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TECHNOLOGICAL OPTIONS FOR THE CONSTRUCTION OF FERTILIZER PLANTS, MINI-PLANTS*

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* This document is a translation of an unedited original. The views expressed therein are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

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CONTENTS

1. ECONOMIC JUSTIFICATION FOR THE CONSTRUCTION OF MINI-PLANTS

At the end of the twentieth century, at a time when the development of technological and computer resources has paved the way for industrial operations on a gigantic scale aimed at squeezing the cost price of manufactured goods, we may ask whether there is still any point in talking about fertilizer mini-plants.

The numerous contacts and meetings organized in recent years by UNIDO, particularly in Africa, make it possible to give a positive reply to this question.

In land-locked developing countries, transport costs may represent several times the ex-plant value of the fertilizers, and it is therefore natural to consider whether small-scale local production, hence not burdened with excessive transport costs, may be competitive with imported goods.

This is the subject that will be discussed in the following pages.

1.1 Establishment of mega-plants and mega-groups

The 1980s witnessed the general spread of important changes which had appeared earlier in the fertilizer industry and market. Reference may be made to:

A. Mega-plants producing the basic materials for the fertilizer industry:

Ammonia	1,000 to 1,500 tons NH_3/day
Urea	1,000 to 2,000 tons urea/day
Nitric acid	1,000 to 1,500 tons HNO_3/day
Ammonium nitrate	1,000 to 2,000 tons NH_4NO_3/day
Sulphuric acid	2,000 to 2,500 tons H_2SO_4/day/run
Phosphoric acid	750 to 1,500 tons P_2O_5/day
Diammonium phosphate (DAP)	1,500 to 3,000 tons DAP/day
Triple superphosphate (TSP)	1,500 to 3,000 tons TSP/day
Potassium chloride (MOP)	1,000 to 2,000 tons MOP/day
Compound fertilizers produced by nitric acid attack	
Binary	1,000 to 1,500 tons fertilizer/day
Ternary	

There is no doubt that the advent of these mega-plants has presented engineers with formidable technological challenges, but the development of materials, of methods of processing them and the constant improvement of the control and computerization of industrial processes have made it possible to meet these challenges.

Remembering also that process modelling has revealed all ways and means of exploiting the thermodynamics of systems with a view to limiting energy consumption, and even to producing an exportable surplus thereof, one can easily see that present mega-plants do not represent a cost-free phenomenon but are really the outcome of a technological breakthrough which has brought about a substantial reduction in cost prices.

B. Another contribution by mega-plants to cost-price reduction is their location close to raw materials deposits, offering numerous economic advantages. For example:

- Steep reduction in transport costs;

- The possibility of using unprocessed raw materials since, for example, moisture and the non-reactive gangue no longer need to be removed as there is no (or practically no) transport operation between mine and plant, thus involving a reduction in the cost of the raw material;

- The possibility of combining, at least partially, mining operations (which make holes) and processing activities (which need a hole for the deposit of the wastes).

C. However, the size of the investment required both for process development and for constructing processing units has led to a remarkable concentration of enterprises, with the weakest disappearing or being absorbed by the strongest.

This situation has led to the formation of mega-groups engaged in the winning of raw materials and/or in their first stages of processing, groups which are not only multinational but intercontinental.

D. Similarly, international traders have emerged and have acquired ever more importance as international commerce has grown. Among the causes of their expansion reference is generally made to the re-purchase contracts concluded by construction firms delivering fertilizer plants to countries rich in raw materials but poor in foreign exchange.

This is indeed a circumstance in which these traders have been in a position to render a valuable service to their customers while introducing very cheap commodities onto the market.

Thus, under the influence of these international traders, the basic fertilizer market has assumed world-wide proportions; market information (quantities and prices) is accessible to all as in the case of stocks and shares, and this has led to a consolidation of prices; consequently, world trade can deliver to ports accessible to sea-going vessels basic fertilizers at world prices plus freight charges, which virtually never represent more than 25 per cent of the ex-plant price.

But watch out! This is applicable only to basic fertilizers, also called "standard products". With any departure from the standard specifications, competition is limited and prices shoot up.

Needless to say, in order to handle business on a world scale, these traders need to be pretty solid, financially speaking. As a result, a concentration process has occurred likewise here, which has allowed only sufficiently strong groups to survive.

1.2 <u>The world fertilizer set-up in 1990</u>

Observed schematically, the world fertilizer set-up is composed on the one hand of a few mega-groups producing standardized products and on the other hand of a few mega-traders controlling world commerce, capable of purchasing anywhere in the world at the best price and delivering anywhere in the world with as wide a profit margin as competition allows.

It is not difficult to detect here the seeds of an oligopolistic situation, where producers and sellers make mutual arrangements to the disadvantage of purchasers.

This fear is all the more founded in that some groupings are already operating in two scenarios: mega-producers have gone into trading and mega-traders have invested in production.

What can be done to prevent domination of the market by such oligopolies? Any system of regulation, even if effective in the short term, will end up by being circumvented; consequently, the only effective reaction is to bring competition into play. This can be achieved:

- For example, by establishing powerful purchasing syndicates whose financial strength can match that of the producers and vendors. The examples of SINOCHEM (in China), MMTC (in India) and MULTIFERT (in South America) are familiar to all;

- Or by encouraging local or regional production operations adapted to the relevant market conditions, raw materials resources and transport facilities.

It should be emphasized that these countermeasures can be effective only to the extent that the market is dealing with standardized products.

With any deviation from these, as a result of physical, chemical or analytical specifications, the realm of standardized products is replaced by that of specific products, which command prices of a completely different order of magnitude as a result of reduced competition.

Incidentally, some producers have seen what is going on; they attempt to capture markets through the intermediary of agronomic publicity and extension agents whose role - decidedly commercial - is to convince everybody of their special characteristics.

According to them, recourse can only be had to a market of special products whose high cost will always constitute a check to the development of fertilization.

To sum up, provided that it is limited to standardized products, the "world" fertilizer set-up may be described, very schematically, by table 1.

It can be interpreted as follows.

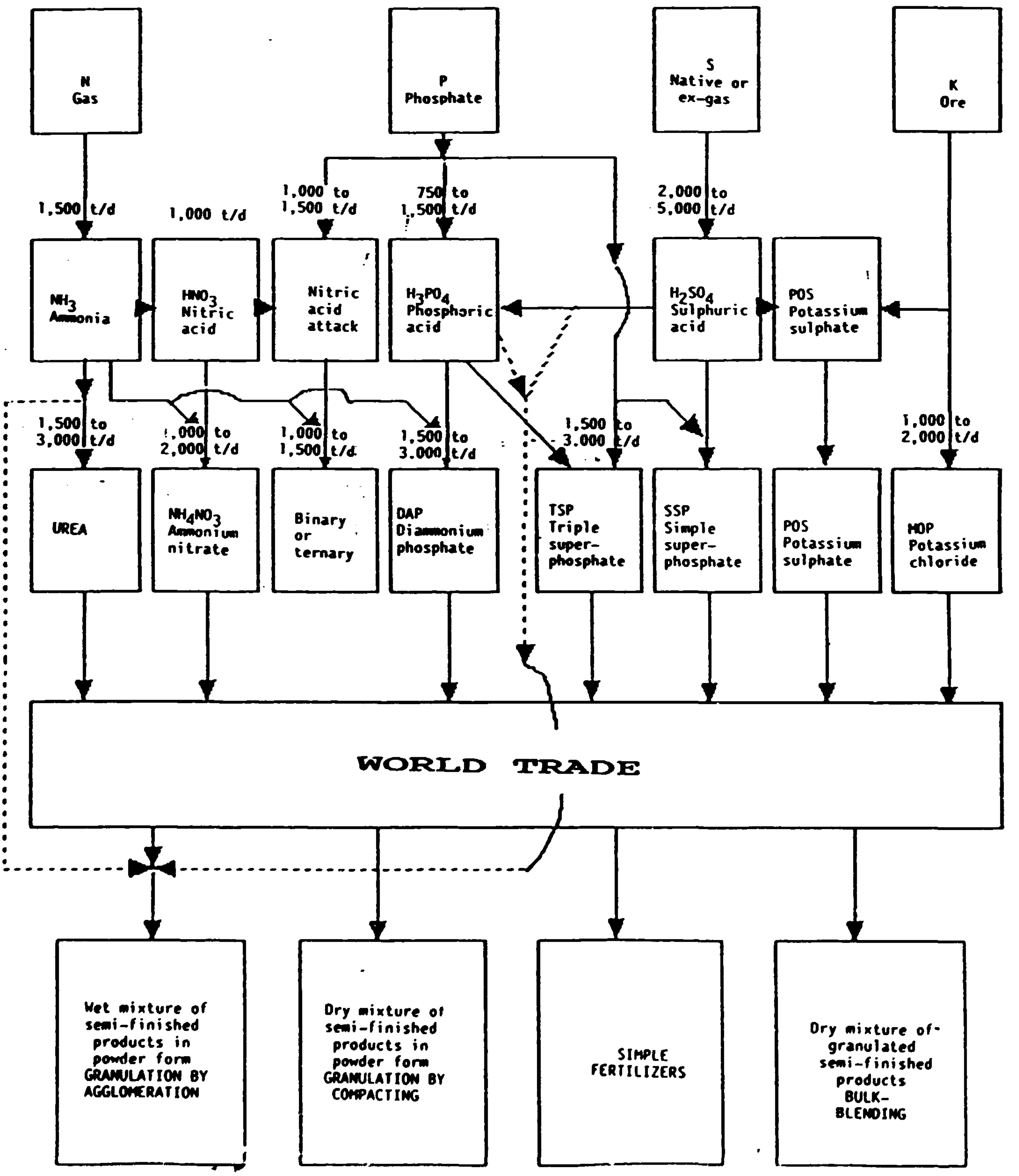
All standard products, in the first or second processing stages, manufactured in mega-plants located close to raw materials deposits come onto the world market at competitive prices, since the universalization of the business brings all prices close together, taking the lowest as plane of reference. Under this same effect of competition as applied to traders and by the latter to carriers, the world fertilizer trade can deliver these standard products at any port on the high seas at a cost scarcely 10-25 per cent above the ex-plant price.

If the user is prepared to use the standard products as such (simple fertilizers) or merely dry mixed (bulk blending), he will have available fertilizing substances at the minimum possible price delivered at the port. To this will then come the ancillary items of bagging, storage, transport (in one or more stages), re-storing, distribution, credit, etc.

If the user requires a fertilizer granulated after blending, the present trend is to carry out granulation by compacting semi-finished fertilizers in powder form, which have previously been dry mixed (bulk blended). This procedure increases the price of fertilizers obtained by bulk blending only by the cost of the relatively simple operation of agglomeration under pressure.

Figure 1

Standard fertilizer production and distribution flow-sheet, 1990



If, on the other hand, the user calls for a wet mixture of semi-finished fertilizer subsequently regranulated, this will need the supply of liquid or liquefied products (ammonia, sulphuric and/or phosphoric acids) which are not easily transported in small quantities and are liable to be delivered at a cost double or triple their ex-factory price. When the cost of granulation proper is added, it will be seen that we have here a costly alternative which can only be justified financially if it is carried out on a sufficiently large scale (the break-even point in Europe appears to lie at around 250,000 tons/year).

1.3 Influence on fertilizer production operations

In any region economically accessible to products circulating in the world fertilizer trade, manufacturing operations can be undertaken only if they are competitive with these products, which presupposes economic access to raw materials and competitive operating conditions (energy, labour and environmental costs).

In an industrialized country, characterized by very good transport facilities - river, rail and/or road - and by a substantial market for fertilizers, the economic accessibility of world-trade products extends to distances of up to 1,000 or 1,500 km from the ports.

Thus, no phosphate fertilizer plant has been constructed in western Europe for the past 15 years, because the competition of North African and American imports is too strong there.

In fact, numerous small units have been obliged to close down, and the only survivors are sufficiently integrated groupings which have found adequate solutions to their environmental problems. As against this, the production of nitrogenous fertilizers has prospered in this same area since it is based on North Sea natural gas, and has led to the necessary investments being made (expansion, energy economy, environmental protection).

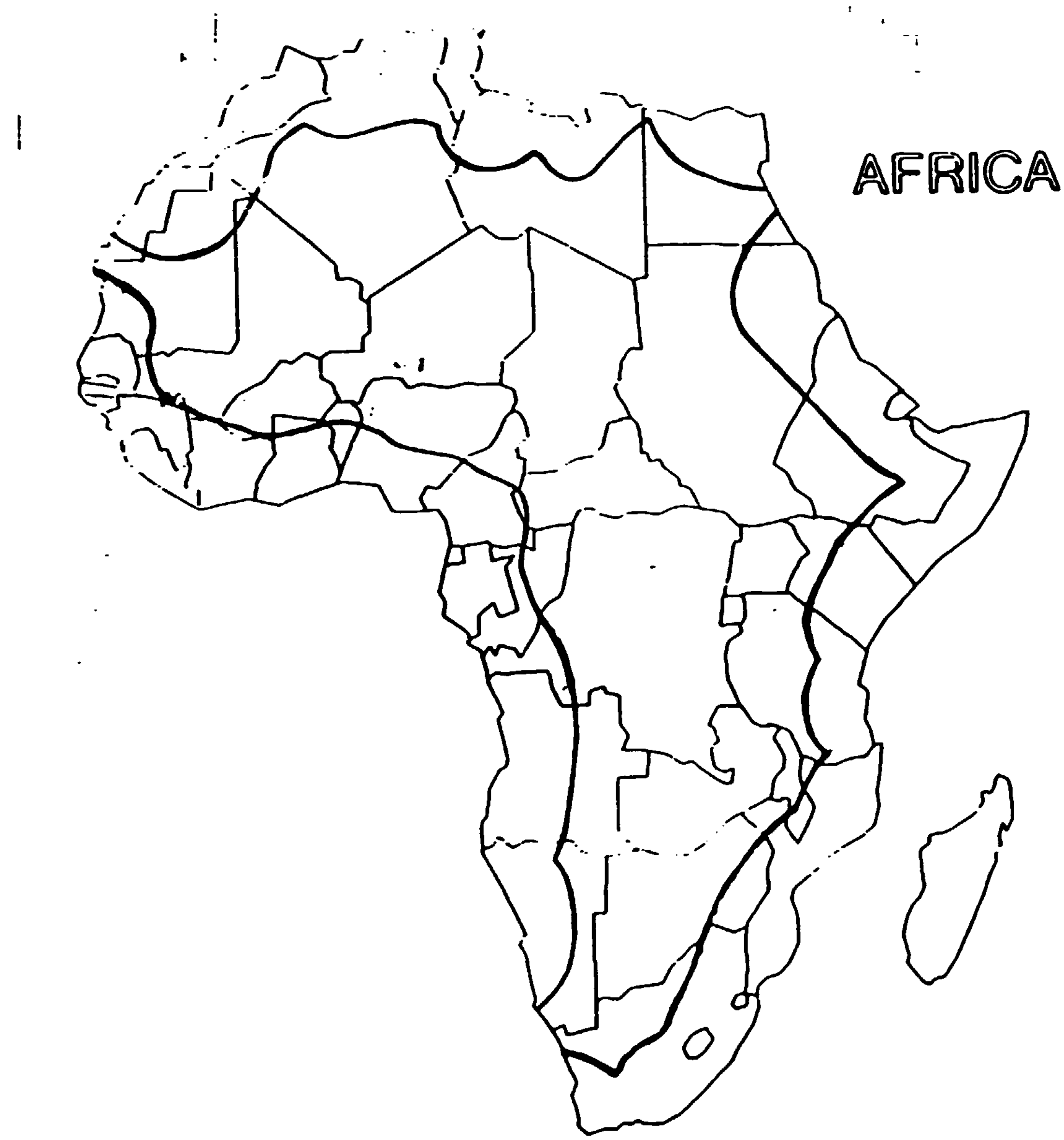
In a developing country, on the other hand, the storage and transport infrastructure is generally weaker, as a result of which it is normally considered that the economic accessibility of world-trade products is limited on average to a distance of 500 km from the ports. When this rule is applied to a continent as large as Africa, it will be seen that the area concerned covers scarcely 20 per cent of that of the continent (see figure 2).

This limit of 500 km is governed by the fact that the transport and storage infrastructures are less developed and that the limited fertilizer consumption does not make it possible to write off infrastructures established solely for fertilizer requirements. The result is that the price of fertilizers delivered to the point of application soon reaches double that of the fertilizers delivered to the port, thanks to the ever-growing effect of the ancillary costs: packaging, storage, transport to local district, re-storage, transport from district to village, further re-storage, application, credit.

This is the point at which it becomes worth while asking whether local production might be competitive. However, since such local production will involve the same ancillary costs as imported products, the quantity involved should be limited to the amount that can be sold within an area where these costs are bearable, say 200 km for example. Since at present consumption is not high, production will be low and hence mini-plants may have a role to play.

Figure 2

Areas within 500 km of African ports



(By courtesy of IFDC - Africa - Lome, Togo)

1.4 Competitiveness of local mini-plant output

A. Firstly, we must be clear about what we mean by "mini-plants".

While these are plants much smaller than the mega-plants referred to in section 1.1 above, their size will vary as a function of the complexity of the process, the material and human infrastructure available and, of course, the existing or anticipated fertilizer consumption in the target area of operations.

Regarding the complexity of the process, we shall here confine ourselves to reference to the two extreme cases:

- Firstly, manufacture of ammonia, which requires - irrespective of the size of the unit - the use of sensitive catalysts, which can be permanently damaged by even a brief maladjustment, and high-pressure operation with all the attendant safety and maintenance constraints;

  In such cases it is normally considered that the size of a mini-plant can vary from 50 to 300 tons NH_3/day as a function of the anticipated market, since it must be of a size sufficient to write off the cost of its complexity. For the same reason, the radius of 500 km can be considerably increased, particularly since ammonia can be transported cheaply thanks to its N concentration of over 82 per cent;

- Secondly, simple phosphate fertilizers such as crushed phosphate or even simple superphosphate or partially acidulated phosphate rock (PAPR), which are very simple products and easy to handle.

  Assuming the availability of phosphate and sulphuric acid, these products call for no sophisticated techniques.

Consequently,

- Investment is limited, which offers the following advantages:
  - The possibility of building very small units;
  - The possibility of operating them in limited runs, for example alternately with phosphate quarry operation;
- The training period of the work-force and the time required for the plant to come on stream is very short, thus permitting fast write-off of the investment.

The result is that, provided the situation regarding supply of raw materials (phosphate and sulphuric acid) is favourable, these units can become competitive quite quickly, i.e. as from a distance of the order of 500 km from the nearest port and where there is a market for 5-10,000 tons of their products.

B. Competitiveness

However, no mini-plant project can be entertained unless it is economically competitive, i.e. unless the final delivery cost of the fertilizer produced (and this includes production, marketing and ancillary costs) is competitive with that of imported goods.

Let us here consider the various possible cases:

- Nitrate fertilizers

It has been noted above that the minimum size for an ammonia mini-plant corresponds to a minimum production of 30-100,000 tons ammonia/year, capable of yielding 50,000-300,000 tons of fertilizer with nitrogen contents ranging from 26 to 45 per cent.

The marketing of such amounts in developing countries may require the competitive coverage of enormous areas, with prohibitive ancillary costs in comparison with those applicable to imported commodities.

In conclusion, it can already be seen that there will be few cases in which ammonia and basic nitrate fertilizer production will be justified. One such case is where hydropower surplus to requirements is available, permitting hydrogen generation by electrolysis of water.

- Phosphate fertilizers

The existence of numerous phosphate ore deposits, together with the possibility of converting the phosphates into fertilizer by very simple acidulation processes, and hence economically feasible on a small scale, suggests the design of units suitable for serving local markets even if they are limited to a few thousand tons of fertilizer per year.

- Potash fertilizers

The main potash ore is potassium chloride; since it is water soluble, it is not found on the surface like phosphates, but only in underground mines; the operation of such a mine will be economic only on the basis of large outputs demanding a correspondingly large market and thus giving rise to ancillary costs which force them to be competitive with imported goods.

The only case in which a more limited level of production, hence of more local interest, is conceivable is that where potash can be extracted from brine rich in one or another soluble potassium salt. The Dead Sea workings are an example of this, but they are on a scale which renders them competitive on the world markets.

In conclusion, the competitiveness factor shows that the countries which are best placed to consider the establishment of fertilizer mini-plants are those having phosphate resources available, while at the same time being sufficiently protected against world-market products thanks to high ancillary costs.

C. Thus far we have concerned ourselves only with the production of primary fertilizers, but there is another activity which can be very important in promoting fertilizer consumption in the developing countries: this is the mixing - with or without granulation - of primary fertilizers, irrespective of whether they are totally or partially imported or are locally produced.

Here we have:

- Mixing without granulation ("bulk blending"), which is the simplest and least expensive technical process. Hence it has met with great success in numerous countries - ranging from the United States of America to the island of Saint Lucia in the Antilles - but is strongly opposed by some agronomists. This method, which yields complete fertilizer at the price of the basic fertilizer plus a very small additional cost for the simple mixing process, will be preferable wherever it has not been possible to demonstrate that the fertilizers in question are not suitable;

- Mixing with granulation, which is intended to include, as far as possible, the same proportions of fertilizing elements in each granule. This can be done:

  - Either by a wet process, agglomerating the solids by liquids (sulphuric, phosphoric and/or nitric acids and ammonia or ammonium nitrate). This is the traditional process, but as was pointed out on page 5, it can be very costly because these liquids are expensive to transport;

  - Or by dry compacting - this mechanical compacting process is simpler, and calls for little or no liquid and no drying; it is now becoming of interest to investors.

2. PRIMARY FERTILIZER MINI-PLANTS

Our consideration of the conditions of competitiveness figuring in chapter 1, pages 7-9 above led to the conclusion that the countries which can most profitably consider the establishment of primary fertilizer mini-plants are those possessing phosphate ore deposits.

The critical threshold for ammonia and nitrogen fertilizer production extends, thanks to the very complexity of the process, well beyond the dimensions of mini-plants; we are in fact dealing with plants whose production must be disposed of on fairly large markets, which reduces their possible geographical advantage and imposes upon them the requirement of competitiveness with world-trade products. Two very rare exceptions may, however, arise, namely:

(1) The existence of natural nitrate deposits: e.g. guano in Peru;

(2) The availability of very cheap surplus electric power, opening the way to generation of hydrogen by electrolysis of water and rendering the subsequent production of ammonia less of a problem.

The situation regarding potash results in the same conclusions, even though the production methods are different:

- Either underground mining, hence involving large investments and the need for a large output to recoup them;

- Or the use of brine more or less rich in potash in a country where solar evaporation can be employed, but here also the substantial investment costs call for units of substantial size, a requirement which may nevertheless be somewhat modified if other items can be recovered.

2.1 <u>Nitrogenous fertilizer mini-plants</u>*

2.1.1 Role and sources of nitrogen

Atmospheric nitrogen is one of the most uniformly distributed and most accessible substances in the world.

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* I am indebted for the greater part of this chapter to the collaboration of Mr. Victor Julemont, a chemical engineer who has devoted his entire career to this branch of industry, ranging from manufacture to managerial posts.

It is also a component of living matter.

Unfortunately, with very few exceptions, it cannot be assimilated by living organisms.

Plants can assimilate nitrogen directly only in its oxidized form (NO_3 nitric ion), obtained naturally by the action of soil micro-organisms which convert ammoniacal nitrogen (NH_4 ion) to ureic nitrogen (NH_2-CO-NH_2), and the latter into nitric nitrogen (NH_3 nitric ion).

The following are the direct consequences of this situation:

(a) With the exception of natural organic fertilizers (manure, liquid manure, vegetable wastes) and of a few natural nitrates, available and usable on a paltry scale in comparison with requirements, synthetic ammonia is the only raw material that can be used for nitrogen fertilization;

(b) The most directly assimilable nitrogenous forms (solid nitrates, urea-nitrate solutions) are preferred in countries with a temperate climate. The less directly assimilable nitrogenated forms (NH_4, urea) will be preferred in hot countries where their conversion to nitric acid is accelerated by temperature;

(c) Since the nitric form of nitrogen is itself degraded by the action of soil micro-organisms, it is not possible to "store" excess nitrogen in the soil as is the case with excess potash or phosphorus, the portion of which not consumed by a crop remains available for the following crop (subject to the effect of leaching by rain-water).

2.1.2 Known and currently used methods for ammonia synthesis

Ammonia is manufactured industrially by reacting atmospheric nitrogen with hydrogen generated from carbonated matter. This reaction takes place at high pressures (200-1,000 bar with the earlier processes, 100-250 bar at present), at high temperatures (400-550° C) and in the presence of a catalyst which is highly sensitive to impurities.

Historically, hydrogen has been produced by the following methods:

(a) Processes developed in Europe as from 1910 based on coal: cryogenic separation of hydrogen from coke-oven gas, water-gas process, and coal gas generators.

These processes are practically no longer used, but remain of some interest for regions with access to cheap coal and cut off from the international ammonia market;

(b) Partial oxidation of liquid or gaseous hydrocarbons (autothermal reforming), in accordance with the reaction: $C_m H_n + m\ H_2O$ -- $m\ CO + (m + n/2)\ H_2$.

Since this reaction is highly endothermic and must be performed in the temperature range 1,000-1,500° C, depending on conditions, the heat required is supplied by burning some of the hydrocarbons in the reaction vessel itself using oxygen or oxygen-enriched air (see flow-sheet annexed).

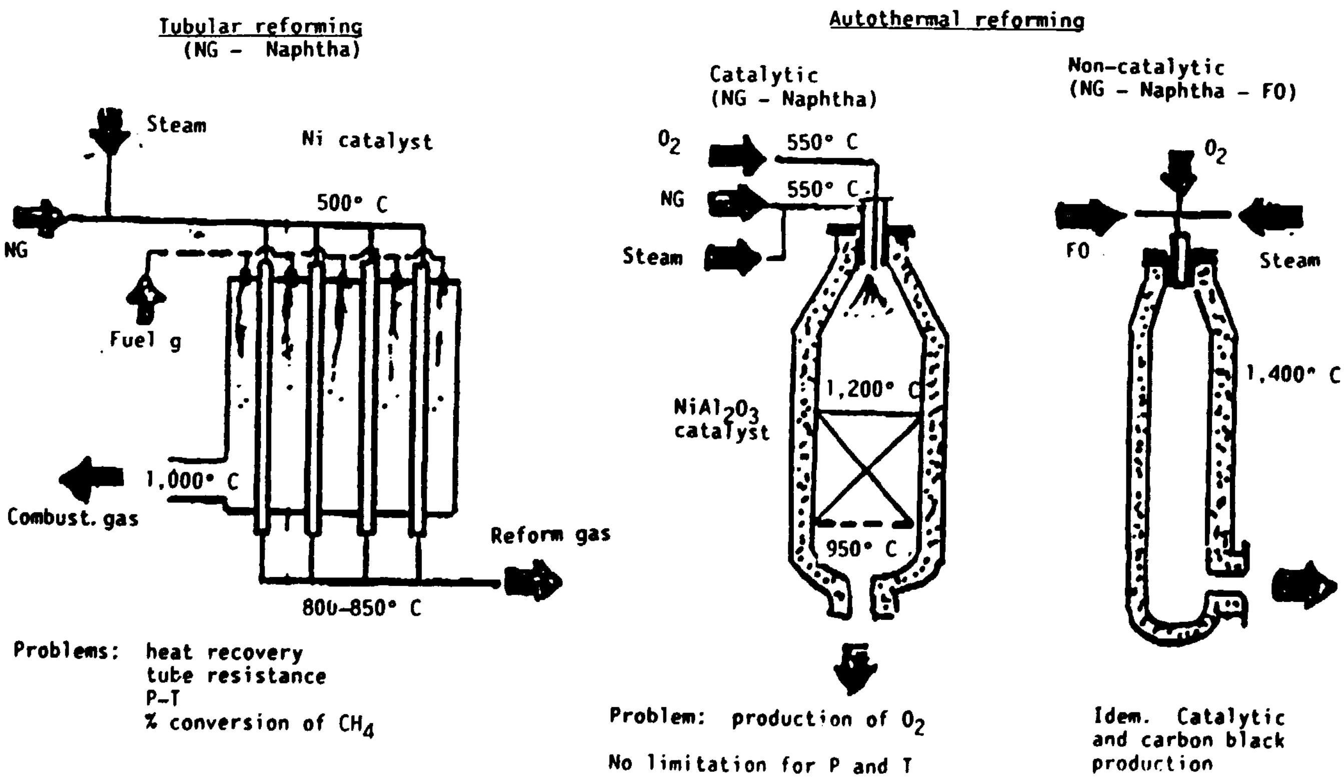
The ammonia production unit has therefore to be supplemented by an atmospheric oxygen cryogenic separation unit, which increases the cost price.

Subject to this reservation, the partial oxidation processes permit the use of all available liquid hydrocarbons, whether "white products" with a low or zero sulphur content (light petroleum spirits, naphtha, propane/butane and natural gas) or "black products" with a high sulphur content (all categories of fuel oil).

In the case of white products, use can be made of partial catalytic oxidation. If black products are to be employed, recourse will be had to non-catalytic partial oxidation followed by removal of soots and desulphurization. These processes were developed mainly in Europe after the Second World War. As from the 1960s they have been largely replaced by catalytic tubular reforming, but remain of value where a small or medium-sized unit is justified and where the available raw materials cannot be processed by tubular reforming;

(c) Catalytic tubular reforming: this process was developed long ago in the United States for the production of hydrogen from natural gas in accordance with the reaction: $CH_4 + H_2O \longrightarrow CO + 3H_2$.

The heat of reaction is in this case supplied by the burning of heating gas outside the reforming tubes and not by partial combustion in the reaction vessel itself. This being so, an atmospheric oxygen separation unit is not necessary (see annexed flow sheet).



In the now traditional set-up, tubular reforming is followed by post-combustion by air which supplies the nitrogen necessary for the ammonia synthesis reaction and the heat necessary to complete the reforming reaction. There then follow:

(a) Conversion of CO according to the reaction $CO + H_2O \text{ -- } CO_2 + H_2$;

(b) Decarbonation, effected by washing with an absorbent solution;

(c) Final purification by methanization of the last traces of carbon monoxide and dioxide.

The gaseous mixture is then compressed for admission to the ammonia synthesis reaction vessel.

As from the mid-1960s, the piston compressors hitherto used for various gas compression operations were replaced by turbo-compressors associated with steam turbines as part of an ever more thorough energy integration of units.

Unit capacities were then rapidly increased from 200-400 tons/day to 1,000 tons/day, with spectacular savings in energy and fixed operating costs.

For many years past, only units of 1,000-1,500 tons/day have been built, and most of the old medium-capacity units have been or will be shut down.

The new units are usually installed near to oil or natural gas wells, where they have access to cheap raw material (which represents more than 80 per cent of the cost price of ammonia before amortization payments).

Ammonia produced under these conditions can be stored and transported cheaply at atmospheric pressure over long distances, primarily in tankers of 30,000 tons or more and refrigerated at -33° C.

On arrival at the big harbour terminals it can be transported by river barge or by tank truck where river transport is not possible.

2.1.3 Conditions required for any new investment in ammonia production

Unless there are fresh technical developments, further investment in ammonia production is conceivable only under the above-described technical and economic conditions.

There can of course be exceptions to this almost general rule if the demand for ammonia is located in areas economically cut off from the world market or if political considerations justify autarkic measures.

Nevertheless, even under such circumstances, it is idle to contemplate small and unsophisticated units, simple to operate. Even leaving out what modern units require thanks to their size and their energy interdependence, the most simplified ammonia production line will always need high-grade personnel for its operation and a highly skilled technological environment for its maintenance.

It is clear that the necessary investment cannot be written off on very low capacities; thus there will be no mini-plants here, but "small" plants of a capacity of 150-300 tons ammonia/day. Only hydrogen production by electrolysis of water, yielding a purer hydrogen, might make it possible to reduce the threshold capacity to about 50-100 tons ammonia/day; however, this kind of hydrogen production is economically acceptable only where extremely cheap electricity is available, as for example in cases of surplus hydropower. One such case has been reported in Peru: the Cachimayo plant at Cuzco, with a capacity of 27,000 tons ammonia/year.

2.1.4 Simple nitrogenous fertilizers

The commonest simple nitrogenous fertilizers are:

- Ammonia itself, the fertilizer richest in nitrogen with 82 kg of available nitrogen per 100 kg. It can be used by direct injection into the soil, but this method calls for a relatively cumbersome infrastructure which confines its application to large, highly mechanized farms;

- Urea (NH_2-CO-NH_2) produced by synthesis from ammonia and CO_2 in a series of separate operations as sophisticated as those used in ammonia production. The CO_2 required is generally obtained as an unavoidable by-product of ammonia manufacture and, this being so, the two lines of production should be integrated at the same site. The nitrogen content of urea (46 per cent) is well able to bear the transport costs;

- Ammonium sulphate $(NH_4)_2\ SO_4$ produced by the reaction of ammonia and sulphuric acid is a fairly weak fertilizer with 21 per cent nitrogen, which bears heavily on the transport costs. Its production and use are justified only if large amounts of sulphuric acid are available (originating for example from pyritiferous ore roasting). It also has to meet the competition of ammonium sulphate obtained as a by-product of other industrial operations;

- Ammonium nitrate produced by the reaction of ammonia with nitric acid and the addition of certain inert fillers such as lime carbonates, which reduce its nitrogen content from the stoichiometric value of 35 per cent to 33.5-34 per cent (high-content nitrates) or to 28-26 per cent (calcium ammonium nitrates - CAN). The high-content nitrates, which are the cheapest to produce, to transport and to apply, nevertheless present explosion hazards which have led States to issue what are frequently restrictive regulations governing their storage and transport. The nitric acid is produced by catalytic combustion of ammonia. The nitrogen monoxide produced by this reaction is oxidized to nitrogen dioxide and the latter is dissolved in water to give an acid with a titre of 52-62 per cent HNO_3. An acid solution of this type contains only 12-14 per cent nitrogen, and its transport over long distances is prohibitive;

- Urea-nitrate solutions titrating 30-35 per cent nitrogen, easily transportable by water, rail or road, at present represent a convenient form of fertilization.

2.1.5 General observations on ammonia and nitrogenous fertilizer production

If the minimum ammonia production of a unit can vary from 25,000 tons/year (as at Cachimayo) to 50,000 or 100,000 tons/year, and if the nitrate fertilizers derived therefrom can contain from 26 (CAN) to 46 (urea) per cent N, this means a production of 45,000-150,000 or 300,000 tons of fertilizer/year at the ammonia production site.

Volumes of this kind have to be transported over long distances in order to find markets - if any - and as a result they will be much more exposed to competition from products circulating in world trade.

Let there be no misunderstanding: we are not saying that it is impossible to exploit local resources for ammonia and nitrogenous fertilizer production, but we do say that, owing to the sophistication, complexity and sensitivity of the processes required, the minimum plant dimensions will greatly exceed the absorption capacity of most local markets. Consequently, the output must be sold on regional or even continental markets, where it will be much more exposed to competition from world-trade products.

Before undertaking such ventures it will therefore be necessary to perform thorough and comprehensive market research, taking account of all the aspects of the problem, from material and human infrastructures to availability of raw materials or of markets for finished products, without omitting the logistic problems both upstream and downstream of production proper.

2.2 Phosphate fertilizer mini-plants

As mentioned in chapter 1 of this paper, the countries with phosphate resources are those which have the most reason and the best hope of meeting all or part of their fertilizer requirements by local production based on their own natural resources, processed in one or more mini-plants.

In fact, the utilization of phosphate resources calls only for the bringing into solution of the phosphorus content, and this can be done by simple acidification to break the insoluble apatite molecule in order to convert it into a mixture of the following forms:

- Monocalcium phosphate: water-soluble;
- Dicalcium phosphate: soluble in ammonium citrate;
- Tricalcium phosphate: soluble in weak acids, citric or formic.

Naturally, this simple scenario is complicated when dealing with phosphate resources with a high content of basic impurities such as iron, alumina, or magnesium, and unfortunately these basic impurities are frequently present in the small phosphate deposits often encountered in the developing countries. As this chapter proceeds we shall see how it is possible to adapt to the presence of these impurities.

2.2.1 Sulphuric acidulation method

The oldest and hence most traditional acidification processes make use of sulphuric acid; this may be:

- Obtained locally from non-ferrous metal ore roasting units;
- Produced locally on the basis of imported sulphur, a proceeding which can be economical because sulphur is an ore with 100 per cent concentration which can therefore be transported cheaply, and furthermore its conversion to sulphuric acid is exothermic and hence produces energy;
- Imported, if the transportation mechanisms are sufficiently efficient.

2.2.1.1 Treatment principles

In the case of mini-plants, acidification will not normally be taken to the phosphoric acid production stage because:

- On the one hand the complexity and cost of a phosphoric plant can scarcely be amortized on the basis of a low production;

- On the other hand, the frequent presence of substantial amounts of basic impurities in the available phosphates would excessively complicate the phosphoric acid production process.

Acidification will thus generally be limited to a simple reaction between previously crushed phosphate and a volume of sulphuric acid at the most sufficient to bring the greater part of the phosphate into monocalcium form. This is the actual principle of manufacture of the oldest chemical fertilizer: simple superphosphate (SSP).

Nevertheless, if the ore is rich in basic impurities, SSP will have some unattractive characteristics:

- Physically, it will take the form of an agglutinative paste, which does not harden properly;

- Chemically, it will tend to revert to less soluble forms.

In order to counter these drawbacks, the International Fertilizer Development Centre (IFDC) has for long been studying and developing the production of under-acidified superphosphates, also called "partially acidulated phosphate rock" (PAPR).

The idea of partial acidulation, designating the use of less acid than is necessary to convert the phosphate into SSP, frequently makes it possible to process ores rich in basic impurities and to convert them to valuable fertilizing materials. Very often in such cases, production of merchantable-quality SSP would be impossible.

Furthermore, the various forms of PAPR may be of particular interest for producers obliged to import either their sulphur or their sulphuric acid, since they require less acid than SSP and by this fact yield a significant saving in hard currency. Generally speaking, the cost ex-plant of P_2O_5 from PAPR is reckoned at about 80 per cent of that of SSP. As for the performance of PAPR in the field, this will be comparable with that of SSP when it is used under optimum conditions (acid soils characterized by a strong phosphorus fixation capacity, which is generally the case in tropical countries).

2.2.1.2 Production technologies

The raw materials must first be properly prepared:

- The phosphate is crushed to a degree of fineness which will increase with the hardness of the material and the weakness of its reactivity. Crushing is generally carried out in an oscillating crusher, although it is also possible to use ball or bar crushers;

- The sulphuric acid will be diluted and cooled; the weaker the reactivity of the phosphate, the greater should be the degree of dilution of the acid used (for example, 60 to 75 per cent H_2SO_4 as against 75 to 90 per cent for soft phosphate), and the less will be the acidulation permissible before the acidity renders the product agglutinative;

- The reaction can then be undertaken; this is normally quite short and yields a product with the consistency of pulp; this is collected in a closed container where the reaction continues and causes the mass to solidify when it has been properly completed. The solid mass is then chopped up by appropriate tools and placed in a storage pile where it requires a further few weeks to "mature".

The product can be granulated:

- Either upon leaving the container, but in this case the reaction is blocked and the solubility is limited;

- Or after maturing in the storage pile, which yields better solubility.

The reaction can be performed in continuous or batch process equipment.

2.2.1.3 Batch production of SSP or PAPR

The very simple manufacturing process lends itself extremely well to batch production.

Control is easy; weighing of the raw materials presents no problem and their stoichiometry can be adjusted without difficulty, which is essential for the production of a quality fertilizer.

That is why this process has survived until quite recently even in very progressive companies: KEMIRA OY will tell you that its batch production line operated until 1988, yielding simple or triple superphosphate or "KOTKA phosphate", which is in a way a PAPR before its time.

Also KEMIRA lists the following advantages of a batch unit:

- Very simple construction and operation;

- Highly flexible capacity, since the plant can easily operate with one, two or three intermissions;

- Only a very limited degree of automation, yet the plant is operated by a small staff;

- Very low energy and maintenance costs;

- Reasonable investment costs; these largely concern phosphate crushing and gas scrubbing.

See figures 3, 4 and 5 below.

2.2.1.4 Continuous SSP or PAPR production

In industrialized countries, continuous processing has more and more come to replace batch manufacture.

This has been happening because:

- Labour costs were increasing;

- Production volumes were increasing;

- And the degree of complexity of plant was increasing.

Figure 3

Process sheet of superphosphate plant

(Batch process)

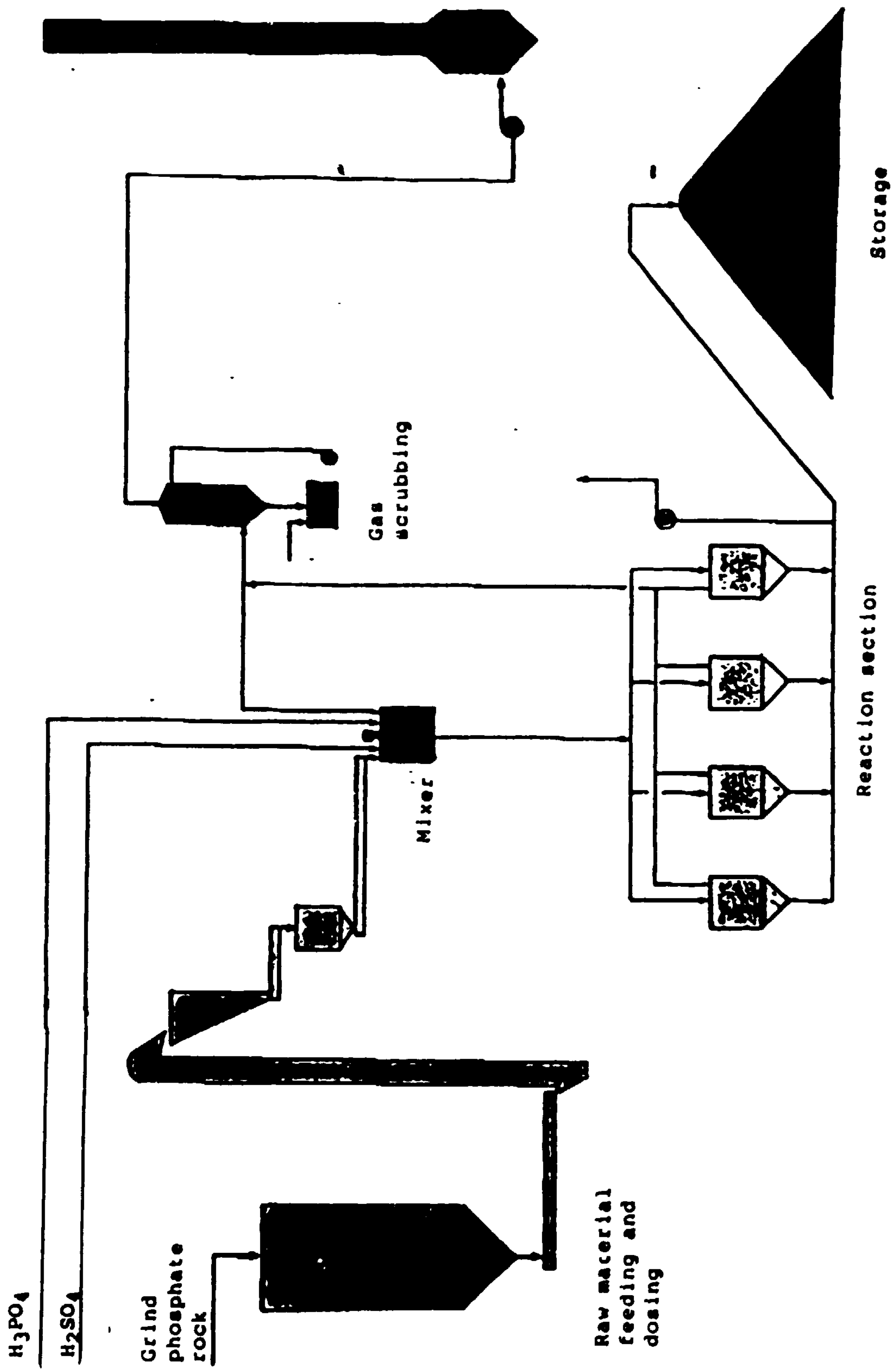


Figure 4

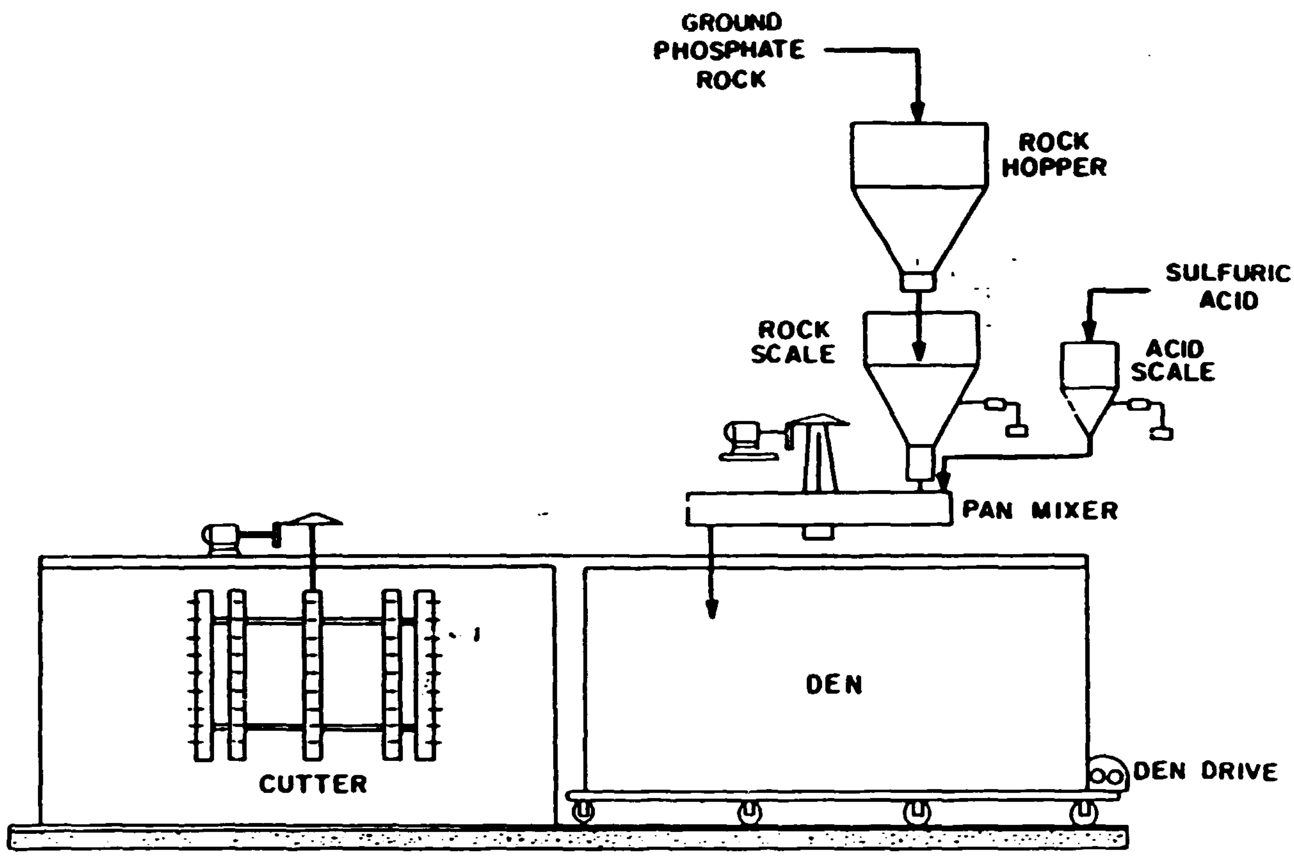


Figure 1. Batch Manufacture of Single Superphosphate.

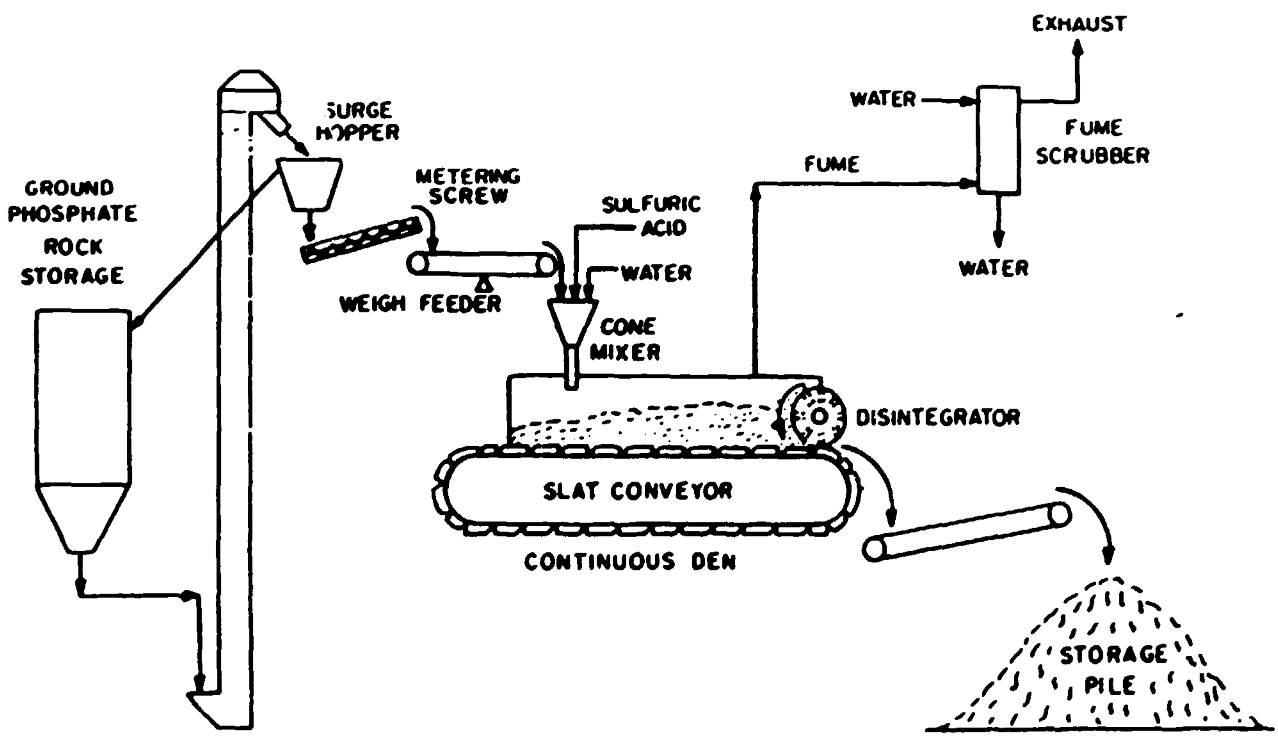


Figure 2. Continuous Manufacture of Single Superphosphate

Figure 5

Table 2. Chemical Composition and Relative Reactivity of Phosphate Rocks Evaluated in Laboratory- or Pilot Plant-Scale SAB-PAPR Studies

Phosphate Rock Source	Total P_2O_5	P_2O_5 Soluble in NAC	P_2O_5 Soluble in 2% Citric Acid	P_2O_5 Soluble in 2% Formic Acid	CaO	Fe_2O_3	Al_2O_3	MgO	CO_2	F	SiO_2	Na_2O	K_2O	SO_3	Relative[a] Reactivity
	(%)														
Central Florida (U.S.A.)	31.0	4.2	11.2	17.8	46.6	1.3	0.89	0.38	4.1	3.5	6.8	0.64	0.11	1.10	Medium
El-Hassa (Jordan)	30.4	4.5	13.9	27.8	50.8	0.31	0.44	0.21	6.8	3.9	7.1	0.58	0.02	1.62	Medium
Hahotoe (Togo)	35.9	3.0	7.2	14.3	51.3	1.3	1.1	0.05	1.9	4.0	4.6	0.23	0.04	0.60	Medium
Huila (Colombia)	20.7	3.5	7.8	16.1	40.0	0.6	1.7	0.17	8.3	2.7	23.6	0.16	0.09	0.96	Medium
Kodjari (Burkina Faso)	25.3	1.9	6.2	10.6	33.6	3.1	4.0	0.29	1.3	3.1	25.7	0.09	0.43	0.08	Low
Media Luna (Colombia)	30.0	2.3	10.5	22.6	45.5	0.44	0.47	0.12	4.6	3.6	12.6	0.12	0.07	0.75	Low
Mussoorie (India)—Concentrate	25.0	0.4	2.1	6.6	46.3	6.0	0.55	1.2	10.0	2.6	6.1	0.10	0.16	8.26	Low
Mussoorie (India)—Run-of-Mine	18.6	1.0	2.8	7.5	43.8	4.0	1.7	1.4	13.6	1.8	16.4	0.26	0.45	6.74	Low
Parc W (Niger)	28.5	2.6	7.5	14.9	39.9	1.9	1.0	0.03	1.2	1.6	23.2	0.13	0.04	0.10	Low
Pesca (Colombia)	19.5	3.3	10.0	15.1	27.9	1.0	1.4	0.15	1.3	2.1	40.3	0.14	0.15	0.45	Medium
Sukulu Hills (Uganda)	37.9	2.7	1.5	4.8	50.5	2.8	0.77	0.05	0.6	2.4	1.9	0.20	0.03	0.05	Low
Tahoua (Niger)	27.9	2.5	7.6	16.0	39.2	10.3	2.1	0.2	1.6	2.8	11.7	6.16	0.12	0.46	Low
Tilemsi Valley (Mali)	26.2	4.2	12.1	19.9	38.5	6.3	2.5	0.65	2.3	3.1	11.6	0.29	0.16	0.7	Medium
Utah (U.S.A.)	30.2	2.4	6.4	16.6	47.6	1.0	1.8	0.64	3.7	3.6	8.7	0.66	0.32	2.6	Low

a. Relative reactivity criteria: NAC-soluble P_2O_5 0%-2.9%—Low.
NAC-soluble P_2O_5 3.0%-4.9%—Medium.
NAC-soluble P_2O_5 6.0% and above—High.

Table 3. Typical Product Characteristics—Granular SAB-PAPR

Phosphate Rock Source	Degree of Acidulation	Total P_2O_5	P_2O_5 Soluble in Water	P_2O_5 Soluble in NAC[a]	P_2O_5 Soluble in 2% Citric Acid[a]	P_2O_5 Soluble in 2% Formic Acid[a]	Free Acid (P_2O_5 Basis)	Free Water
	(%)							
Laboratory-Scale Production								
Central Florida (U.S.A.)	40	23.3	10.7	3.1	7.3	9.8	<0.1	1.0
El-Hassa (Jordan)	16	28.0	3.8	4.8	11.5	19.2	0.1	0.9
	30	26.6	7.5	4.2	11.4	16.7	0.2	0.7
Hahotoe (Togo)	25	28.7	4.9	3.8	10.0	13.8	0.3	1.1
	60	25.1	10.6	2.5	7.8	10.3	0.4	0.6
Huila (Colombia)	60	14.8	6.1	2.8	5.8	7.7	0.1	0.6
Kodjari (Burkina Faso)	30	20.6	0.7	5.2	7.1	7.3	<0.1	1.9
	60	18.6	3.0	4.8	10.0	9.8	<0.1	0.6
Media Luna (Colombia)	60	23.4	10.1	1.6	6.8	11.4	0.8	2.1
Mussoorie (India)—Concentrate	60	20.3	7.4	2.6	3.6	6.9	0.3	2.0
Mussoorie (India)—Run-of-Mine	36	14.7	3.6	2.3	4.2	7.3	0.2	2.0
Parc W (Niger)	26	24.3	4.4	3.4	7.3	10.8	0.1	0.6
	60	22.3	9.3	2.8	7.0	8.4	<0.1	0.8
Pesca (Colombia)	20	17.6	4.3	2.2	NA[b]	NA	0.7	1.7
	40	16.2	6.7	3.6	6.9	8.6	0.1	0.1
Sukulu Hills (Uganda)	25	30.3	6.1	1.0	2.0	6.1	<0.1	0.4
	60	26.8	12.1	1.6	2.6	6.0	<0.1	0.4
Tahoua (Niger)	25	24.3	1.1	4.7	8.5	10.7	<0.1	1.0
	60	23.0	2.6	4.6	7.8	9.8	0.2	1.4
Tilemsi Valley (Mali)	15	25.6	0.6	6.3	11.8	16.2	<0.1	2.0
	30	22.7	1.6	6.6	12.3	14.6	<0.1	1.8
Pilot Plant-Scale Production								
Central Florida (U.S.A.)	30	26.6	6.4	4.4	11.3	16.2	0.3	1.7
	60	21.9	9.6	4.2	9.0	11.8	0.7	2.8
Utah (U.S.A.)	30	25.3	7.3	1.2	NA	NA	0.2	0.9
	60	22.6	11.1	1.8	7.7	11.9	0.2	1.3

a. Does not include P_2O_5 soluble in water.
b. Not analyzed.

While continuous production yields larger outputs with a smaller labour force thanks to automation of the process, it does by that very fact call for increased equipment sophistication, involving:

- Higher purchase prices;
- More difficult and expensive maintenance:
  - Purchase and storage of spare parts;
  - Training of operative and supervisory labour;
- Greater fault-susceptibility, the risk of breakdown or simple disfunctioning being enhanced by heightened equipment sophistication, and furthermore the continuous nature of operation implying that any outage of an item of equipment brings the whole line to a halt.

It is likewise important to stress the difficulties involved in strictly stoichiometric proportioning of the raw materials.

In particular, the continuous weighing of the crushed phosphate is a highly delicate operation, which in modern plants calls for an often unsuspected degree of mechanical and electronic sophistication.

Continuous measuring of liquids (sulphuric acid and water) and their dosing to deliver a continuous and regular acid flow with a constant titre are almost as difficult.

We are stressing these points only because we believe them essential for the success of the operation.

Anyone who has already manufactured SSP with equipment in poor condition or with underskilled operators knows what operating for a period of time in an over-acidification régime costs; one then obtains at the mixer outlet a product which has no longer the consistency of the traditional "paste" but is on the contrary much too liquid: it is what is known in the trade as producing a "liquid cellar". And in any case this is not the whole story since a substantial part of the product escapes from the "cellar" or container and spreads itself over unventilated infrastructures giving off fluorine compounds which poison the atmosphere of the workplace.

As for the portion remaining more or less within the container, the reaction is not completed and the product does not set normally.

There then soon arrives at the outlet a viscous mass which the knives cannot cut out properly, but instead hurl in all directions, putting to flight the operators who are not keen on being bombarded by acid bubbles burning their eyes and skin.

Even if some of the product arrives at the storage conveyors, the situation is not improved because it sticks to the belts, and is only partially discharged through the congested chutes, while the part adhering to the belt is crushed by the return rollers and cast out into the environment, including the operators.

All this happens in an atmosphere poisoned by release of fluorinated gases at abnormal, hence non-ventilated, points, and soon the only remedy is to stop the line and wait a number of hours to enable the product to harden somewhat and for the operators to recover physically and morally.

Then, very slowly and carefully, the container will be emptied and the equipment controlling the raw materials flow cleaned before operation can recommence.

Generally speaking, one half-hour of maladjustment will involve one to two days' shutdown if it is hoped to limit the definitive damage to equipment to 5-10 per cent of its value.

2.2.1.5 Conclusion

In the light of the above description of the impressive effects of over-acid operation, the reader will not be surprised that the author strongly recommends the use of a batch process for SSP or PAPR mini-plants, for in principle they will offer the following advantages:

- The volumes produced will be low;

- The labour costs will be low;

- The overall technical complexity of the undertaking will be limited, as will be that of its environment.

It will therefore be important to aim at:

- Minimum financial investment;

- Simple design making maximum use of local construction facilities;

- Easy maintenance, avoiding the use of highly sophisticated imported equipment.

2.2.2 Nitric acidulation method

Whereas ammonia (NH_3 = 82 per cent N) can be cheaply transported (although under pressure) thanks to its high concentration, nitric acid is used only in highly dilute form, which means that transport is uneconomical.

Consequently:

- The import of nitric acid involving transport over long distances cannot be contemplated;

- Local production of nitric acid on the basis of imported ammonia could be envisaged (just as sulphuric acid production on the basis of imported sulphur), but on the one hand the process is fairly sophisticated, thus calling for a certain minimum capacity for it to be economic, and on the other hand the diluted product cannot be transported very far, thus limiting production to what can be consumed locally.

Since in practice these two propositions are incompatible, there have so far been no plants built along these lines.

There then remains the solution proposed by SOFRECHIM, namely local combustion of imported ammonia in order to produce nitrous gases; these are not converted into nitric acid but are used directly to react with local phosphates supplemented with various organic substances (peat, millet chaff, rice husks, cane bagasse, etc.) which absorb the nitrous gases.

This process, called HUMIFERT, involves successively (see figure 6):

- The production of nitrogen oxides by combustion of ammonia in a suitable reaction vessel (an operation identical to the first stage of nitric acid production);

- The manufacture of the fertilizer proper, consisting of three successive phases, namely:

  - Nitrous gas attack on the phosphate-organic matter mixture, an operation which proceeds in a reaction vessel under slight over-pressure;

  - Oxidation by atmospheric air in the reaction vessel;

  - Maturing on the storage pile;

  - After maturing, the fertilizer is dried and extruded in the form of cylinders.

The result is an organo-mineral fertilizer whose contents will vary within the following range:

N	between 3 and 6 per cent;
P_2O_5	between 9 and 20 per cent;
N + P_2O_5	between 15 and 25 per cent.

The manufacturers emphasize the particularly valuable characteristics of the product in tropical acid soils naturally rich in iron and alumina.

All this process really needs is a first instance of industrial use for it to challenge the sulphuric processes on an equal footing.

2.3 Potash fertilizer mini-plants

We have seen (cf. section 1.4, page 7) that underground mining can in no case be written off from mini-plant output, but certainly from "world-class" plant output, i.e. at prices which are competitive on the world market.

Regarding potash production from brines, Jacobs Engineering Inc., which designed the base unit for the Arab Potash Company exploiting the Dead Sea brines on the Jordan side, with an original capacity of 1.2 million tons of potash/year followed by a 50 per cent increase in two stages, states the following:

> "Even having recourse to solar evaporation (cheap energy!), it is difficult to justify the economics of a plant with a capacity of less than one million tons of potash/year at present prices (see figure 7).
>
> "However, an exception is possible:
>
> - Either if other products are recoverable from the same brine;
>
> - Or if the ancillary costs of bringing the product onto the world market are much more favourable than those applicable to 'world-trade' products."

Figure 6

Production flow-sheet

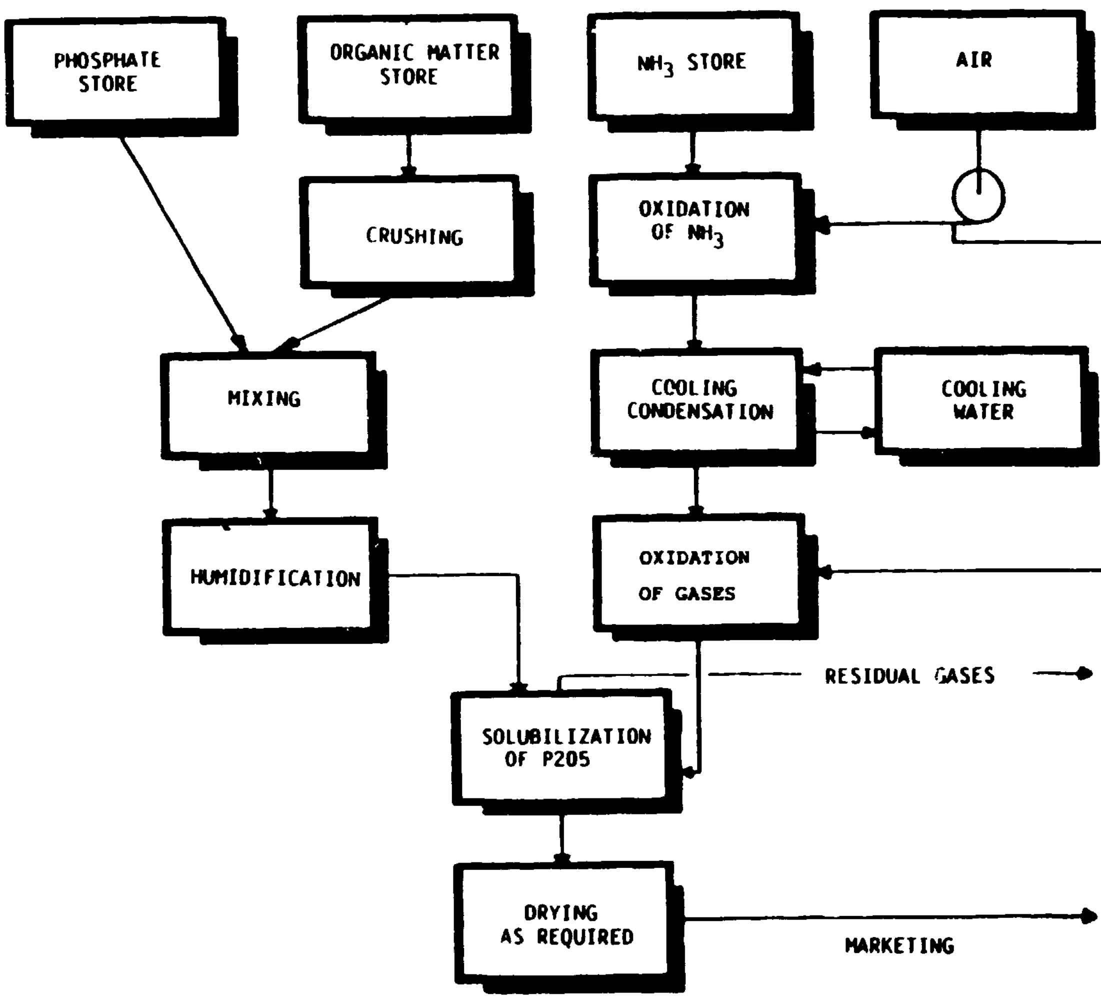


Figure 7

Potash prouuction by the Arab Potash Company

(Extract from a paper entitled "Solar Evaporation and the Production of Potash from Dead Sea Brines" by P. H. Kittredge, Project Manager, Jacobs Engineering Group Inc.)

The basic project, with a capacity of 1.2 million tons of potash/year, involves a two-phase operation, as follows:

1. A solar evaporation process to produce carnallite;

2. A refining process to produce potash from carnallite.

The solar evaporation process involves six basins with a total area of 87 km^2, of which 50 km^2 relate to the first basin where precipitation of NaCl begins; it is fed by a brine whose potash content is of the order of 14.3 g/l. After passage through three basins connected in series, where the NaCl is separated by precipitation, the brine proceeds to the finishing basins where carnallite ($KCl.MgCl_2.6H_2O$) starts to precipitate. Diluted with about 15 per cent NaCl, it yields a product which has a titre of 23 per cent potash. In terms of gross yield, therefore, 4.4 tons are required to produce 1 ton of potash. The flow rate of header-fed brine varies in accordance with the rate of evaporation, which is seasonal; at maximum evaporation, in July, the flow rate is 8.5 m^3/sec.

The refining process is fed by a carnallite-enriched brine and comprises the following stages (see next sheet):

1. Carnallite processing;

2. Sylvinite processing;

3. Crystallization of potash;

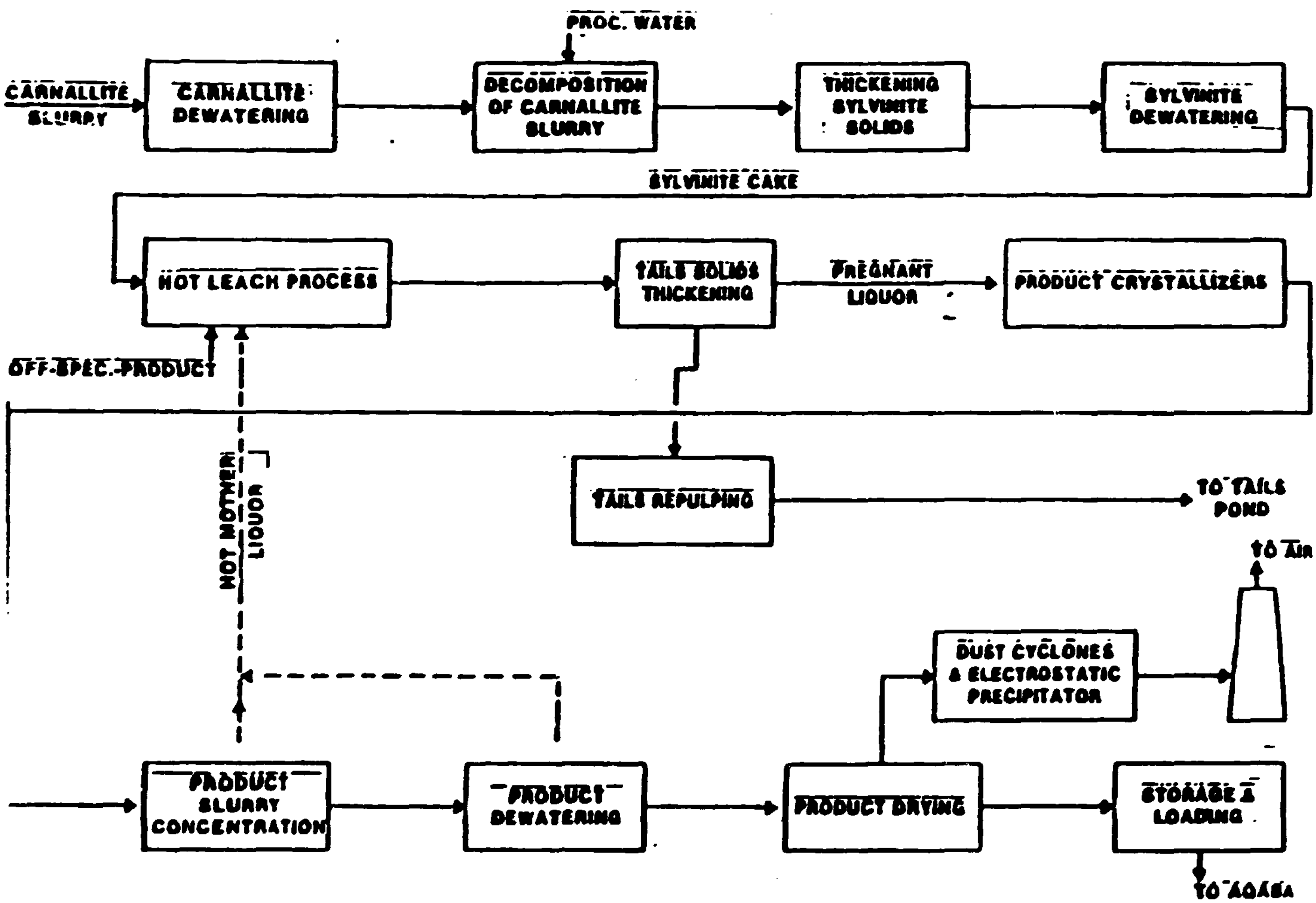
4. Mechanical dewatering of potash;

5. Drying of potash, storage and dispatch.

Figure 7 (continued)

Solar Evaporation and the Production of Potash from Dead Sea Brines
P. H. Kittredge, Jacobs Engineering Group
ACS, New York, New York, 26 August 1981

REFINERY FLOW DIAGRAM



3. MIXED FERTILIZER MINI-PLANTS

It was seen in chapter 1, page 3, that the cheapest fertilizers on the world market are standardized products, i.e. first or second-process fertilizers, specialized on the basis not of usage but of origin, hence basically simple or binary fertilizers such as: urea, NH_4NO_3
SSP, TSP, DAP
MOP, SOP

For any country which has to purchase fertilizers abroad, these are therefore the types which efforts should be made to obtain.

But how to proceed thereafter?

One can apply simple fertilizers, taking care to give instruction on the methods of use: quantities to be applied as a function of soil and crop, periods of application and so on. In view of the general weakness of the logistic chain and the poorness of agricultural popularization and extension facilities, it is reasonable to believe that the ideal recommended fertilization will not be achieved in this way, particularly since the work of the farmer, who is thus obliged to carry out two or three applications, is thereby increased.

Consequently, even where standardized fertilizers are obtained at minimum cost, it is frequently recommendable to make provision in each logistic chain for a mixing unit which can offer a choice of one or more formulae corresponding to the needs of the area being served. This can be effected in various ways, namely:

3.1 Mixing without granulation (bulk blending)

This is the most popular and by far the cheapest formula; it consists of mixing, in pre-weighed quantities, various standardized fertilizers of similar, or even identical, grain size.

Well broken in after 30 years of use in the United States, this process is carried out in fully purpose-designed standardized units and generally concludes by the bagging of the mixture.

This inexpensive operation yields mixtures which have met with remarkable success even in an agriculture as efficient as that of the United States. In view of this growing success, the process has blossomed out, in some places even finding conditions where it has won most of the market. This is the case in Ireland, which also has a powerful agriculture, and of Saint Lucia, a tropical island in the Antilles.

We should be failing in our duty if we did not point out that some agronomists are fiercely opposed to bulk blending, because they claim that the mixture becomes disassociated owing to segregation during transport and that the fertilizer actually applied is extremely heterogeneous. Without being experts on this subject, we nevertheless do not accept these arguments, because European farmers, who know where their interests lie, have adopted the use of mixed fertilizers in makeshift installations in cases where they were able to import standardized fertilizers offering a definite albeit slight margin by comparison with compound fertilizers originating from their traditional suppliers.

We would add in this connection that when the mixed fertilizer is put into 50 kg bags, segregation has no marked separating effect on the grains, and after emptying of the sacks into the spreader the result is a mixture better than those produced by manual mixing of simple fertilizers.

In brief, we consider - and in this we find support in the opinions of undoubted authorities in the fertilizer field (IFDC for example) - that bulk blending is to be recommended wherever it has not been possible to prove its unsuitability, since by furnishing any mixing formula at minimum price it gives the best chance of improved fertilization.

3.2 Mixing with granulation

The purpose of this operation is to mix basic products of similar grain size and if possible sufficiently fine to obtain a homogeneous mixture which is subsequently granulated, hoping, or at least affirming, that each grain will contain the same proportion of each component.

Here we distinguish:

3.2.1 Granulation by agglomeration of a wet mixture

This operation requires humidification of the mixture in powder form by significant (of the order of 10 per cent of the total weight) quantities of sulphuric and phosphoric acids, which are thereafter solidified by neutralization with ammonia. This procedure involves substantial costs when the base of operations is remote from the great world-trade routes:

- The provision of quantities of acid which, while significant from the viewpoint of price, are small in logistic terms;

- Ditto for ammonia;

- A sophisticated and sensitive process;

- Requiring energy for drying.

Under western European conditions, the break-even threshold lies at a capacity of 250,000 tons/year. There are few developing countries where the requisite conditions will apply.

3.2.2 Granulation by compacting of a dry mixture

Unlike granulation by agglomeration, compacting uses only solid starting materials, which means that no heat will be required for subsequent drying.

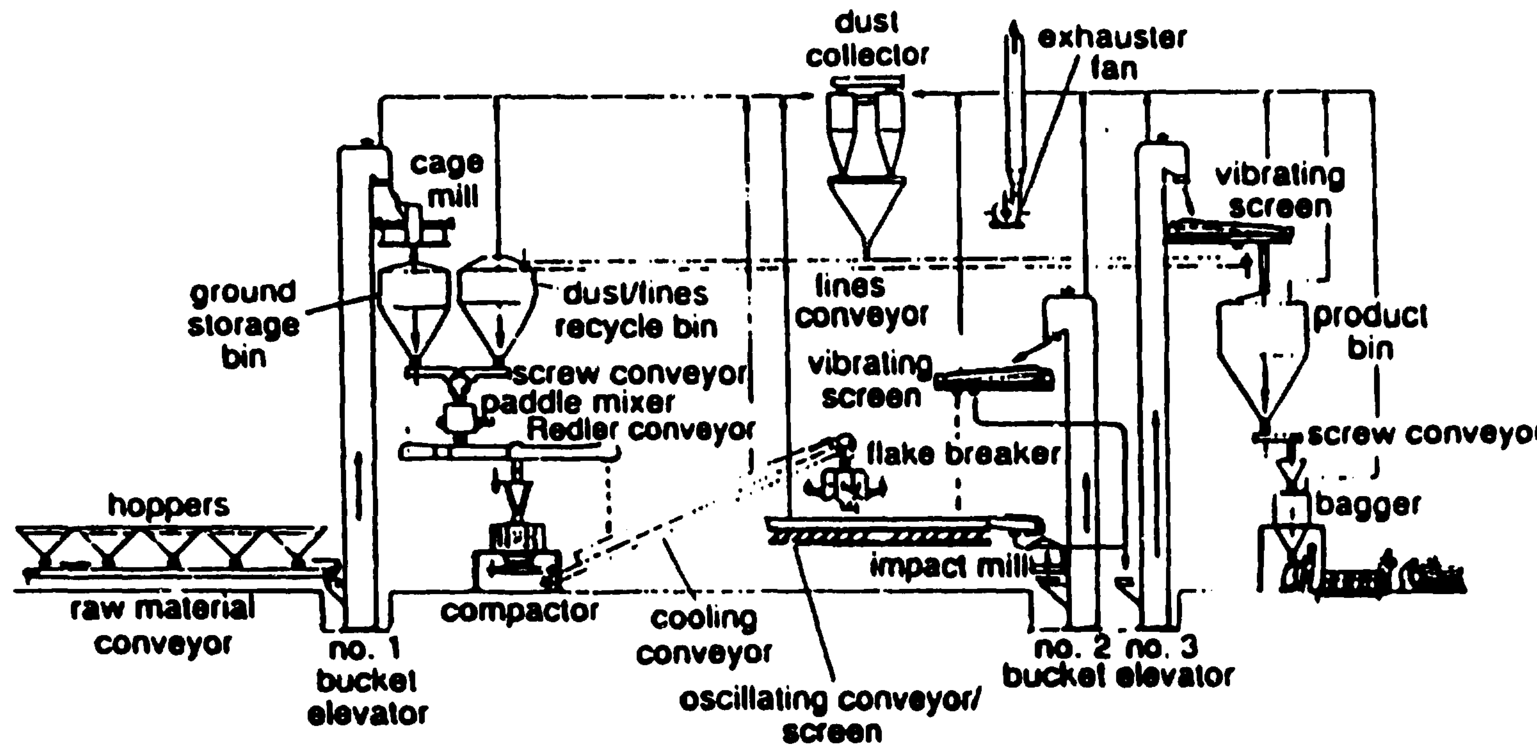
Making no special demands as regards particle size or distribution, the process can be used for handling starting materials of practically any origin.

Furthermore, it is highly flexible and perfectly suitable for small and intermittently operating units.

Thanks to these advantages and others, it is not surprising that compacting is becoming ever more attractive for developing countries and for tropical and semi-tropical agricultural areas where many different crops, with various fertilization requirements, are grown on relatively small areas (see figure 8).

Figure 8

Process flow-sheet for AFC's fertilizer compaction plant



4. PHYSICAL INFRASTRUCTURES

This subject has frequently received due attention on the part of UNIDO, for its vital nature is clear. In this connection we cannot do better than recall what was written in document ID/WG.475/9(SPEC.) of 19 October 1988, prepared by the secretariat of UNIDO [for] the meeting held in 1988 at Yamoussoukro (Côte d'Ivoire).

The investments required for the associated infrastructures are particularly high in the case of fertilizer plants, because we are here dealing with plants producing bulky goods intended for a geographically widely dispersed clientele, using large quantities of a bulky raw material whose production sites are not numerous, and working with a technology which, although well known, makes stringent demands as regards operational timing and precision of applications, hence calls for a labour force well qualified in various fields, and furthermore depends on good maintenance and regular supplies of energy, various inputs and spare parts. For all these reasons, whatever the site chosen for the plant (proximity to a densely populated agricultural region, proximity to the energy source or raw materials source), allowance must be made for heavy infrastructural investments which, while not intended to meet the sole needs of the plant, must nevertheless frequently be effected or undertaken by the very fact that it is there.

A non-exhaustive list of the associated infrastructural investments required already gives an idea of the scale of the essential financing: port facilities, road or rail networks to assure the arrival of inputs or to dispatch finished products to their destination, water, energy installations, electric power plants or high-voltage lines, gas pipelines or oil pipelines, opening or expansion of coal mines, construction of workers' settlements, municipal, educational or medical administrative infrastructures to meet the needs of a large labour force, research centres and vocational training centres, storage capacity at the key trading points etc.

The investments required to ensure the satisfactory marketing of the fertilizers (road and rail networks, warehouses, wholesale and retail stores, transport facilities) together with the cost of personnel capable of performing the operations of ordering, delivery, billing, credit and encashment are enormous, and cannot be borne by the manufacturer alone. It appears probable that certain investments necessary for the distribution of fertilizers would have to be performed by the State in numerous African countries, where the co-operative movement has not yet reached the requisite level of development. This by no means means that the State should itself systematically undertake the marketing of fertilizers. The purpose is that the fertilizer should arrive on the farm, at the right time and in the right quantity and quality, and that the final price to the user should be reasonable. In certain cases the agricultural extension services could take over this task; in other instances, traditional merchants could offer acceptable efficiencies, under a régime either of free prices or prices controlled by the State - depending on local conditions.

The main problem is to decide whether these supplementary investments should be included in the industrial project or not.

Inclusion of infrastructural costs in the industrial project may lead to total investment cost estimates amounting to as much as two or three times the cost of the industrial investment itself. Here it is sufficient to recall the cost of a kilometre of asphalted road in the developing countries or even more the cost of a kilometre of railway, which can easily come to more than a billion dollars. On the other hand, to take into consideration only the plant-internal investments and announce that as soon as the plant is built "the infrastructure will follow suit" would be a sign of dangerous optimism, for how will the plant be able to work if there is no gas pipeline, if the imported items cannot be unloaded at the port, if the raw materials do not arrive at the plant for lack of roads or railways, if electricity supplies are irregular, if storage capacity is insufficient, or if suitable labour cannot be recruited on the spot?

In general, experts in the field of fertilizer plant financing agree that:

- The previous availability or the simultaneous provision of the accompanying infrastructures constitutes an essential prerequisite for implementation of the industrial project;

- The listing and costing of these infrastructures, which are indispensable but still non-existent, should appear in the industrial project;

- The problems presented by allowance for these investments and for their financing should be solved outside the arrangements for financing the project as such, and should not appear in the forecasts of profitability of the fertilizer plant;

- The financing of the accompanying infrastructures should be explicitly based on funds other than those reserved for the industrial project.

In this connection reference may be made to certain recent cases where the distinction between these two types of investment has been clearly set forth:

(a) A recent East Asian regional project provides for the construction in Indonesia of a urea plant of 570,000 tons/year capacity, regionally oriented (the States members of the Association of South-East Asian Nations (ASEAN)). The cost of local labour, the level of Indonesian technical skill, the availability of natural gas in the area chosen (northern Sumatra) and the proximity of the latter to the centres of consumption in the member countries explain the decision taken by the ASEAN Conference. The plant is financed by share capital from the member States concerned and by long-term Japanese loans. Nevertheless, the poorly industrialized and poorly equipped nature of the plant site has obliged the promoters of the project to participate likewise in the financing of certain specific accompanying infrastructures: equipment of a port to permit the import of input materials and the export of urea to member States, installation of a water supply, and construction of a workers' settlement.

(b) In its feasibility studies, the IBRD does not include in its economic or financial profitability calculations for the industrial project any estimates of the infrastructural investment required. However, it does take account of these in determining the technical feasibility of the project, and ensures that the government or the region have made or are prepared to make the requisite infrastructural investments. The Bank may possibly itself participate in financing these infrastructures, but within the framework of other projects (for example a project to promote energy equipment for oil or gas pipelines in which account is taken of industrial projects making use of these infrastructures). One paragraph of the feasibility report for a fertilizer plant, for example, states that:

> "... the timely implementation of the following infrastructural arrangements is essential for the start-up of the project: completion of the gas pipeline to the project site, construction of a barrage and a canal, rail link to the site for the transport of heavy equipment and the dispatch of the urea product. The Bank has been assured that ...".

To sum up, fertilizer plants are particularly demanding in terms of associated infrastructures. In the developing countries, integration of infrastructural facilities or improvements into the industrial project could easily double or triple the financing requirements and reduce or wipe out the profitability of the industrial unit. It is recommended that the developing countries should take account of this need for structural facilities before undertaking a project to construct a plant, which without the appropriate infrastructural environment could not function. Specific financial arrangements must be made for the infrastructural facilities, drawing on public sources on easy conditions (State budget, bilateral or multilateral aid), and they should not be charged to the anticipated investment or operating costs of the industrial project.

The cost of the new infrastructures will be subsequently written off by the entire industrial fabric brought into being by the fertilizer plant and further developed by the existence of the infrastructural facilities.

5. HUMAN INFRASTRUCTURES

5.1 Their importance

Although human infrastructures are every bit as important as physical infrastructures for the success of any industrial or commercial undertaking, their more indefinable character has meant that they received much less, indeed far too much less, attention than they should have been given.

When any operation calls for a technology unknown to the population of the country, training of the necessary personnel cannot be limited to a few weeks of instruction for the principal executives; this procedure, which is current in societies where there is no technolgical gap, is shown to be quite inadequate in a society less developed at technical level.

To prove this point, let us take the example of a young newly graduated technician; on the face of it, his diploma will guarantee that he has theoretical knowledge adequate to carry out the task assigned to him, but it remains for him to learn through practice how this knowledge is applied on the factory floor.

If he is working in an industrial society, this practical training raises no major problems; buttressed on all sides, the young technician learns to apply his knowledge through the instructions he receives from his superiors, through the advice of his colleagues or through observation of the work of his subordinates. And thus, gradually, immersed in a skilled and experienced human environment, the young technician will see how everyday operations - simple or complex - are successfully performed, and how to avoid the hazards which can result in disastrous incidents; in short he will progressively acquire the experience which will imperceptibly turn him into a stalwart of the undertaking, capable in his turn of transferring his knowledge to others because he has become capable of directing his own activities and of reacting coolly in the face of any contretemps that occur - resulting in his taking the right decisions at the right time.

On the other hand, if this same technician starts his industrial career in a pre-industrial society, his training will suffer from the fact that there will not always be (or that there frequently will not be) anyone able to guide him or to show him how to tackle a situation and to analyse it so as to take an informed decision. Quite the contrary, even if he issues correct instructions, it is possible that his assistants will be incapable of executing them correctly and that consequently he will be obliged to pass an inordinate amount of his time in supervisory functions, with the result that he neglects his own real duties and thus, owing to the lack of time and of support, risks making mistakes.

If that happens and the material consequences are serious, he becomes discouraged and liable to lose confidence in himself.

If the above phenomenon is repeated in too many jobs in the undertaking, then the very existence of the latter is at stake. There are quite a few undertakings which have been shut down on grounds of financial loss, whereas the real cause of failure was the frailty of the human pyramid which should have inspired them.

5.2 Action to be taken in order to establish human infrastructures

Apart from the general level of education of the population, which is looked after in other programmes, the establishment of human infrastructures to accompany the transfer of technology should be organized in a thoroughly professional manner. The scope of this operation - the number and status of the persons trained, the duration of training etc. - will depend on the size and degree of sophistication of the undertakings concerned.

At all events, any transfer of technology should include the establishment of human infrastructures necessarily involving the three stages which we shall denominate by the terms "training", "assistance", "guidance".

These three stages can be described in greater detail as follows:

Training is undertaken prior to the commissioning of the plant; it should include theoretical instruction on the subjects involved and should then be supplemented by the practical application of these subjects by means of a course at a plant belonging to the same or a similar industry.

It should embrace a sufficient number of technical and administrative executives to impart solidity to the human pyramid as constituted, making allowance for an anticipated rate of failure or drop-out.

Assistance in commissioning the plant:

- Should be provided by an adequate team (in terms of numbers, quality and personality), appointed by the builder and/or the licensor;

- Should include the physical acceptance of equipment (inspection, checking of its suitability for the intended purpose), industrial commissioning of the plant and the obtaining of the stipulated performance.

Guidance following training should be carried out by experienced executives:

- Recruited from outside on the basis of their knowledge, experience and ability to teach by example and by precept;

- For a lengthy period (several years if necessary);

- Whose clearly defined task, apart from their technical assignment proper, is to train the staff under their supervision, some of whom will be called upon to replace them subsequently.

It is important to note that human infrastructures involve not only the plant operators but also the entire machinery of the enterprise, in the form of commercial, financial, administrative or technical services.

6. COST AND FINANCING

6.1 Cost of establishing human infrastructures

An organization responsible for establishing human infrastructures may require the services of many people for several years; it will therefore be appreciated that it is expensive and that the few percentage points of the total investment generally assigned to these infrastructures represent the preliminary costs in an industrialized society.

In a non-industrialized human environment, it is essential to undertake a thorough evaluation and one will not be surprised that these costs amount to more than 10 per cent of the total investment, and even several tens of per cent if the degree of sophistication of the undertaking is fairly high.

Furthermore, it must be clearly recognized that the training of human infrastructures and their "breaking in" are ongoing processes and reach their full fruition only with the commercial operation of the undertaking. It is at the same time clear that, when human infrastructures are in course of training, the coming onto stream of the plant will be slower and that this constitutes an appreciable factor weighing on the initial profitability of the undertaking.

When the staff begins to come to grips with actual practice, it is recommended that it should be supported and encouraged by having it participate in courses or sessions of further training, to which it will now be more receptive because it will be more motivated. And this will represent yet another item of expense to be allowed for in advance.

Anyone who has known the operational hazards attending modern undertakings in non-industrialized environments and the financial and human failures to which such hazards have given rise cannot but be ready to underwrite this concept of establishing human infrastructures.

As set forth in the preceding pages, this concept is much wider than the simple idea of specialized training normally included in cost estimates. Furthermore, it does not stop with the commissioning of the plant, but continues for a long time afterwards, until the plant has been fully taken over by the local teams.

Thus, the relevant costs do not figure in the item "Prior expenditure: 1-5 per cent" appearing on page 13 of document ID/WG.475/9(SPEC.) referred to at the beginning of chapter 4. The calculation, or rather the estimation, of this item should be done on a case-by-case basis. It will depend to a large extent on the degree of complexity of the undertaking and the technological threshold between it and its human environment.

However, the important thing is to remember that the order of magnitude is not 1-5 per cent but quite probably 25-50 per cent of the total investment.

6.2 Financing of human infrastructures

It was no accident that chapter 4, devoted to physical infrastructures, has been borrowed from an earlier UNIDO document. It is recommended therein that "developing countries take account of such structural matters before launching into a project to instal a plant which will be unable to function without this back-up. But they must be provided with specific financing for this purpose, from public sources, on easy terms (State budget, bilateral or multilateral aid) and not charge the investment expenditure or running costs in question to the industrial project". This view is not only that of the secretariat of UNIDO, which prepared the document, but also that of other international organizations such as the IBRD, and has likewise been sanctioned by experience in a number of projects mentioned.

Now, let us clearly ask ourselves:

- Since "training costs" of the order of 1 to 5 per cent of the investment have been proved to be inadequate;

- Since there is in fact a need to establish human infrastructures costing several dozen per cent of the investment;

- Why not handle their financing like that of the physical infrastructures, i.e. by having recourse to sources offering easy terms and not by charging the cost to the industrial project?

A responsible attitude like this, which consists of looking facts in the face and of taking full account of them, seems much more likely to lead to success than the attitude allowing only 1 to 5 per cent for "training costs", followed by the discovery after a year's operation that the enterprise is in the red and requires restructuring.

How to go about things in practice?

It is necessary:

- Either to deal with entities which have available or are capable of recruiting the manpower necessary for establishing the human infrastructures. In this case payment can be made either directly or through the intermediary of settlement agreements (barter, parallel import and export agreements, repurchase of finished products etc.);

- Or resort to forms of association with foreign entrepreneurs and financiers such as the type of joint venture known as B.O.T. (build, operate and transfer). This is an agreement concluded under government auspices between a local undertaking and a foreign enterprise or group with a view not only to implementing but also to financing and managing ("provisionally for a long time") a large-scale economic project, normally an industrial one. The agreement, which bears a strong resemblance to a temporary public service concession applied to the industrial sector, provides in particular that the foreign partner will be responsible for locating sources of financing, making the financial arrangements, profitably managing the project for 15 years and then selling to the local minority partner the entire industrial concern after it has given evidence of its viability. Such a system is conceivable only in the framework of a liberal and open economy, and it obliges the foreign partner to ensure highly efficient and profitable operation, since in practice his investment outlay will be recovered only after 15 years, and if he still wishes to start making a profit on his investment, his management must be excellent.

Another advantage is that the local minority partner has a low investment burden to bear and will benefit from a genuine transfer of technology (including management skills), which will extend over many years. Finally, the local economy will benefit immediately, without undue initial expenditure, from the production of the plant and will recover full ownership of the latter at a modest cost, since a large part of the equipment will by then have been written off.

Thus far, operations of this type have had to do mainly with the energy sector (a thermal power plant in Turkey and a nuclear power plant in Indonesia), i.e. large-scale projects (over a billion dollars).

There is no doubt that such a procedure represents a gamble on the part of the foreign partner, in terms of respect by the local economy for the undertakings into which it has entered and of a relative freedom of selling prices, and as a pre-condition assumes advance agreement on the final transfer price etc. An immediate problem, which however appears to have been solved in the case of the Turkish project, is the attitude of export credit institutions in the industrialized countries, since it seems likely that the foreign partner, investor and financier will definitely need to refinance part of his investment. But this does not become a real export operation until the expiry of the 15 years, a period on the face of it too long to qualify for a normal export credit.

An alternative consists in lowering the technological threshold, but we saw in chapter 1 that this is possible only in land-locked areas shielded from world price competition by the effect of very high ancillary costs. In such cases mini-plants based on simplified processes may be in a good position to defend themselves; one of their advantages, and not the least, consists in simplicity and lack of sophistication, which make it possible to reduce the cost and duration of manpower training and permit the rapid achievement of full capacity utilization.

7. CONCLUSION

The purpose of this meeting is to determine under what circumstances the establishment of fertilizer mini-plants may contribute to the development of agriculture in the developing countries. That being so, cases will be sought where these conditions apply or where their existence can be encouraged, and then efforts will be made to promote the establishment of a number of mini-plants.

Economically speaking, the establishment of fertilizer mini-plants will favour agricultural development in places where such installations are capable of producing fertilizer cheaper than is at present possible. But, as we have seen in this paper, the universalization of the fertilizer trade, based on mega-plants close to large raw materials sources, has brought about a downward levelling of fertilizer prices, at least in respect of standardized fertilizers having undergone a first or second processing stage.

The establishment of mini-plants can therefore be contemplated only in places sufficiently remote from the great world-trade routes, in this instance deep-sea ports, with the result that the ancillary costs (made up of unloading, storage, maintenance, transport, re-storage, distribution and credit costs) represent a significant proportion with regard to the price of the fertilizers delivered free port.

And here again, in such cases, it is necessary to define what fertilizers are to be produced.

If raw materials are available for the production of nitrogenous or potash fertilizer, the complexity of the chemical and/or physical processes involved demands a minimum scale which exceeds that of mini-plants. It is thus necessary to have access to adequate material and human resources and to a sufficiently large market, which normally goes beyond local dimensions and reaches those of at least a regional market.

If on the other hand phosphate resources are available, it is enough to supply under adequate conditions the acid required for solubilization of the phosphate in order to derive fertilizer products which are simple and adaptable to local market capacities.

It is thus in the field of phosphates that a start could be made on the construction of fertilizer mini-plants offering the greatest chance of success.

This is favoured by the following circumstances:

- Many countries, particularly in Africa, have phosphate resources of more or less acceptable quality;

- The acidification methods - whether total or partial - are simple; they can take the form of batch or continuous processes;

- The technologies involved adapt themeselves well to simple plants making maximum use of local materials and manpower;

- The level of sophistication of these plants can be very low, thus putting them within reach of the operators.

That is therefore the framework within which a search should be made for situations favourable to the establishment of fertilizer mini-plants and their construction encouraged.

Naturally, it can be maintained that circumstances or factors other than economic conditions come into play, such as for example:

- Strategic considerations;

- Exchange control policy.

However, these factors should be treated with care, because whenever making allowance for them increases the price for fertilizers, it holds up agricultural development to a corresponding degree.

Furthermore, whereas such a price increase may possibly be accepted by the country where the plant is located, this does not mean that it can be imposed on other countries.

The result would be the need to stay on the domestic market only, or engagement in export operations at prices lower than cost.

That is why schemes for the establishment of mini-plants should in all cases be economically competitive.