarified acid further to about 70 percent P_2O_5 adds at least another $7 per ton to the cost (6). Indications are that, with the possible exception of very long hauls, the cost of concentration would offset the shipping advantage gained by the higher concentration. While a considerable amount of wet-process super acid is shipped for long distances overland in the United States, it is used almost exclusively in liquid fertilizer production where the polyphosphate content is an advantage.

Phosphoric acid produced from electrothermally produced elemental phosphorus can be readily made either as ortho acid at a concentration of 76 percent P_2O_5 or as 80 to 83 percent P_2O_5 superphosphoric acid without additional cost. Acid produced in this manner has lower viscosity, does not form sludge, and generally would offer the best prospects for shipment were it not for its high cost of production. Presently, it is competitive with wet-process acid only in the super acid form for the production of high-analysis clear liquid fertilizer. It will not become competitive for general fertilizer use as long as sulfur prices remain as they are and wet-process acid is in such plentiful supply.

Elemental Phosphorus

Somewhat better prospects for electrothermally processed phosphate exist when the possibility of shipping elemental phosphorus as an intermediate for fertilizer production is considered. Equivalent to 229 percent P_2O_5, it is the most concentrated material available. One ton of phosphorus is equivalent to about 7 tons of rock or 5 tons of diammonium phosphate or triple superphosphate. Although there are some hazards in handling it, it has been shipped by rail and stored routinely for years. Recently, two vessels for ocean transport have been constructed to ship phosphorus for industrial use from a large new plant in Newfoundland. Plants to convert phosphorus to phosphoric acid are relatively inexpensive and the investment cost for producing fertilizers could be kept low.

The shipment of elemental phosphorus as an intermediate appeared to be a competitive alternative to manufacturing fertilizer-grade phosphates within the country or importing fertilizers in some circumstances several years ago (7). However, sharply decreasing sulfur prices and an oversupply of wet-process acid have changed this situation. As a result, it is probable that elemental phosphorus will not find a place of any significance in overseas shipment of fertilizers in the next 10 years. It may later, but many factors cloud this picture. Some of these are the uncertain direction of power costs as influenced by increasing fuel costs in contrast to promised cost-reducing improvement in the technology of nuclear generation, and the influence of pollution control on byproduct sulfuric acid supply and on the amount of phosphates used in detergent production.

Other Potential Intermediates

Technological advances during the past few years have resulted in several other materials that may warrant consideration as fertilizer intermediates for overseas shipment. Ammonium polyphosphate solutions or suspensions may have some potential. They are made by ammoniation of superphosphoric acid and are shipped and used extensively in the U. S. as an intermediate in the production of clear liquid and suspension fertilizers. Means of production from ordinary wet-process acid have been developed and will soon be in commercial practice. These materials are of moderate to high concentration (10-34-0 to 14-47-0), can be readily loaded and unloaded by pumps, and can be shipped and stored in mild steel, nonpressure vessels.

Another relatively new material that has more potential as a fertilizer intermediate is powdered monoammonium phosphate (MAP). Several plants for its production are under construction or in operation. With a grade of about 11-53-0, it contains nearly as much P_2O_5 as wet-process acid and likely could be shipped in overseas transport with greater convenience and less cost. Its production is somewhat simpler and therefore should be less costly than granular diammonium phosphate, the ammonium phosphate commonly found in world trade.

Powdered MAP is a versatile material, useful as a major component in the production of granular fertilizers. It can be co-granulated with urea and other commonly used materials to produce a variety of high-grade fertilizers.

The evaluation of the potential for intermediates is highly dependent on a large number of factors including price, shipping distances, import tariffs, the type of fertilizers needed, the quantities needed, and the indigenous materials available. These are so variable within an area such as Latin America that it is impossible to make generalizations. However, studies have been published that evaluate a wide range of alternatives, including import of intermediates, under specific conditions--some including those found in Latin America (5, 6, 7, 8). These should be useful as a guide to those who wish to make similar evaluations for their own conditions.

Process Routes

Over the last two decades, three distinct systems for providing the large variety of mixed fertilizer needed for the farmers have developed in the United States. These systems are quite different from each other in many respects and are more or less in competition with each other. The three systems are:

1. Co-granulation of intermediates in small plants to produce homogeneous granular fertilizer in the grades needed.
2. Production of blends of the various grades by mixing already granulated intermediates.
3. Supplying the needed grades in liquid form blended or manufactured largely from liquid intermediates.

The proponents of each of the three systems claim a distinct advantage, so it is not surprising that there is sometimes some confusion in trying to translate the U. S. experience to help plan developments in other countries.

Granulation

While granular fertilizers have been known and used for a long time, it was not until the early 1950's that granular fertilizers began to replace early pulverized forms in a large and irreversible way. Replacement of the pulverant products took place in a surprisingly short time. The first and probably the most important reason was the improvement granulation makes in the physical properties of fertilizers. It lessens or prevents caking in storage and it facilitates distribution in the field. The second important reason for growth was economic. It lowered the costs by allowing the use of cheaper ingredients and, as discussed earlier, by permitting the production of much higher grades than could be produced with satisfactory physical properties in pulverized form.

Earliest methods for making homogeneous granular fertilizers involved wetting the ingredients to cause them to granulate and then drying the granules to remove the added water. However, a much better method soon evolved in which the liquid phase required for granulation was produced during granulation by highly soluble salts dissolving in a limited amount of water at a high temperature. The heat required was generated by the reaction of ammonia with superphosphate (ordinary or triple) and, in some formulations, sulfuric or phosphoric acid. The chemical transformations and the crystallization on cooling made products that generally were much stronger than were made by the wet and dry method, and less drying usually was required. Furthermore, the raw materials for some formulations were less expensive because a larger portion of the nitrogen could be added as ammonia or ammoniating solutions containing ammonia, ammonium nitrate, and urea or some combination of these.

While several different adaptations of this granulation principle evolved, the most widely used one has been a process developed by TVA (9).

Sketch of a typical TVA-type granulation plant is shown in figure 9. The unique feature of the TVA process is the rotary drum ammoniator-granulator which serves as a mixer and a reactor and also provides a rolling action needed for the formation of granules and disengagement of water vapor. Other equipment in a typical TVA-type plant includes a rotary dryer, usually fired directly by gas or fuel oil; a rotary cooler; screens to separate and remove a product fraction of granules of the desired particle size; a crusher to reduce the size of overly large granules, and conveying equipment to return the undersized product to the ammoniator-granulator.

Phosphate raw materials for the process are ordinary superphosphate, sometimes produced at the site, and usually higher analysis intermediates--triple superphosphate, ammonium phosphates, or phosphoric acid. Nitrogen is supplied by ammonia, ammoniating solutions, and often some solid source--urea or ammonium sulfate. Potassium usually is supplied as the chloride. The ammonia and ammoniating solutions are fed through a perforated pipe under the moving bed of solids in the ammoniator. Acid may be sparged from above. Sometimes a reaction tank, referred to as a pre-neutralizer, is added to give more flexibility in formulation. It permits using more liquid ingredients and allows for more dissipation of heat of reaction than could be accommodated in the ammoniator-granulator.

Some commonly used formulations for the TVA continuous ammoniation process are shown in table 2. The formulation for a given grade may vary from plant to plant, depending largely on the cost of ingredients at each location. However, the formulation must provide the proper amount of moisture and heat of reaction for granulation and the free ammonia must not exceed the levels that can be fixed by reaction with the acids and superphosphate present. The amounts of ammonia that can ordinarily be reacted with the phosphate ingredients without excessive loss are as follows.

Material	Lbs. NH_3 per lb. P_2O_5
Ordinary superphosphate	0.30
Triple superphosphate	0.175
Phosphoric acid	0.36
Monoammonium phosphate	0.12

There have been 200 or more granulation plants using the TVA continuous ammoniator built in the United States. A typical plant would have a capacity of about 15 to 20 tons per hour. It would serve an area in a radius about 150 miles by producing perhaps 50,000 tons per year, operating only a part of the year.

Granulation is practiced in generally similar plants in many parts of the world. However, formulation must be different in countries such as the United Kingdom where it is desired that all of the P_2O_5 be in water-soluble form. Here it is necessary to limit the extent of ammoniation of superphosphate to neutralize only the small amount of free phosphoric acid contained therein. Further ammoniation would form water-insoluble dicalcium phosphate. In such cases, high-analysis grades may be made by co-granulating urea and superphosphate, and adding ammonia and phosphoric (or sulfuric) acid to supply heat of reaction for granulation. Steam or gas flames also might be used for additional heat. The products generally have good physical properties when well dried and coated with a small amount of clay.

Another approach to simplified granulation in the same type of equipment is through the use of a nongranular form of monoammonium phosphate (MAP) now available from several sources. The MAP may be used to upgrade formulations containing ordinary superphosphate or to replace it entirely. Steam or ammoniation or both may be used to supply heat for granulation. The MAP is produced by simple methods (10, 11, 12) at low cost and does not have the problems associated with shipping phosphoric acid.

Bulk Blending

In the late 1950's another system was developed that rivaled and in many areas replaced the small granulation plants. In this system granular intermediates are produced in large plants located near the source of raw materials rather than in the farm areas. These intermediates are then shipped in bulk to relatively small bulk blending plants dispersed throughout the farming areas. Here the materials are stored in bulk, usually for only a short period, and simply mixed together as needed to fill orders from individual farmers. While a small portion of bulk blended material is bagged for delivery, it is usually delivered in bulk. It may be taken to the farm in the blender's truck or in the farmer's truck. In more sophisticated systems it is delivered to the farm in a hopper that is left at the farm temporarily to make it convenient for the farmer to fill his distribution equipment. In many cases the blender may apply the blend on the field for the farmer. He may also take soil samples, have them analysed, and use the results to recommend a fertilization program for the farmer.

Because bulk blending plants are simple and inexpensive, they need not be large to be profitable. Most plants serve an area having a radius of only 25 to 30 miles and have outputs in the range of 2,000 to 5,000 tons per year. There are well over 3,000 such plants in the U. S. They may be owned by the basic manufacturer that supplies the intermediates or they may be independently owned. It has been estimated that they market about 40 percent of the granular fertilizer produced in the United States. In some local areas the proportion is much higher.

Nitrogen intermediates commonly used in bulk blending are ammonium nitrate, ammonium sulfate, urea, and ammonium phosphate nitrate. Phosphate materials are granular triple superphosphate, ordinary superphosphate, and diammonium phosphate. Nitric phosphate is sometimes used. The usual source of potassium is coarse or granular potassium chloride, although the sulfate sometimes is used. Secondary or micronutrients are added in some areas.

Plants vary in complexity. Some are very simple, providing crude mixing equipment and very little raw material storage. A design fairly typical of the better plants is shown in figure 10.

Incoming materials are unloaded into a conveyor and elevator for transport to several intermediate storage bins. From these they are recovered by a motorized shovel and fed to a weighing device. The materials are weighed batchwise and dropped into a rotary drum mixer. The mixer will handle a batch of 1 to 6 tons, depending on the size of the plant. After a short mixing period, usually not much more than 2 minutes, the batch is elevated to a temporary storage bin or delivered directly to a highway truck. When micronutrients are needed they may be added in granular form also, or preferably as a finely divided dust to coat the granules in the blend.

Simpler plant designs are possible by combining the functions of the elevators, for example. Many different types of mixers are available and are described in the literature (13).

Bulk blending has several advantages. It places most of the manufacturing process in large, efficient plants that can be operated throughout the year. It shortens the marketing channel by combining the functions of the mixer and the dealer. Shipping and handling costs are lowered for this reason and because the raw materials are shipped separately from their various sources to very near their point of use, rather than being detoured through a common manufacturing facility. The mixer-dealer, covering only a small area, is close to and therefore can be more readily responsive to the needs of his customers, the farmers. The flexibility of the system helps him meet these needs.

The most serious technical problem associated with bulk blending is the tendency for materials to become unmixed when they are handled. This segregation may cause wide variations in analysis from one part or sample of the batch to another. It may result in very poor crop response in some parts of the area fertilized by the batch and thus lead to customer dissatisfaction.

The primary cause of segregation in blends is mismatching of the particle size of the ingredients, rather than differences in the shape or density. Even the variations found in a relatively narrow size range such as 6- to 16-mesh can cause serious segregation unless additional precautions are taken. One precaution that must be taken is to avoid dropping either raw materials or finished product into conical piles because the larger particles tend to roll to the edge of such piles and fine particles accumulate in the center. Therefore, severe nonuniformity can result as the material is recovered from the edge of the pile. Some equipment used in spreading fertilizers also results in segregation on the field according to size. If the carriers of the individual nutrients are not of the same size, there obviously will be nonuniformity in distribution of nutrients. Liquid binders such as oil or water may be helpful in avoiding segregation of micronutrients when they are added in finely divided form

Chemical incompatibility also can be a problem. Urea and unammoniated superphosphate cannot be used in the same blend because the urea extracts water of hydration from the superphosphate, causing the mixture to become wet and sticky. Mixing ammonium nitrate and urea in the same blend would cause it to be so hydroscopic that the blend would be unmanageable. Ammonium phosphate and triple superphosphate can be used only if they are well granulated and dry and the blend is not to be stored.

Liquid Mixed Fertilizers

It has been said that the most logical solution to the problems of granulation (and bulk blending) is found in liquid fertilizers. While this may be an overstatement, the truth it contains accounts at least in part for the rapid rise in popularity of liquid mixed fertilizers in the U. S. Consumption has grown phenomenally over a short period. While good statistics are not available, it is estimated that use was 1.0 milli tons in 1965, 1.6 million in 1966, and 2.5 million in 1967 (14). This quantity in 1967 accounted for about 12 percent of all mixed fertilizers consumed.

The main advantage of liquid fertilizer that has been responsible for this growth is its convenience. It can be handled by pumps and hoses with a minimum of labor. This is an important advantage in the U. S. where farm labor is scarce and expensive. Liquids are not affected by high humidity that sometimes causes problems in storage and application of solid fertilizers.

For the producer, liquid fertilizer has the advantage that it can be made by simpler processes carried out in lower cost equipment. Control of composition and segregation is not a problem as long as the limits of solubility are not exceeded.

The main disadvantage of liquid fertilizer is low analysis compared to solid fertilizers, especially in mixed fertilizers that contain potash. Another disadvantage is that distribution equipment for liquids is not as widely available among farmers as for solids and it tends to be somewhat more complex.

Formulation of liquid mixed fertilizers almost always starts with ammonium phosphate solutions, either purchased by the formulator or manufactured by him during the mixing process from phosphoric acid and ammonia. If he uses an already prepared base solution, his operation is simply one of blending and his plant is known as a "cold mix" plant. If he uses acid and ammonia he operates a "hot mix" plant and he carries out a chemical operation. A sketch of a cold mix plant is hown in figure 11. The main difference between this and a hot mix plant is that the hot mix plant would need storage for acid and a cooling system to remove the heat of neutralization of the acid.

Phosphate solutions used in the preparation of liquid fertilizers usually contain polyphosphate rather than orthophosphate because the former results in greater solubility (hence higher analysis) and has the ability to sequester a certain amount of impurities that would otherwise precipitate and cause handling problems. A base solution having an analysis of 10-34-0 made with wet-process superphosphoric acid or 11-37-0 made with thermal (electric furnace) superphosphoric acid is used by cold mix plants. Solid ammonium polyphosphate (15-62-0) may be used rather than a base solution. It is available from TVA experimentally, but is not yet available from commercial sources.

Hot mix plants usually use superphosphoric acid rather than the ortho form in order to obtain the benefits of polyphosphate in the product. However, the technology is advancing to the point that soon the polyphosphate will be formed directly by the reaction of ortho acid with ammonia.

The usual nitrogen materials for liquid mixed fertilizers are urea - ammonium nitrate (UAN) solutions containing 28 to 32 percent N. Solid urea is sometimes used but it is more expensive. The UAN solutions give greater solubility than solutions that contain only ammonium nitrate. Potash is almost always added as a solid in a refined form that contains 62 to 63 percent K_2O.

The disadvantage of low grade can be overcome somewhat by exceeding solubility limits and making fluid fertilizers in the form of a suspension of solids rather than clear liquid. If this is done in a properly controlled manner, the solids are in the form of finely divided crystals which can be held in suspension for long periods by the addition of a small amount (1 to 3%) of a gelling-type clay. Popular grades of suspension fertilizers in the U. S. are 7-21-21, 3-10-30, 10-20-20, and 15-15-15. These are close to the maximum produced in granular fertilizers and are about twice as high as can be made in clear liquid form. They are made in the same types of plants as clear liquids. The base suspension for use in cold mix plants has a grade of 12-40-0.

Unfortunately, some of the advantage of liquid fertilizer is lost in substituting suspensions for clear liquids. Storage, handling, and application become more difficult and for that reason suspensions have not gained wide popularity. However, they have an added advantage of being suitable carriers for micronutrients and pesticides in amounts in excess of those that could be dissolved in clear liquids. This advantage, plus their high analysis, gives considerable incentive for continued work with suspensions to overcome some of their shortcomings.

Like bulk blends, liquid fertilizers are usually made in small plants producing, on the average, about 2,000 to 3,000 tons per year. Being small, they serve an area of a relatively small radius. The proprietors often offer custom mixing and custom application to their customers, and perform other services such as soil sampling and testing. Sometimes one hot mix plant will make base solutions for a number of very simple cold mix satellite plants owned by the same company.

The choice among the three routes to mixed fertilizers discussed above can be made only after careful study of the situation in the country involved, and no clear-cut generalizations can be made. Liquid fertilizers probably would not be well suited in many situations where farms are small and labor is cheap. The specialized equipment for handling and distributing liquids would not be widely available and would be difficult to maintain in some countries. The success of both liquid fertilizer production and bulk blending of solids depends heavily on a good transportation system that can be depended upon to supply the materials needed during the busy fertilizer season. Facilities for transporting liquids may present the greatest problem. Successful bulk blending is highly dependent on a source of materials that are well matched with respect to particle size. If the materials all come through a single port, some of the advantage of bulk blending is lost and it may be better to co-granulate them at the port rather than shipping them separately for blending in the field and risking problems of segregation. In considering which alternative is the most advantageous, it is most important to include the whole system, from procurement of raw material down to the final marketing and transport of the product to the farmer.

The Case for Nitric Phosphate

A large number of processes that use nitric acid rather than phosphoric or sulfuric as the primary acidulating agent for phosphate rock have been developed during the past 30 years. The products are known as nitric phosphates (or nitrophosphates). They make up a major part of fertilizer production in Europe but have not been widely used in the Western Hemisphere.

The potential advantage of nitric phosphate production is that the need for sulfur is eliminated or reduced. The nitric acid serves two purposes. It solubilizes the phosphate and provides part of the nitrogen content of that fertilizer. The potential disadvantages of nitric phosphate production are low water solubility of the P_2O_5 in products made by some processes, the problem of dealing with the hydroscopic calcium nitrate formed, and the limited range of ratio of N to P_2O_5 in the product (usually about 1:2 to 2:1). The nitric phosphate process itself is complex compared to some alternatives, but in cases where it replaces a sulfuric acid plant and a phosphoric acid plant, the overall system may be less complex. In most nitric phosphate processes, dissolution of the phosphate rock takes place in a slurry-type operation in accordance with the following reaction:

$$Ca_{10}F_2(PO_4)_6 + 20HNO_3 \dashrightarrow 6H_3PO_4 + 10Ca(NO_3)_2 + 2HF \qquad (1)$$

If the solution obtained is simply ammoniated, the following reaction occurs:

$$6H_3PO_4 + 10Ca(NO_3)_2 + 2HF + 4NH_3 \dashrightarrow 6CaHPO_4 +$$
$$14NH_4NO_3 + 3Ca(NO_3)_2 + CaF_2 \qquad (2)$$

This reaction produces insoluble dicalcium phosphate and hygroscopic calcium nitrate. There are many process variations designed to modify this reaction or cope with the problems it imposes. They may be divided into three main types.

Calcium nitrate removal: A portion of the calcium nitrate may be removed before ammoniation by cooling, crystallization, and centrifuging. This approach is generally known as the Odda process (15). The calcium nitrate may be prilled and sold as a byproduct (15% N) or converted to ammonium nitrate by treatment with CO_2 to precipitate calcium carbonate. The remaining solution is ammoniated and granulated or prilled to produce fertilizers containing ammonium nitrate, dicalcium phosphate, and ammonium phosphate. The ratio of ammonium to dicalcium phosphate depends on the proportion of calcium that was removed as nitrate and determines the water solubility of the P_2O_5 in the product. Commercial products range between 25 and 60 percent water solubility, although 80 percent is feasible. Typical product grades are 20-20-0, 13-13-21, and 15-15-15; or with more complete calcium nitrate removal, 23-23-0 and 18-36-0.

Sulfate salt addition: Other modifications cope with the excess calcium through the addition of soluble sulfate salt to precipitate calci sulfate. The addition may be made before or during ammoniation of the extraction slurry. The calcium sulfate may be left in the product but this results in low-analysis grades such as 14-14-0 or 17-13-0. Alternatively, it may be removed by filtration, producing a grade such as 25-15- with nearly complete water solubility of the P_2O_5 (16). Several differe sulfate salts have been used in this type of process but the one most likely to be attractive is ammonium sulfate, since it is a widely available byproduct.

Still another adaptation of this basic approach is the sulfate recycle process (17). In it the calcium sulfate is reacted with ammonia and carbon dioxide to regenerate ammonium sulfate and precipitate calcium carbonate, which is removed as a byproduct or waste.

Mixed acid process: The third basic type of nitric phosphate process is one in which either phosphoric or sulfuric acid is added to the extraction step to react with enough of the calcium to prevent the presence of calcium nitrate in the product. When phosphoric acid is added in sufficient quantity the ammoniation reaction yields ammonium phosphate, and a part of the P_2O_5 in the product is water soluble. The usual practice is to formulate to give 40 to 50 percent water solubility.

The mixed acid process is the only one used in the Western Hemisphere, and there are several of this type in Europe. There are several different designs used but the main variations are the P.E.C. process (18) which in the latest version uses a special granulator-dryer to convert the ammoniated extract to solid form, and the TVA process (19) which uses a rotary drum for the final stage of ammoniation and for granulation. A flowsheet of the TVA mixed acid process is shown in figure 12.

The mixed acid process has the advantage of greater flexibility in the $N:P_2O_5$ ratio than the other processes. Grades such as 26-13-0 and 20-20-0 can be made without the need for producing a nitrogenous co-product.

The phosphonitric process usually is preferred because of the higher grade it produces. However, some of the advantage of nitric phosphate is lost because in effect only part of the P_2O_5 in the finished product is solubilized by nitric acid.

Despite the low price of sulfur there are undoubtedly places in Latin America where the nitric phosphate processes warrant serious consideration in the planning of fertilizer projects. Cost estimates based on somewhat higher sulfur prices than prevail today show an economic advantage for both the mixed acid and the calcium removal processes over processes based entirely on phosphoric acid (20). The Odda process is advantageous even when very low sulfur price is assumed. The sulfate addition process may have good economics where byproduct ammonium sulfate is available.

In evaluating the prospects for nitric phosphate compared to ammonium phosphate based fertilizers, the evaluation should include transportation of the products to the point of use since the analyses of nitric phosphates are generally lower. Also, it should be kept in mind that a part of the nitrogen is in nitrate form which is not desirable for some crops, particularly rice.

New Fertilizers Under Development

As in most industries that are relatively new, there is a constant flow of innovations and new technology generated throughout the world in the fertilizer industry. The question often arises whether a country that is in the early stages of developing its capability for fertilizer production should adopt the very latest, perhaps not fully proven, technology in order to be completely up to date, or whether it is better to choose only well proven products and processes and suffer the penalty of starting with a somewhat old fashioned industry.

While this is partly a matter of philosophy, in general the latter course probably is the most prudent unless the country has an exceptionally large pool of technical skills. The problems involved in building and starting new plants are difficult at best; they are compounded if a strong supporting service industry, and [illegible] technical assistance are not available. They should not be compounded further by having an element of experimentation in the project. The penalties for not achieving expected operating levels promptly and having to make extensive changes are too great.

However, it is important for those in the planning function to know what new technology is emerging so they may become prepared to take advantage of it at the proper time. Some of the new products that appear to have potential for the near future are discussed below.

<u>Ammonium Polyphosphate</u>

The term "polyphosphate" is used to describe materials that contain phosphates in a more condensed form than the orthophosphate found in conventional fertilizers. They are formed when sufficient water is removed from orthophosphate to cause linking of molecules into longer chain compounds having more than one atom of phosphorus. Compounds containing many atoms may be formed in this manner, but the shorter chain compounds such as pyro- and tripolyphosphate with two and three atoms are of more practical interest.

Ammonium polyphosphate fertilizer may be made by ammoniating superphosphoric acid, or directly from orthophosphoric acid by a process that utilizes the heat of neutralization of the acid with ammonia to drive off water. The resulting melt is then granulated. When made with thermal phosphoric acid, the grade is 15-62-0. When made with wet-process acid, the grade is somewhat lower depending on the amount of impurities in the acid.

There has been no commercial production of granular ammonium polypho phate as yet, but TVA produces 15-62-0 for experimental use from thermal acid in a demonstration plant. It is expected that commercial production from wet-process acid will be realized soon.

As mentioned earlier, polyphosphate has a special use in formulating higher analysis liquid fertilizers. It also may be used for direct appli cation to the soil and in bulk blends where high analysis and good physic properties make it attractive.

The agronomic properties of polyphosphates have not yet been well defined, and there is much to be learned about their reaction in the soi Agronomic studies in the United States indicate that ammonium polyphosph usually is equal or superior to monoammonium phosphates. Experiments in France indicated liquid polyphosphates to be superior to other phosphate Field studies in Japan showed greater response to ammonium polyphosphate than to ammonium orthophosphate. There was some suggestion that better utilization of micronutrients may have been a factor.

Reaction products of the polyphosphate in the soil are different fr those of orthophosphates. There is some indication that formation of insoluble precipitates may be inhibited and that polyphosphates may be able to extract insoluble micronutrients from the soil, possibly by forming soluble metal complexes.

These possibilities, plus the high analysis and versatility of ammonium polyphosphate make it an interesting prospect for the not too distant future.

Urea - Ammonium Phosphates

The production of a series of compound fertilizers containing urea and ammonium ortho- or polyphosphate has been developed on a pilot-plant scale by TVA. They are interesting because of their high analysis--approximately 10 percentage points higher than can be made with ammonium nitrate rather than urea. They not only are excellent general purpose fertilizers, but also have properties particularly well suited for rice fertilization.

Several processes have been studied for the production of urea - ammonium phosphate. The preferred process appears to be co-granulation of nearly anhydrous melts of urea and ammonium phosphates using a pug mill. Granular products having satisfactory storage and handling properties were produced in this manner without drying. Typical grades are 28-28-0, 34-17-0, and 19-19-19.

Extensive field tests throughout the world have shown the agronomic value of urea - ammonium phosphate.

Controlled Release Fertilizer

Fertilizers that release their nutrients slowly throughout the growing season or over several seasons would have many advantages. They would increase efficiency of uptake, avoiding luxury consumption by the plants. They would minimize losses by leaching, which might be particularly advantageous in high-rainfall tropical regions, and by decomposition or fixation. They would prevent damage to seedlings and burning of leaves. They would reduce application cost by reducing the number of applications necessary.

Nitrogen fertilization appears to have the most potential for benefit from slow release. Several such nitrogen compounds have been marketed, but none are economical for general agricultural use.

A process developed on a pilot-plant scale by TVA for coating granules to control their solubility seems to have promise of being economical enough to produce material for farm use. In the process, granules of urea are sprayed with molten sulfur in a rotating drum to form a coating of 10 to 25 percent sulfur, depending on the rate of release desired. This is followed by a 3 percent coat of wax to seal the sulfur coating. A small amount of coal tar is added to the wax as a microbicide. Finally, about 1.5 percent of a conditioner such as calcined fuller's earth is added to improve handling.

By varying the amount of coating or by blending the product with uncoated urea, it is possible to produce a wide range of release rates. The rate might be varied from rather quick release such as would be required for corn, for example, to slow release over several years for forest fertilization.

It is estimated that the cost of sulfur-coated urea will be 25 to 50 percent higher per unit of nitrogen than uncoated urea. Hopefully, continued tests will show that this much added cost can be justified by the added benefits for many crops.

In the past decade or so, the advance of technology has brought many new fertilizers to the front at a surprisingly fast rate. A little more than twenty years ago ammonium nitrate was not yet established as a fertilizer, few dreamed that urea would ever be economical enough to find a place in agriculture, diammonium phosphate was barely known, and the most popular phosphate fertilizer contained only 20 percent P_2O_5.

The pace of technology has not diminished, so it is certain that the next decade or two will bring their share of changes. The limit in analysis of fertilizers has by no means been reached. Laboratory and greenhouse tests are being made with compounds that contain twice as much plant food as the highest analysis fertilizers used today. There is much room for improvement in the very limited efficiency of recovery of nutrients by plants that can be realized with today's fertilizers. New compounds that are more readily available to plants or less readily fixed in unavailable form by soil reactions are being sought and will be found. The production of elemental phosphorus is in about the same technological stage as ammonia production was 25 years ago. Possible breakthroughs in the production of elemental phosphorus are under study and could make it more competitive with wet-process acid, broadening the base for the production of new and better fertilizers.

Whatever the fertilizers of tomorrow are, it is certain that they will be better, more convenient, and more economical than those used today. It is hoped that the whole world will be in a position to take advantage of their use.

REFERENCES

1. Guthrie, K. M., "Capital and Operating Costs for 54 Chemical Processes," *Chemical Engineering*, June 15, 1970.
2. *Fertilizer Manual*, U. N. Document ST/CID/15, United Nations Industrial Development Organization, New York 1967.
3. Slack, A. V., *Fertilizer Developments and Trends 1968*, Noyes Development Corp., Park Ridge, New Jersey.
4. Harre, E. A., *Fertilizer Trends 1969*, Tennessee Valley Authority, Muscle Shoals, Alabama.
5. Patterson, G. G., Metcalfe, J. K., and Douglas, J. R., *Economic Comparison of Overseas Manufacture and Importation of Anhydrous Ammonia*, Tennessee Valley Authority, Muscle Shoals, Alabama.
6. Waitzman, D. A., Spencer, N. L., and Tschantre, M. A., *Economic Evaluation of Overseas Shipment of Phosphoric Acid for Fertilizer Production*. Tennessee Valley Authority, Muscle Shoals, Alabama.
7. Scott, W. C., Patterson, G. G., Gahan, J. R., and Hignett, T. P., *Economic and Technical Evaluation of Overseas Shipment and Utilization of Elemental Phosphorus for Fertilizer Production*, Tennessee Valley Authority, Muscle Shoals, Alabama.
8. Hicks, G. C., Young, R. D., Stumpe, J. J., Norton, M. M., and Richards, M. J., *Technical and Economic Evaluation of Fertilizer Intermediates for Developing Countries*, Tennessee Valley Authority, Muscle Shoals, Alabama.
9. Hignett, T. P., "Granulation of Fertilizers," *Farm Chemicals*, January, February, March, and April, 1963.
10. Brownlie, I. A., *Proceedings 14th Fertilizer Industry Round Table*, Washington, D. C., 1964.
11. Hensley, J. D. C., *Proceedings 16th Fertilizer Industry Round Table*, Washington, D. C., 1966.
12. Kearns, T. C., U. S. Patent 3,419,378, December 31, 1968.
13. Hignett, T. P., "Bulk Blending of Fertilizers: Practices and Problems," Proceedings No. 87, The Fertilizer Society, London.
14. Hignett, T. P., "Liquid Mixed Fertilizers: Technology and Economics," presented at Technical Conference of ISMA, Brussels, September 1968.

15. Banthein, H. J., Proceedings 15th Fertilizer Industry Round Table, Washington, D. C., 1965.

16. Piepers, R. J., Proceedings 16th Fertilizer Industry Round Table, Washington, D. C., 1966.

17. Meline, R. S., Faucett, H. L., Davis, C. H., and Shirley, A. R., Jr., "Pilot-Plant Development of the Sulfate Recycle Nitric Phosphate Process," presented at 158th National Meeting of American Chemical Society, September 1969; New York.

18. Norden, R. B., "Process Trend: Nitric Acid Acidulation Frees P_2O_5," Chemical Engineering, October 1956.

19. Davis, C. H., Meline, R. S., and Graham, H. G., Jr., "TVA Mixed Acid Nitric Phosphate Process," Chemical Engineering Progress, May 1968.

20. Black, A. V., Blouin, G. M., and Livingston, O. W., "It's Time to Consider Nitric Phosphates," Farm Chemicals, April, May, June, and July 1967.

Table 1. Estimated Costs of Manufacturing and Importing Anhydrous Ammonia

	Manufacture			Import		
		\$/mt			\$/mt	
Location and tonnage	Capital,[a] million dollars	NH_3	Foreign exchange[b]	Capital[a] million dollars	NH_3	Foreign exchange[b]
INDIA						
330,000 mt/yr (1,000 mt/day)	29.81	48.87	16.47[c]	4.1	43.73	40.54
SOUTH VIETNAM						
198,000 mt/yr (600 mt/day)	20.23	53.05	24.62[d]	3.38	49.97	45.90
URUGUAY						
49,500 mt/yr (150 mt/day)	9.65	90.69	31.07[d]	1.47	52.88	45.56

[a] Including working capital.

[b] Capital and operating requirements; 15-year plant life.

[c] Assuming use of domestic naphtha; if imported naphtha were used, this figure would be \$22.54/mt NH_3.

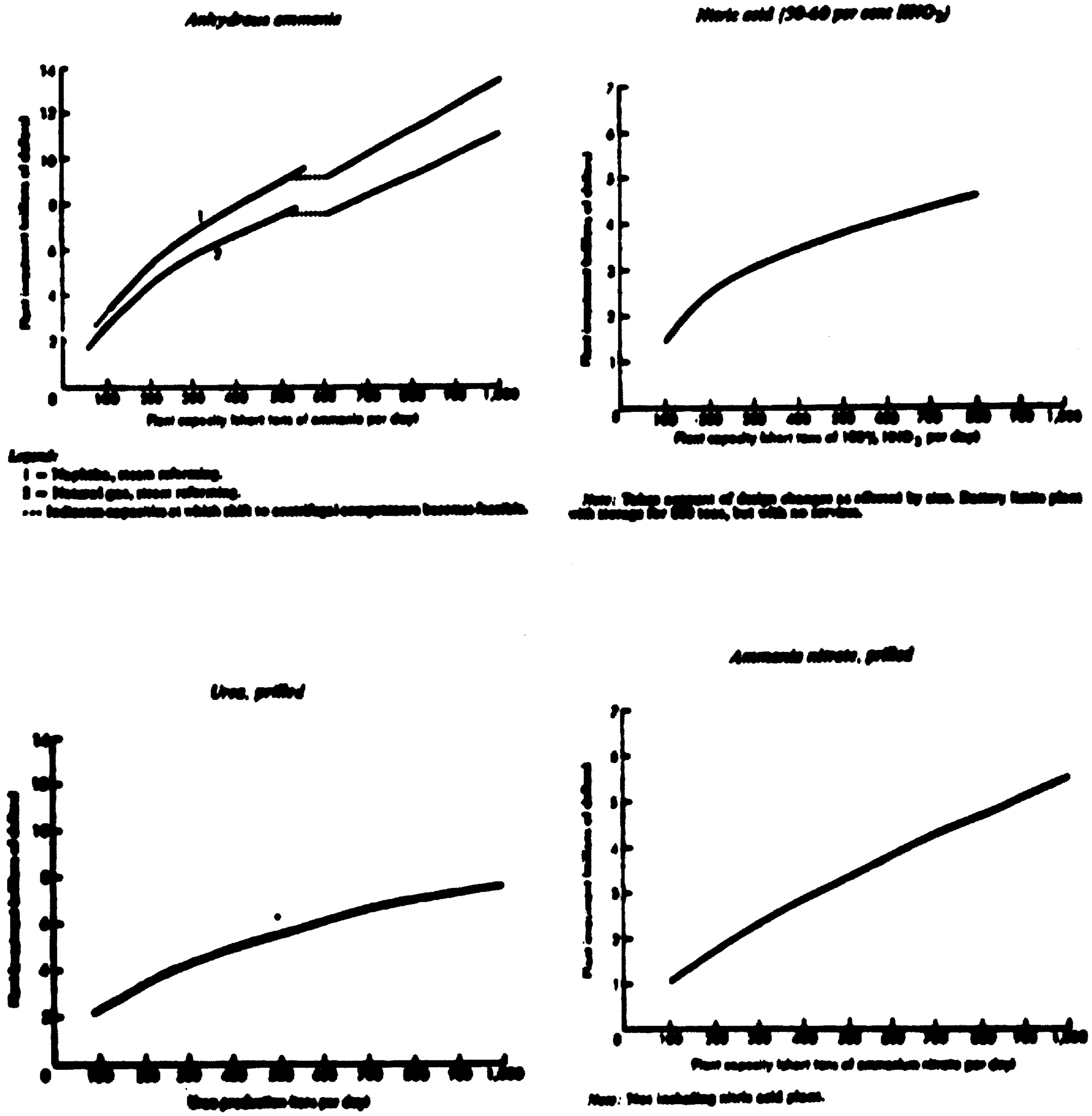
[d] Assuming use of imported naphtha.

Table 2. Some Typical Formulations for the TVA Continuous Ammoniation-Granulation Process

	Lbs. per ton of product					
Grade:	6-12-12	5-20-20	16-8-8	12-12-12	13-13-13	15-15-15[b]
Ammoniating Solution 448[a]	272	-	346	363	352	690
Anhydrous Ammonia	-	125	-	-	-	-
Ordinary Superphosphate	1285	293	96	312	465	350
Triple Superphosphate	-	761	335	394	-	-
Potassium Chloride	400	667	270	400	433	500
Ammonium Sulfate	-	-	821	362	536	-
Sulfuric Acid (93%)	-	140	157	135	-	127
Phosphoric Acid (54%)	-	-	-	-	315	431
Filler	145	-	-	-	-	-

[a] Contains 25% ammonia, 69% ammonium nitrate, 6% water.

[b] Requires preneutralizer tank and scrubber to recover ammonia.

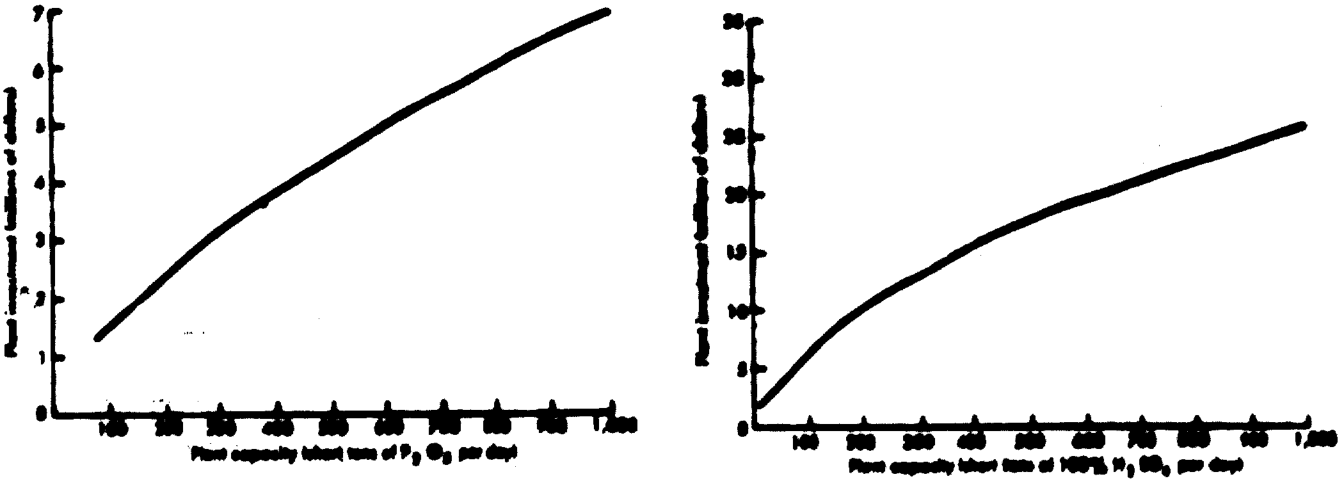


Legend:
1 = Naphtha, steam reforming.
2 = Natural gas, steam reforming.
--- Indicates capacities at which shift to centrifugal compressors becomes feasible.

Note: Takes account of design changes as allowed by size. Battery limits plant with storage for 500 tons, but with no services.

Note: Not including nitric acid plant.

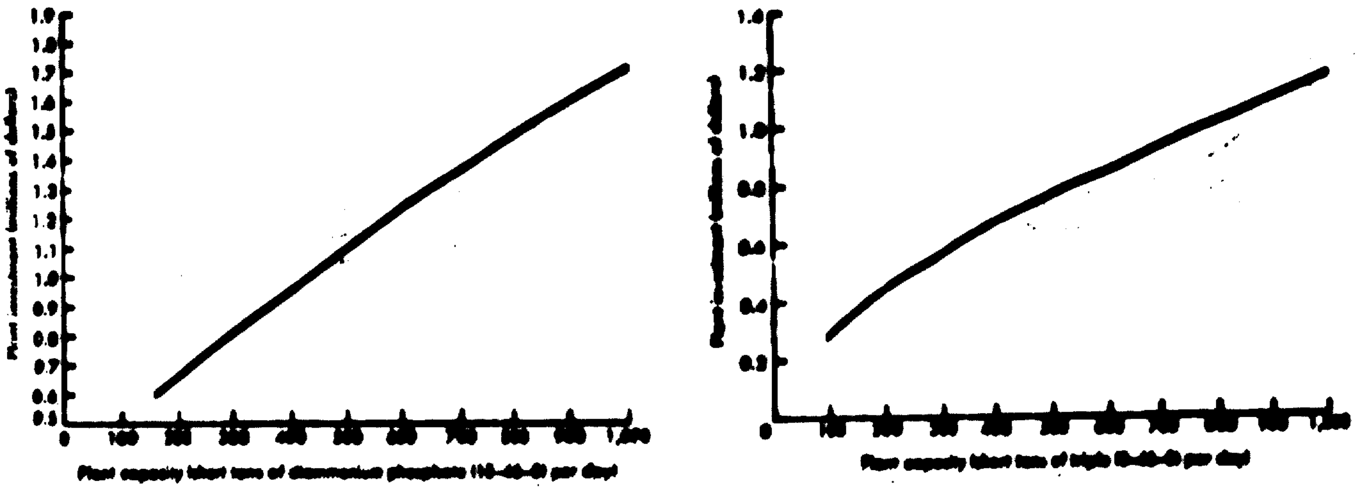
Figure 1. Effect of Plant Capacity on Investment Cost for Various Nitrogen Fertilizer Processes



Wet-process phosphoric acid (54 per cent P_2O_5)

Sulphuric acid

Note: Including rock storage, handling and grinding; and acid clarification and two weeks' storage. Excluding sulphuric acid plant and gypsum disposal.



Diammonium phosphate (18-46-0)

Triple superphosphate (0-46-0)

Note: Excluding phosphoric acid or ammonia production units. Including storage for thirty days' production.

Note: Including storage for one month's production. Excluding rock-grinding capacity, for which allowance is made in costs for phosphoric acid plant.

Figure 2. Effect of Plant Capacity on Investment Cost for Various Processes Related to Phosphates

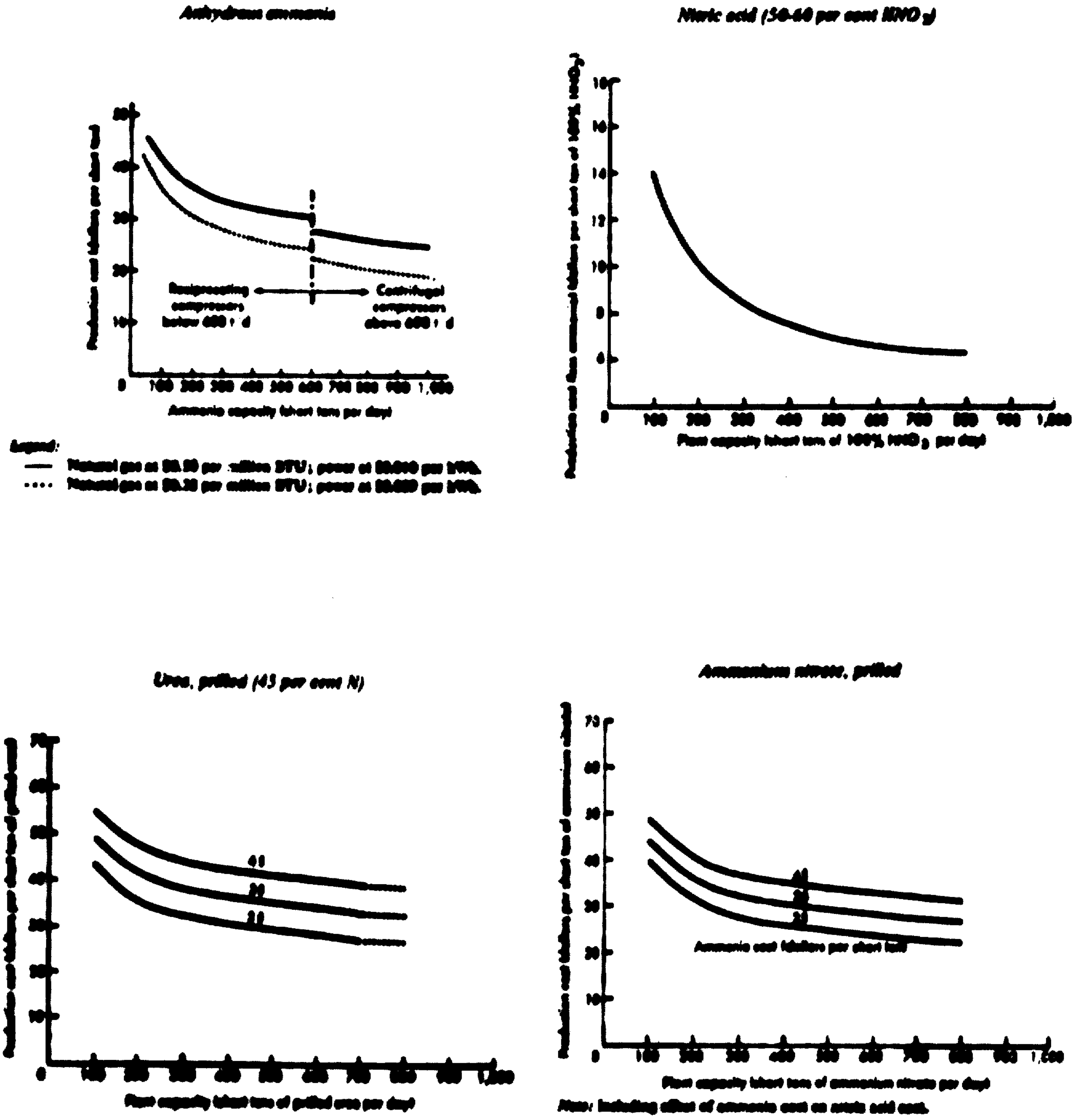
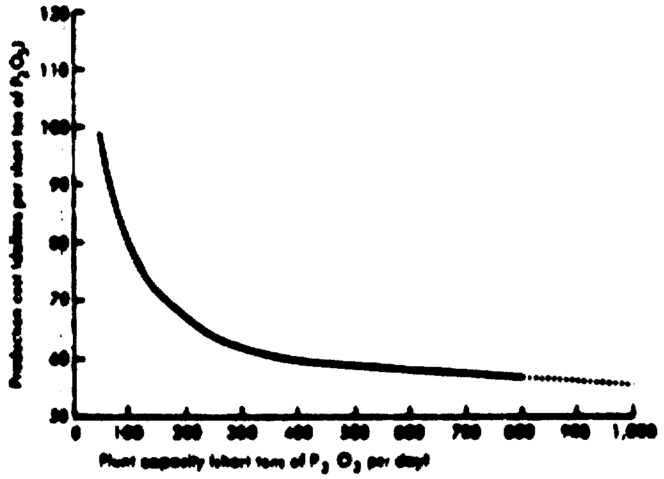


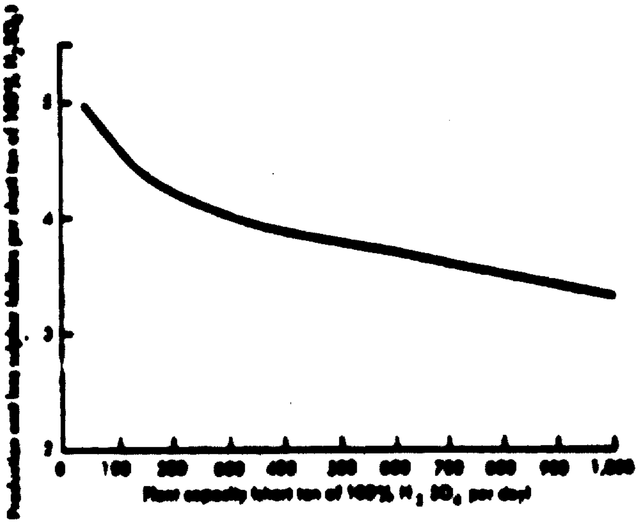
Figure 3. Effect of Plant Capacity on Operating Costs—Nitrogen Processes

Wet-process phosphoric acid (54 per cent P_2O_5)

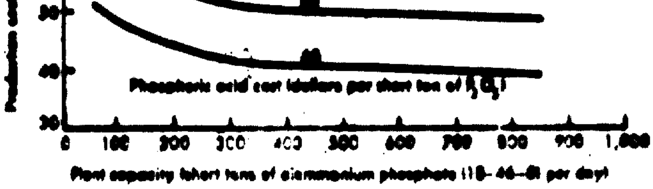


Basis: 66 bpl phosphate rock, $6.00 per short ton; 100 per cent H_2SO_4, $11.00 per short ton.

Sulphuric acid

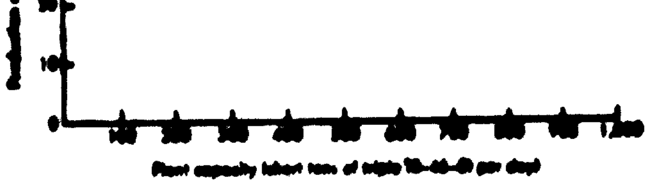


Diammonium phosphate (18-46-0)



Note: Assume an ammonia cost of $35 per short ton.

Triple superphosphate (0-46-0)



Basis: 75 bpl phosphate rock at $8.10 per short ton; phosphoric acid at $66 per ton P_2O_5.

Figure 4. Effect of Plant Capacity on Operating Costs—Phosphate Related Processes

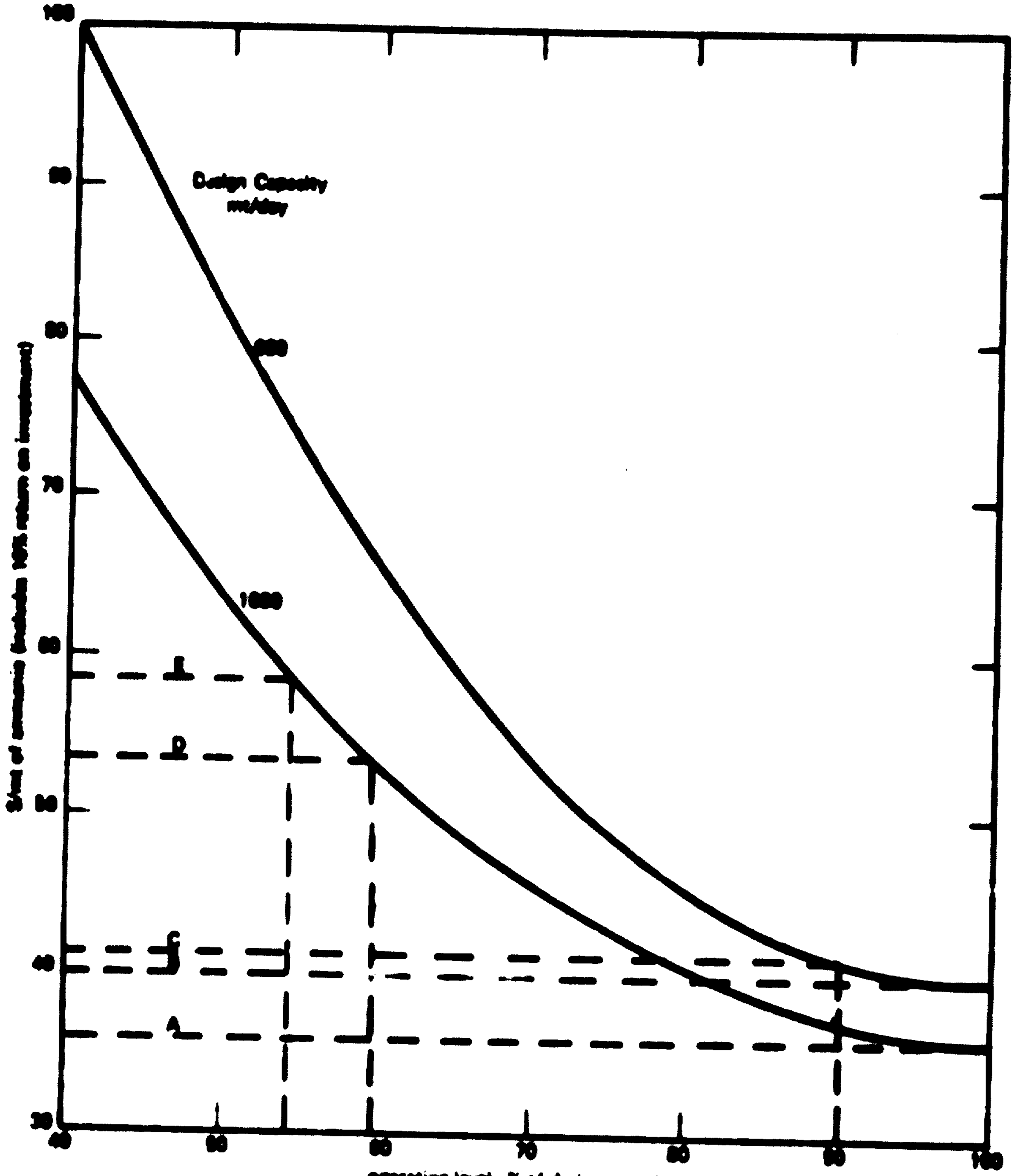


Fig. 5. Effect of Operating Level on Cost of Producing Ammonia
(Natural Gas @ $0.10/1000 ft³)

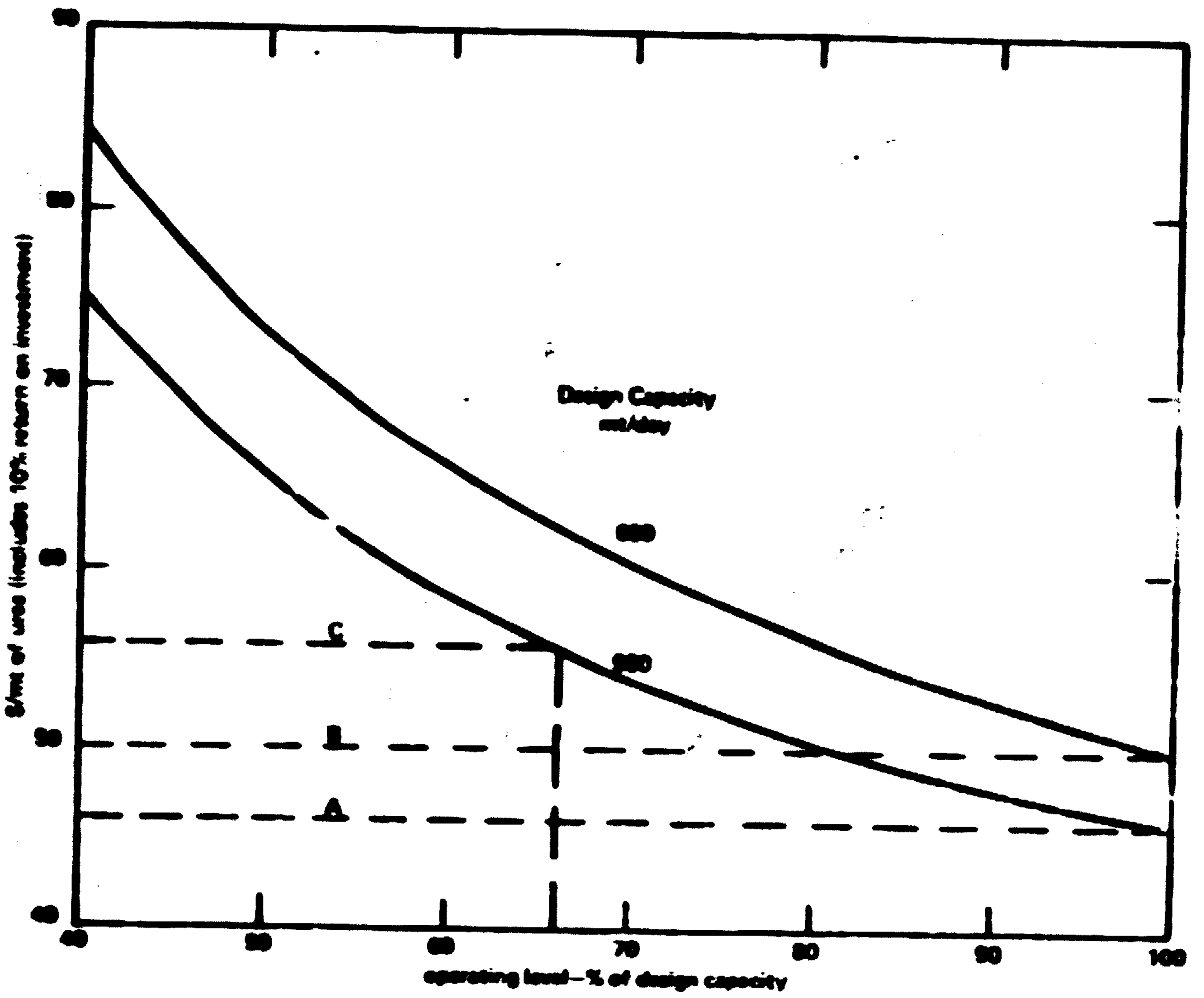


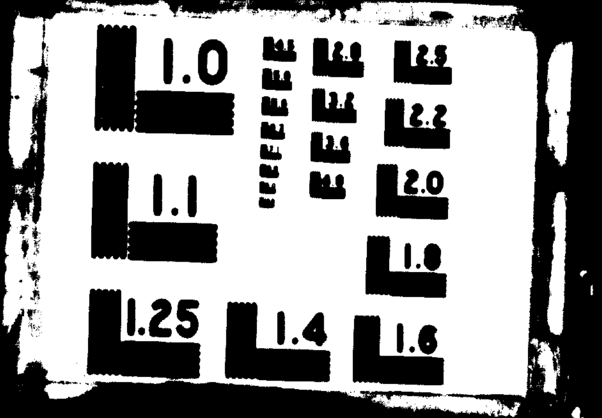
Fig. 6. Effects of Operating Level on Cost of Producing Urea
(Ammonia @ $32.50/mt)

→

74.10.14

2 OF 2

01434



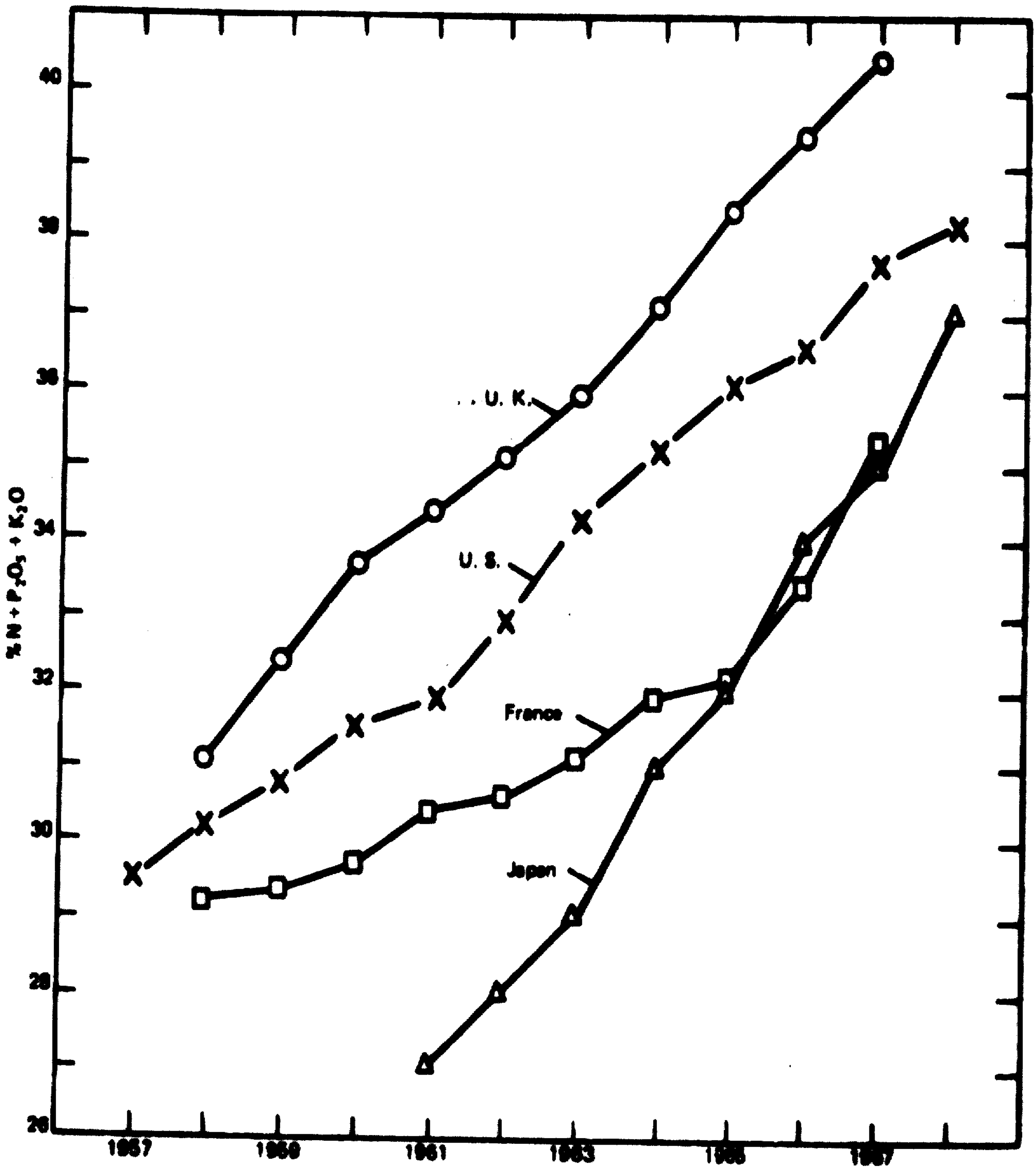


Fig. 7. Trends in Concentration of Compound Fertilizers

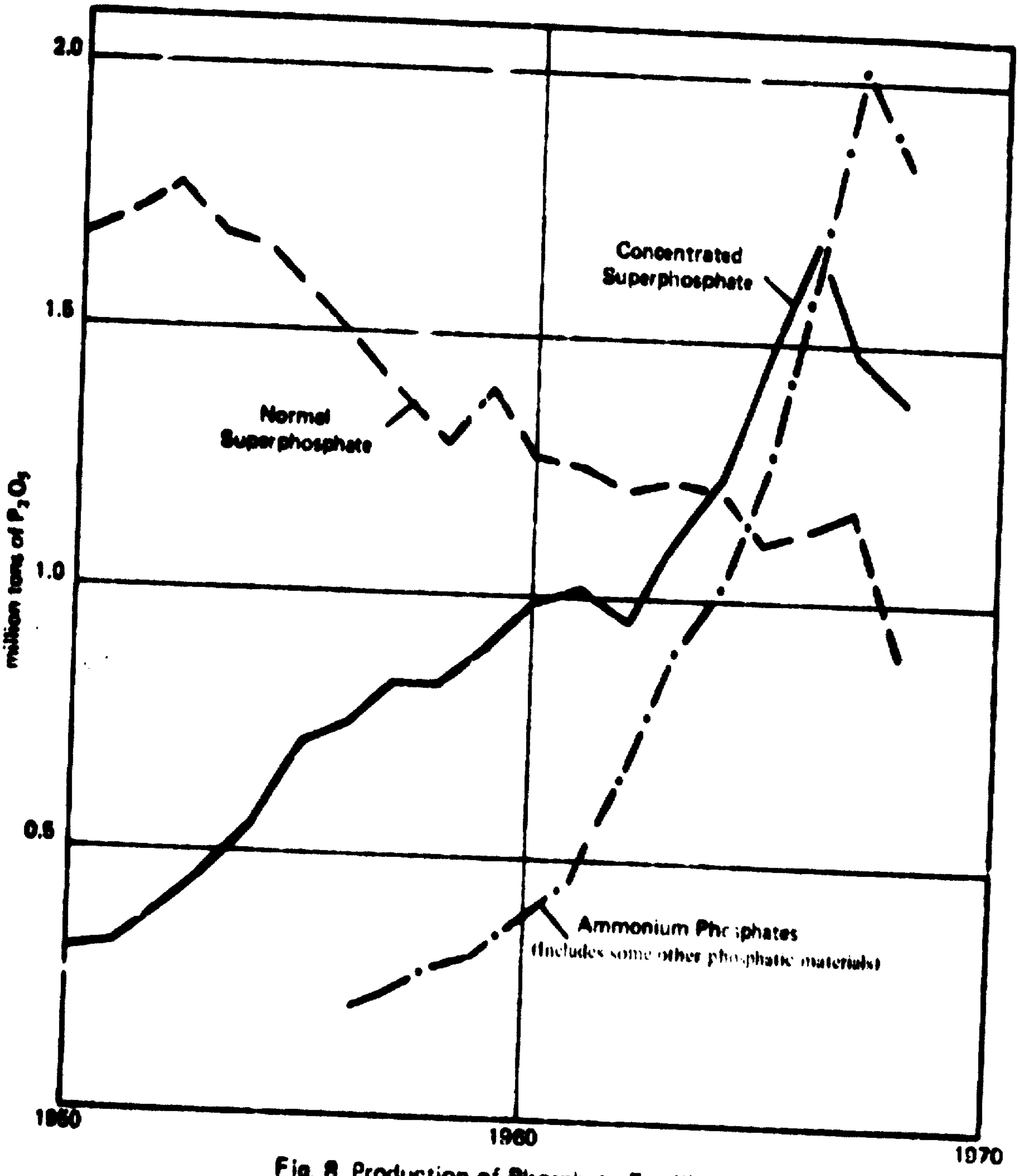


Fig. 8. Production of Phosphate Fertilizers
United States

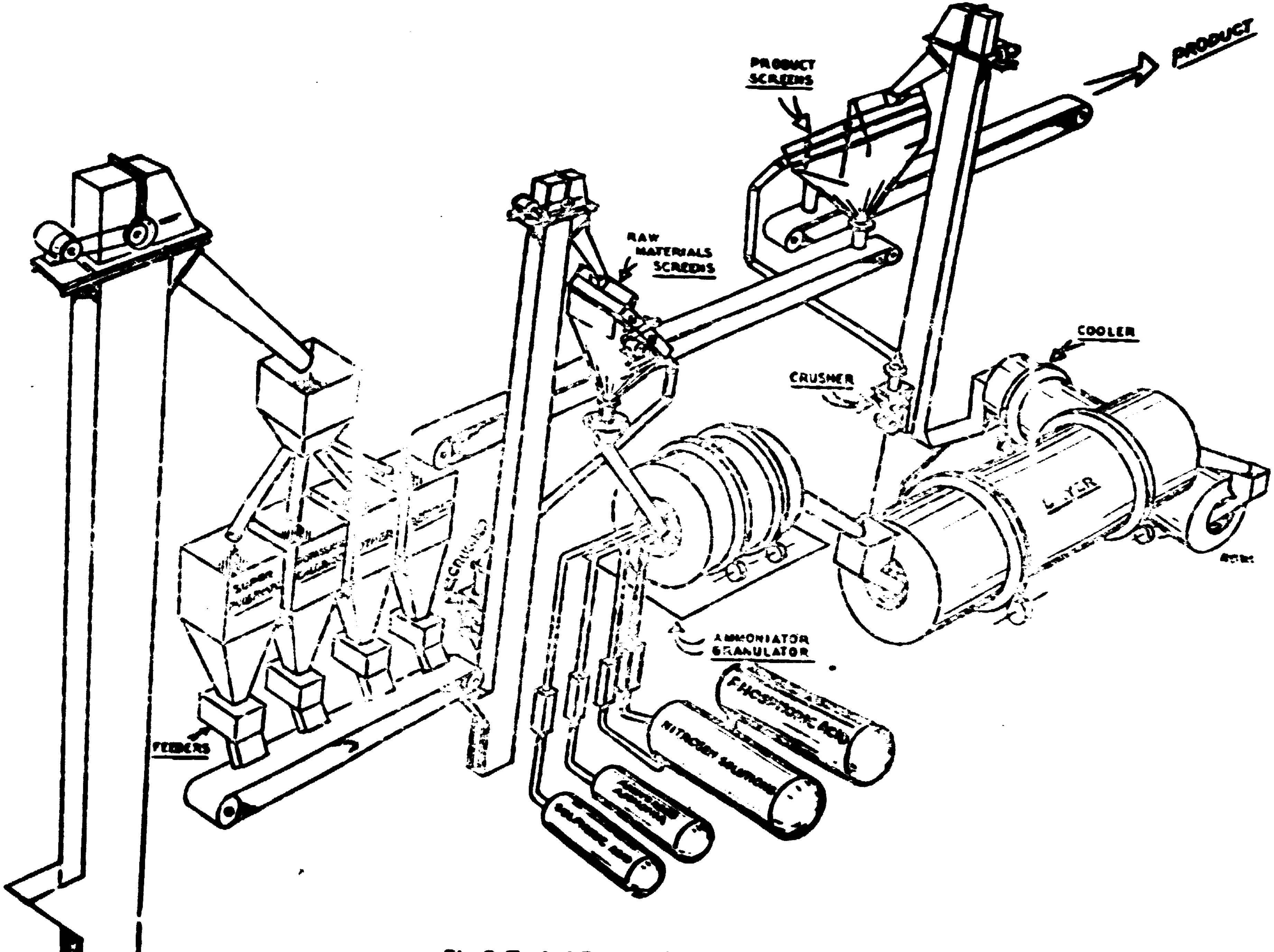


Fig. 9. Typical Granular Fertilizer Plant

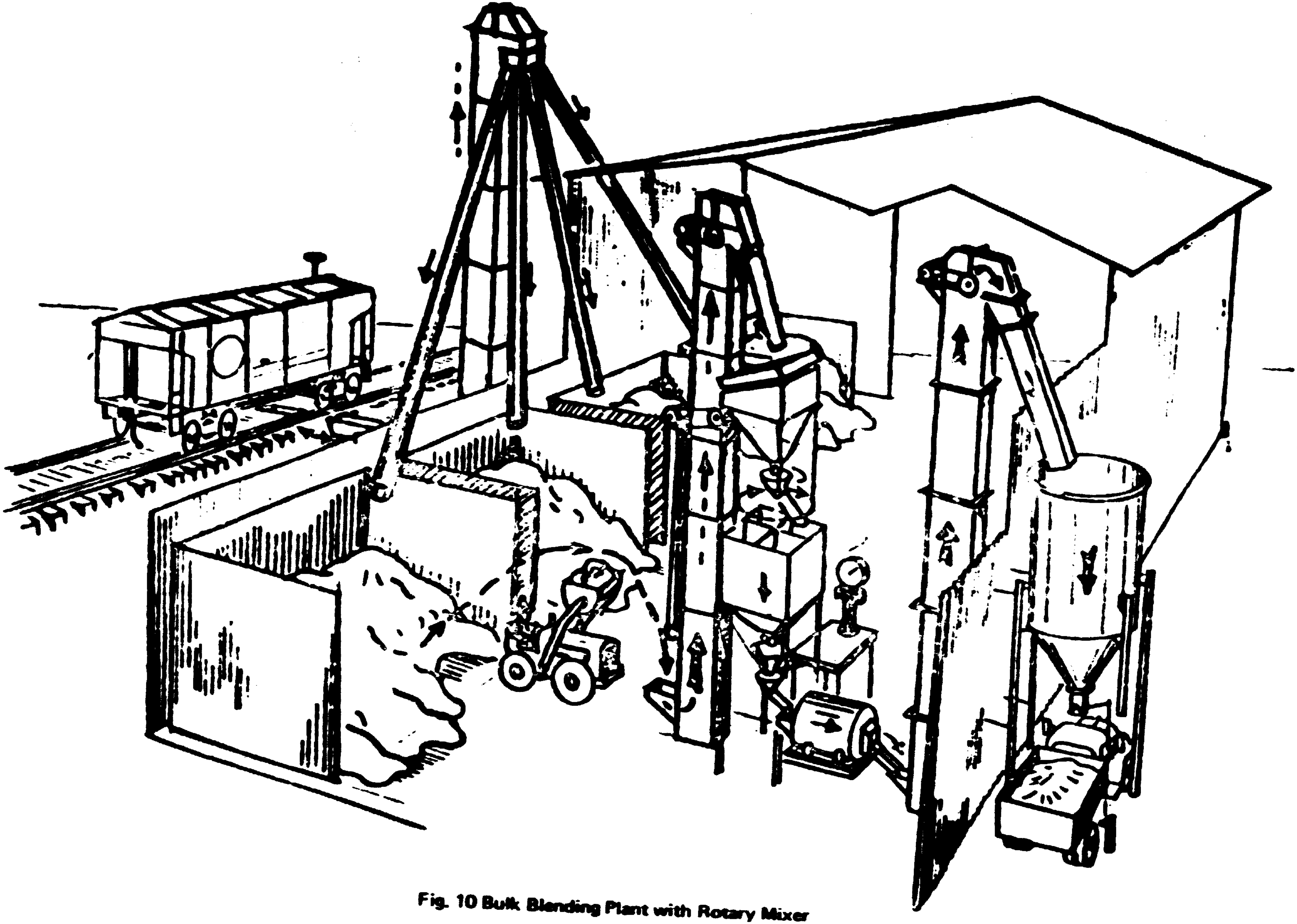


Fig. 10 Bulk Blending Plant with Rotary Mixer

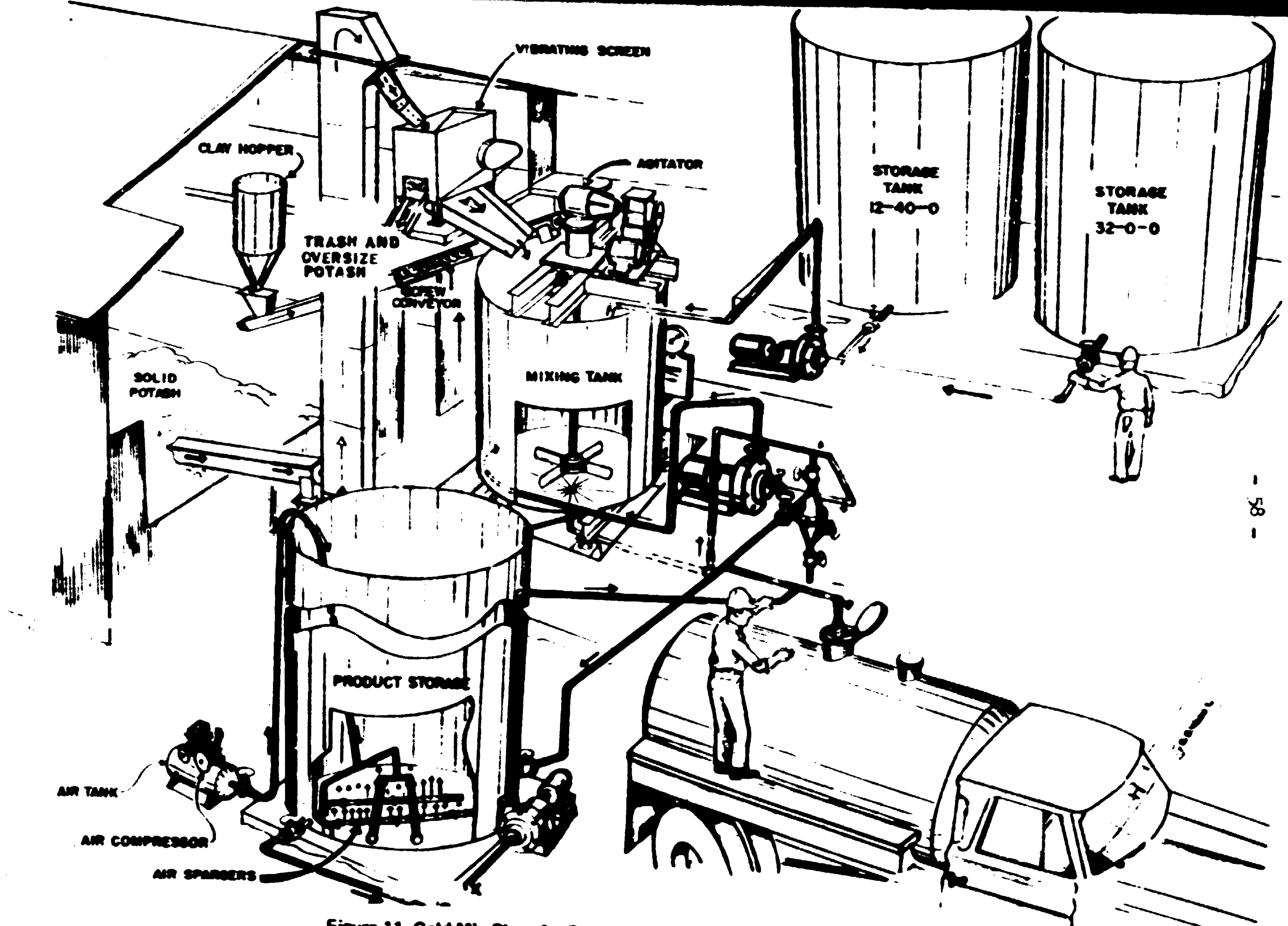


Figure 11. Cold-Mix Plant for Production of Clear Liquids or Suspensions

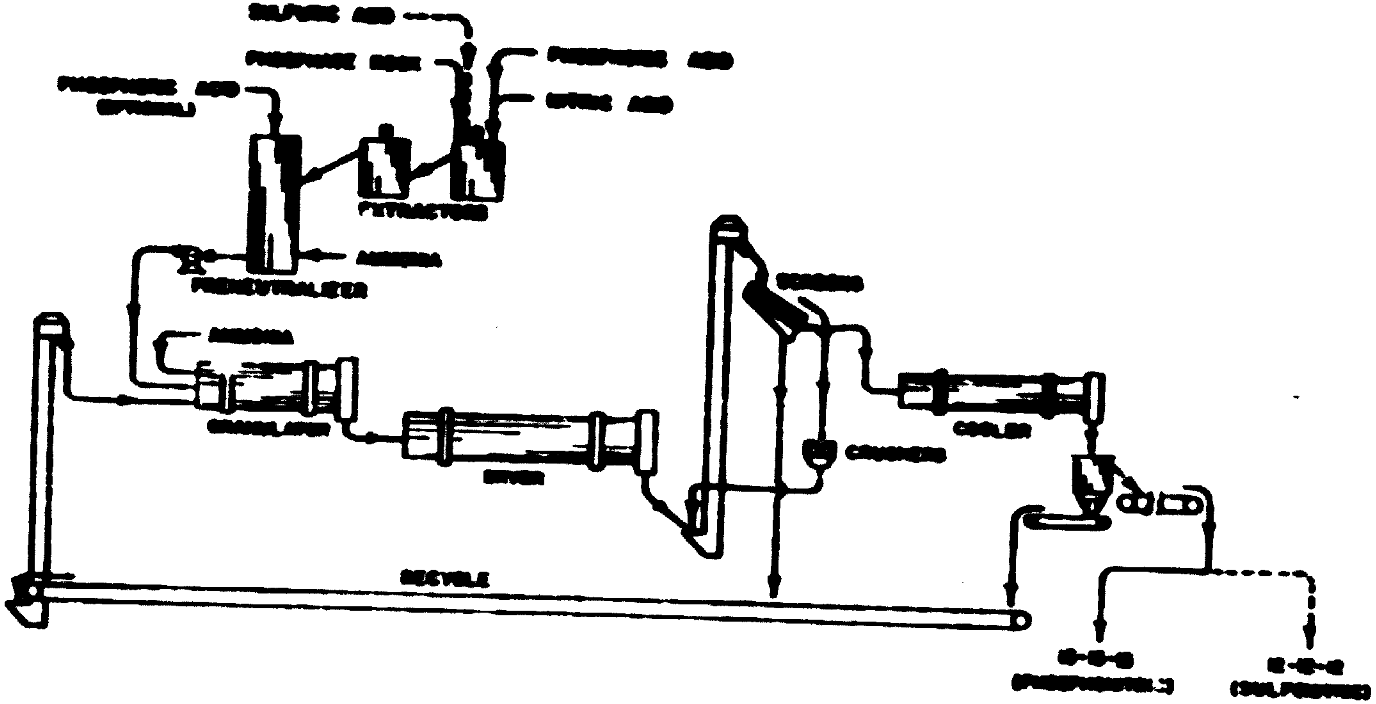
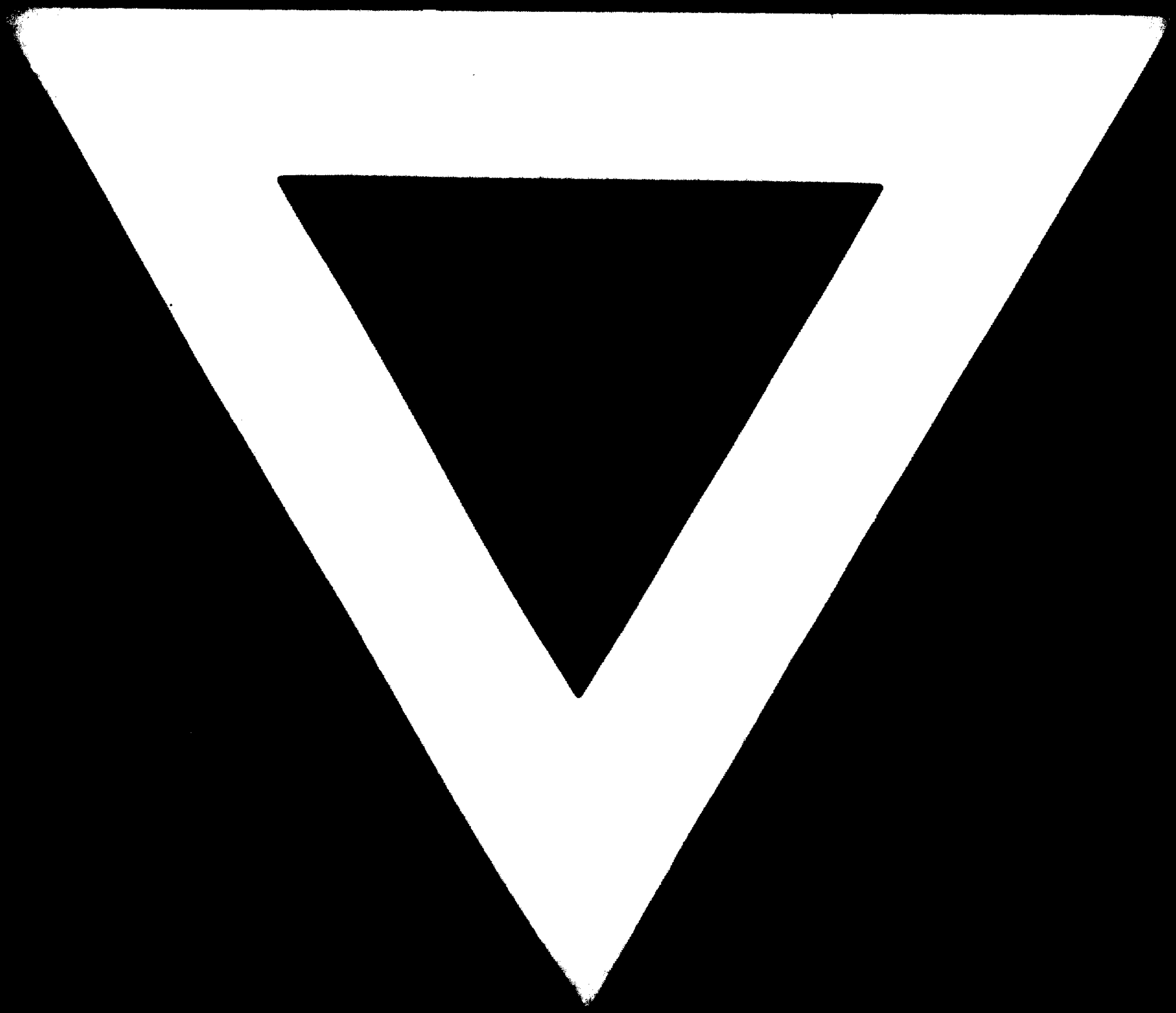


Figure 12. TVA Mixed Acid Nitrophosphate Process



74.10.14