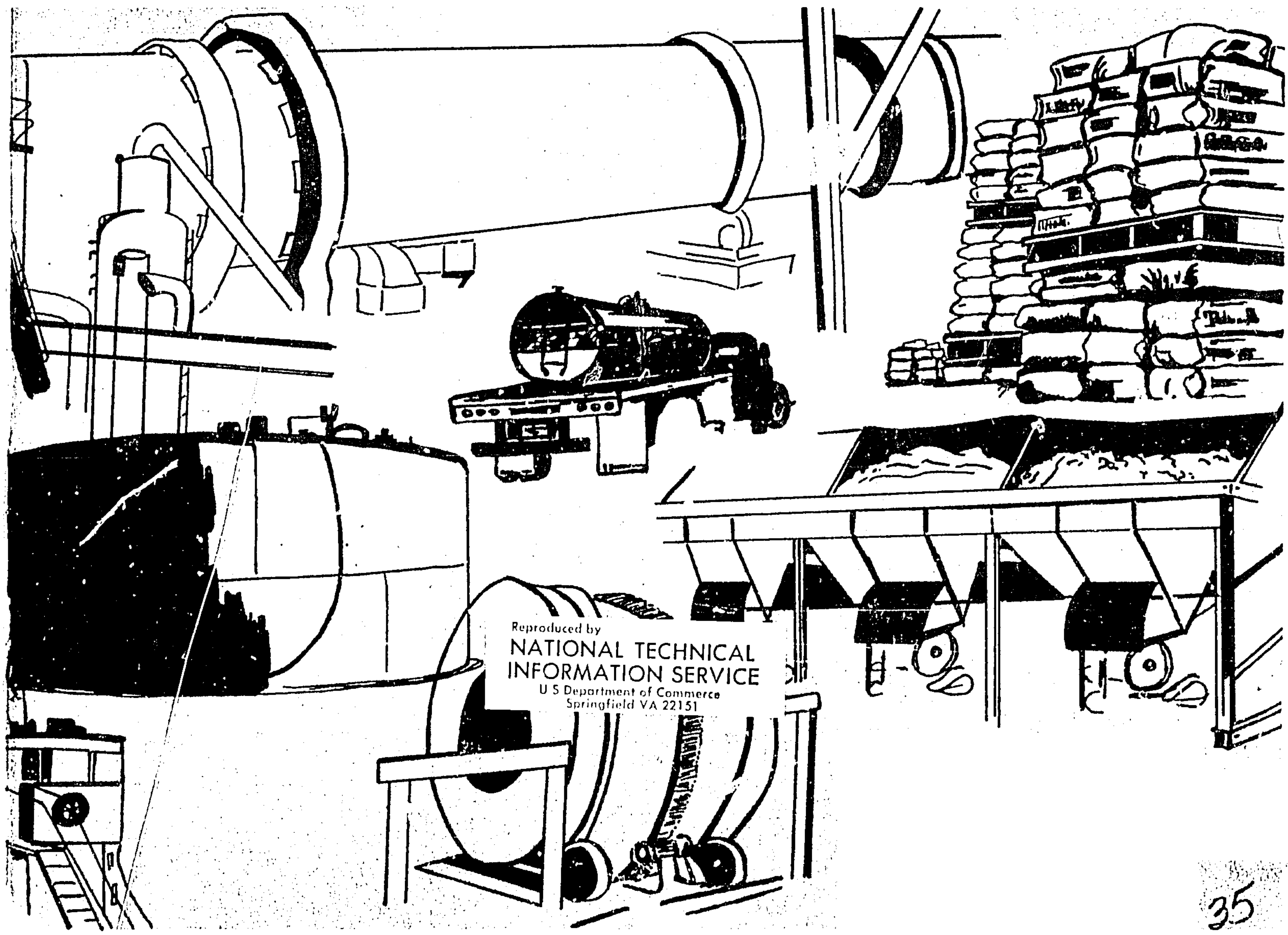
PB 219 740

Ammonia-Urea Solution for Ammoniation-Granulation in BRAZIL



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by

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Many countries are considering alternative methods for increasing the output of fertilizers and fertilizer intermediates. Numerous studies have been made for various countries surveying alternative production schemes which could be utilized. This report gives details of a granulation process based on the ammoniation of superphosphates with ammonia-urea solution in a rotary-type drum granulator. Granulation is a process whereby rounded or spherical particles are produced through a fusion, solution, crystallization, or cementing process between various materials. To obtain spherical particles, it is necessary to impart a rolling-type action to nuclei; these nuclei serve as a base for building larger particles which grow to product size. Information for this report is based on actual experience during startup and operation of a plant in Porto Alegre, Brazil. The ammoniation-granulation plant there consists of a volumetric-type solid feed system, ammonia-urea solution feed system, TVA drum ammoniator-granulator, dual pan granulators, dryer, cooler, and screening system. Data are given to illustrate the possibility of grades that can be made, ~~but are not meant to be a limiting factor for a plant of this type.~~ The data were obtained during full-scale plant operation. Grades such as 5-22-10, 8-24-12, 10-30-15, 6-30-12, and 9-36-12 were produced. Products made during the testing program were hard, well-rounded, and less dusty than those previously made by water granulation. The grades were not as precise as desired since some difficulties were encountered in feeding solid raw materials accurately. This report is intended to serve as a guide in granulation for countries not having such conventional materials as anhydrous ammonia and acids. Equipment used in this process is readily adaptable to the use of anhydrous ammonia and acids as they become available.

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Introduction

Many countries are considering alternative methods for increasing the output of fertilizers and fertilizer intermediates. Numerous studies have been made for various countries surveying alternative production schemes which could be utilized. This report gives details of a granulation process based on the ammoniation of superphosphates with ammonia-urea solution in a rotary-type drum granulator. The process is in use in Brazil and may have potential application in other developing countries. At least it should be considered, along with other processes, such as production of single materials or intermediates, bulk blending, other granulation processes, or even fluid fertilizer production.

Information is based on actual experience during startup and operation of a plant in Porto Alegre, Brazil. Data are given to illustrate the possibility of grades that can be made, but are not meant to be a limiting factor for a plant of this type. The data were obtained during full-scale plant operation. Grades such as 5-22-10, 8-24-12, 10-30-15, 6-30-12, and 9-36-12 were produced and standard formulations are given for these grades. Other possible grades and formulations are discussed.

This report is intended to serve as a guide in granulation for countries not having such conventional materials as anhydrous ammonia and acids. The process may serve for an intermediate period to allow production of homogenous, granular products until such time that other granulation materials become available. Equipment used in this process is readily adaptable to the use of anhydrous ammonia and acids as they become available.

Background

A TVA-AID (Tennessee Valley Authority-Agency for International Development) study—*Cost Comparison of Ocean Shipment of Anhydrous Ammonia and Solid Urea Versus Shipment of Urea-Ammonia Solution*, December 1966—was made to indicate the technical and economic feasibility of storage, handling, and transport of a solution containing ammonia, urea, and water which exhibits no gauge pressure at ambient temperatures. This solution was suggested for use as an alternate material for ammoniation-granulation. The solution can be handled in mild steel, nonpressure tanks which are usually available, even in less developed countries. This study was initiated by Dr. D. L. McCune of TVA who recognized the need for such a solution in developing countries. A pressure system is required for handling, storage, and transport of anhydrous ammonia.

At a meeting of ANDA (Associacao National para Difusao de Adubos) held in Sao Paulo, Brazil, in May 1970, Frank Achorn reported on "Some Processes for the Production of Granular Fertilizers" in which he described raw materials, equipment, and formulations for granulation of fertilizers. Dr. Shu Lin Peng of CRA (Companhia Riograndense de Adubos) exhibited much interest in the use of ammonia-urea solution in a TVA-type ammoniation-granulation process. CRA, which is located in the southern part of Brazil, does not have anhydrous ammonia. Facilities are being constructed at the ocean port of Rio Grande, Brazil, for storage of liquid anhydrous ammonia at low temperature and atmospheric pressure. However, river shipment is required over a distance of 300 km (kilometers) (180 miles) to reach the CRA plant at Porto Alegre, Brazil. At some time in the future, it is expected that barge and storage facilities for anhydrous ammonia will be available in Porto Alegre, Brazil. To proceed with production of granular fertilizers, CRA chose to install a TVA-type rotary ammoniator-granulator and to obtain facilities for storage, handling, and transport of ammonia-urea solution. Some equipment—such as dual pan granulators, dryer, cooler, and screens—was already installed and had been used previously to produce granular normal superphosphate (NSP, 0-20-0) and some mixed grades based on water granulation.

At the request of CRA, two chemical engineers, Frank P. Achorn and Owen W. Livingston, were made available to the company during February 14 to March 24, 1972, to provide formulations and supervise startup tests for the process. This report is mainly a summary of TVA experience in operation of this plant.

Granulation Plants

Methods of Granulation

Granulation is a process whereby rounded or spherical particles are produced through a fusion, solution, crystallization, or cementing process between various materials. To obtain spherical particles, it is necessary to impart a rolling-type action to nuclei; these nuclei serve as a base for building larger particles which ultimately grow to product size. In order to achieve granulation, liquid phase must be present. Liquid phase consists of water plus fertilizer salts dissolved in it. Most operators agree that best granulation is achieved when the temperature is increased to increase salt solubility rather than by addition of extra water. At elevated temperature, granulation can occur at a lower moisture content and generally leads to the production of stronger granules.

Three basic types of equipment are used in granulation processes employing ammoniation: (1) batch mixer, (2) pugmill, and (3) rotary drum. Other types, such as the pan granulator and fluidized bed also have been used.

The most widely used ammoniation-granulation process employs the rotary drum (figure 1). This system is operated on a continuous basis. It consists of solid and liquid feed systems, drum ammoniator-granulator, dryer, cooler, and screens. An oversize mill removes the oversize particles by grinding; fine material is recycled to the drum ammoniator-granulator along with solid feed materials.

Numerous formulations generally can be used to make a certain grade depending on availability of raw materials. The chemistry and physics of the formulation should be studied in detail as they will affect the operating characteristics. For example, if heat generated by the chemical reactions is insufficient to dry the product, a dryer will be required. If too much heat is generated, water will be required to remove the excess. Most granulation plants now in operation require a dryer.

Ammoniation-Granulation in Porto Alegre, Brazil

Figure 2 shows the ammoniation-granulation plant in Porto Alegre, Brazil. It consists of a volumetric-type solid feed system, ammonia-urea solution feed system, TVA drum ammoniator-granulator, dual pan granulators, dryer, cooler, and screening system. This system is different from conventional plants in that two pan granulators operating in parallel follow the rotary drum. This equipment without the drum granulator had been used previously for granulation of NSP and some mixed grades using water as the granulating medium. Also, the dryer and cooler are mounted on the same level and are connected via a transfer chute and lifting flights in the dryer. Since the heat of reaction between ammonia-urea solution and superphosphates in the process is relatively low, a steam boiler is used to supply supplemental heat.

The process is based primarily on the reaction of ammonia-urea solution with run-of-pile NSP (ROP NSP) and run-of-pile triple superphosphate (ROP TSP, 0-46-0). Other materials such as granular diammonium phosphate (DAP, 18-46-0), monoammonium phosphate (MAP, 11-55-0), and potassium chloride (KCl, 0-0-60) are used

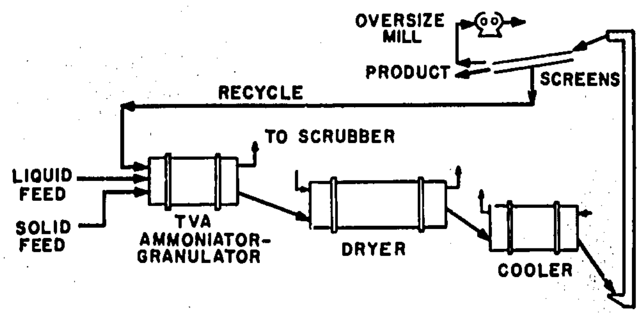


Figure 1. Conventional granulation system using TVA ammoniator-granulator

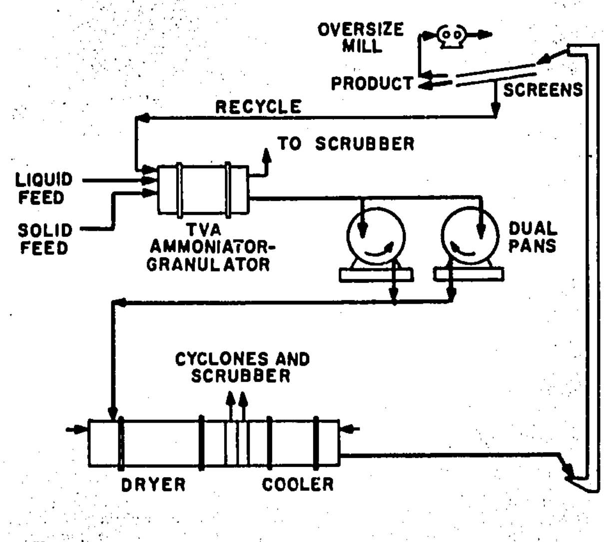
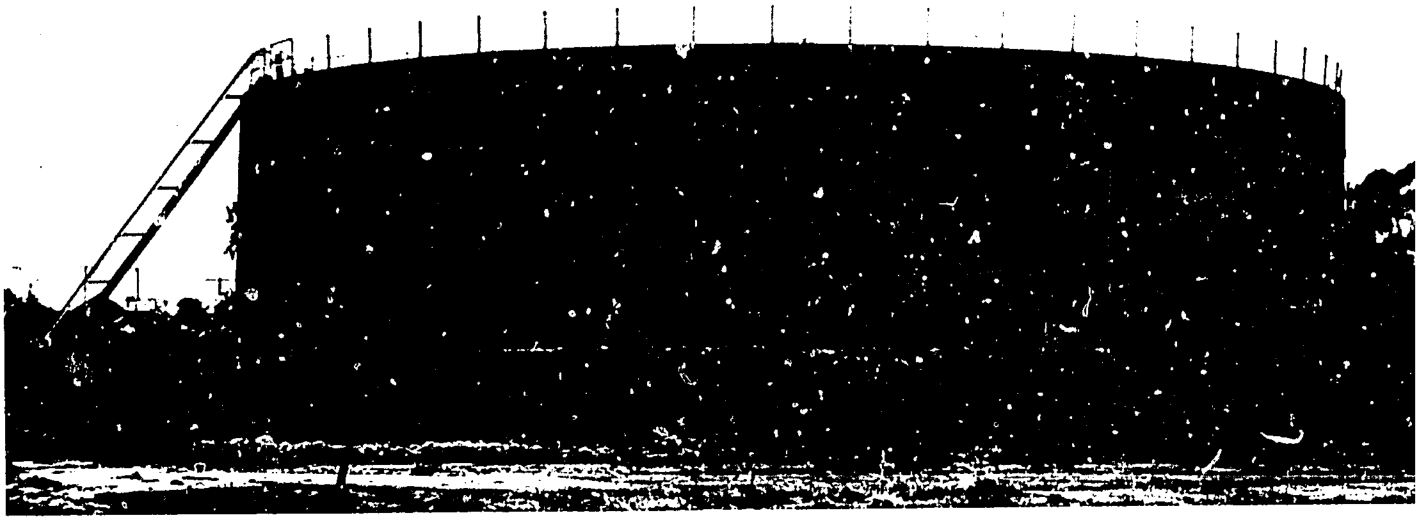
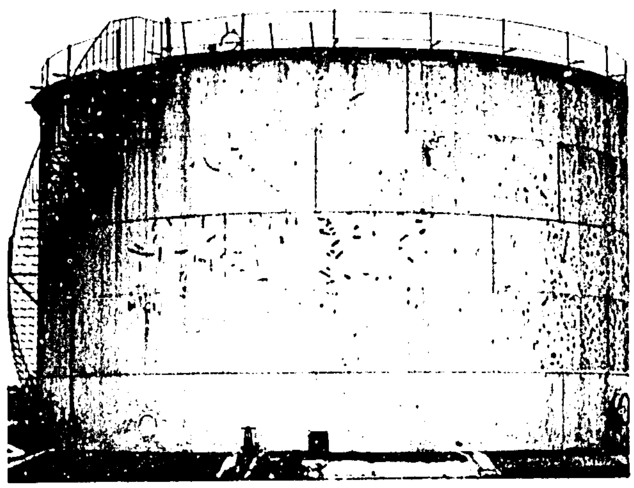


Figure 2. CRA granulation using TVA ammoniator-granulator followed by dual pan granulators



Storage of ammonia-urea solution in Rio Grande is in a tank previously used for fuel oil (above). Water in tank at right is available for cooling the ammonia-urea storage tank but has not been necessary.



when available. No acids such as phosphoric or sulfuric are used at this time. Recycle fines are premixed with the fresh feed before entry into the granulator. The plant is described in more detail in other sections of this report.

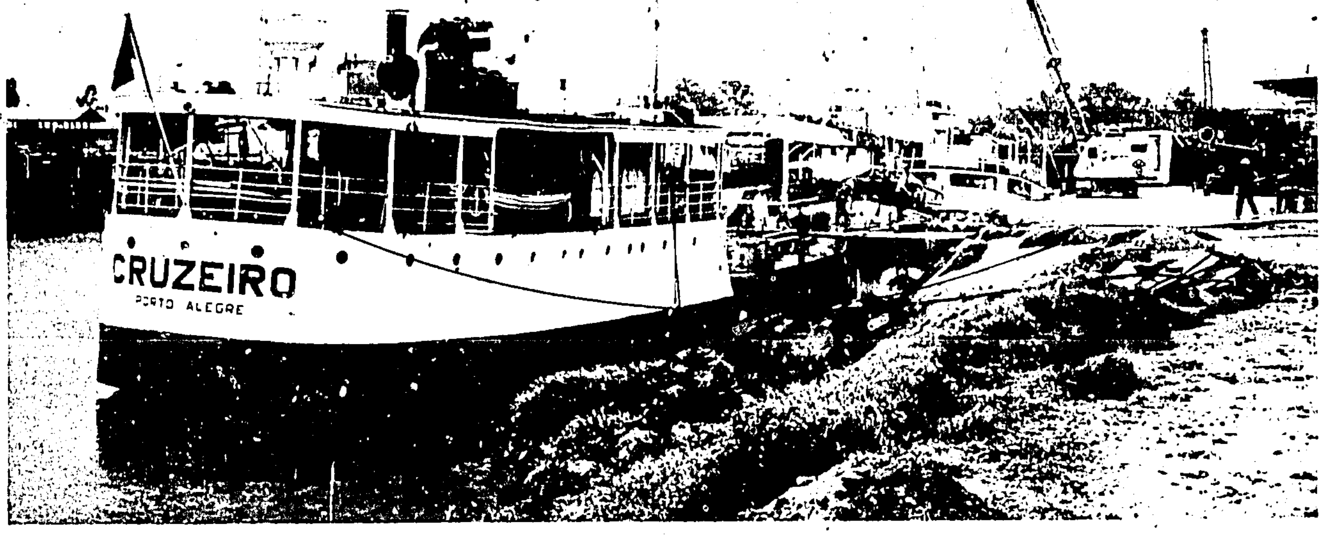
Raw Materials Used

The ammoniation-granulation plant is highly dependent on imported raw materials. Only ROP NSP is produced at the plant. Other materials–such as ROP TSP, MAP, DAP, and KCl–are imported through the ocean port of Rio Grande and transshipped via river barge to Porto Alegre. A small amount of urea is imported. Ammonia-urea solution also comes through Rio Grande to Porto Alegre; storage is provided for solution at both locations.

Storage of Ammonia-Urea Solution [33 Percent (%) N] —The ammonia-urea solution (30-33% N) was obtained from a Dutch company (see appendix) and contained up to 33% N, 16% ammonia, and 44% urea. TVA originally recommended a composition of 33% N, 19% ammonia, and 37.5% urea. However, due to possible vapor pressure of 0.35 kg/cm^2 (kilograms per square centimeter) [5 psig (pounds per square inch gauge) at 41°C (105°F)] of the TVA solution, the Dutch company lowered the ammonia content and increased the urea content. The solution was made in Sluiskil, The Netherlands. The first ocean shipment, consisting of 6,488 mt (metric tons), arrived in Rio Grande on February 9, 1972. The maximum temperature reached during the voyage in any of the tanks was 32°C (89°F) (see appendix).

Storage in Rio Grande is in a used tank with a capacity of 8,500 mt in which fuel oil had been stored. The tank is vented to the atmosphere, and cooling water is available to the top of the tank but has not been used. The maximum temperature recorded in the tank, thus far, is 27°C (80°F). The filling procedure for the large tank at Rio Grande and the smaller tanks (300 mt) at Porto Alegre is as follows: (1) a thin layer of 2.5-5.0 cm (1-2 in.) of water is first pumped into the tank, (2) about a 12.5 cm (5-in.) layer of bunker-C fuel oil is next added, and (3) ammonia-urea solution is then pumped in. A 12.5 cm (5-in.) layer of fuel oil was found to render the solution essentially nonvolatile. No ammonia odor was apparent at the tank vent.

When solution is loaded onto a river barge for transshipment, gravity is used to fill the tanks, but a pump is available for later use. The first shipment consisted of 300 mt and was loaded in only two of the four tanks of the river barge. The barge is used for hauling gasoline from Porto Alegre to Rio Grande and uses bronze for pump impeller and valves. During backhaul of ammonia-urea solution from Rio Grande to Porto Alegre, these are changed to mild steel. The barge is equipped with one centrifugal pump with a capacity of 100 mt per hour (mt/hr). The transfer line from the barge to the plant-site storage tank consists of 10-cm (4-in.) PVC of length 130 meters (m) (426 ft). About 24 m (82 ft) length of a special



This gasoline barge delivers ammonia-urea solution from Rio Grande to Porto Alegre as a backhaul.

kind of flexible material (trade name Heliflex) is used to connect the barge to the fill line.

It should be pointed out here that special precaution should be taken in regard to barge tanks during cleaning. It is advisable to ventilate the tanks, such as with a forced-air fan, to obtain a low level of ammonia. The rapid dissolution of ammonia vapor left in the tank could cause the tanks to collapse. Additional information on ammonia-urea solution is given in the appendix.

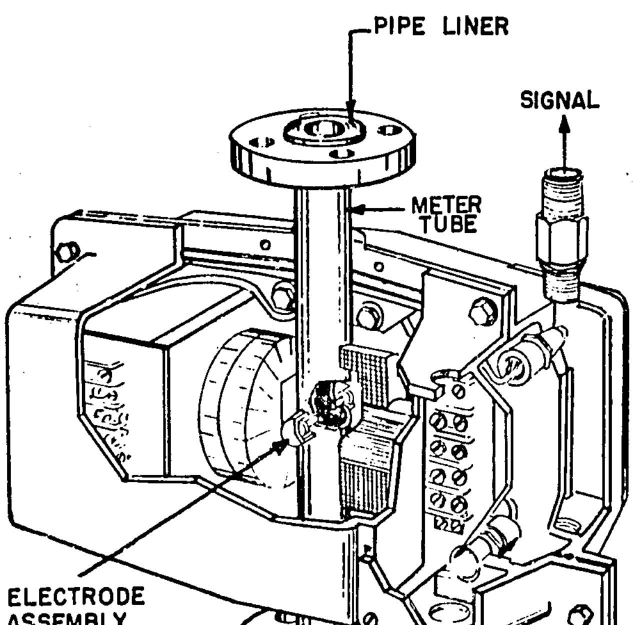
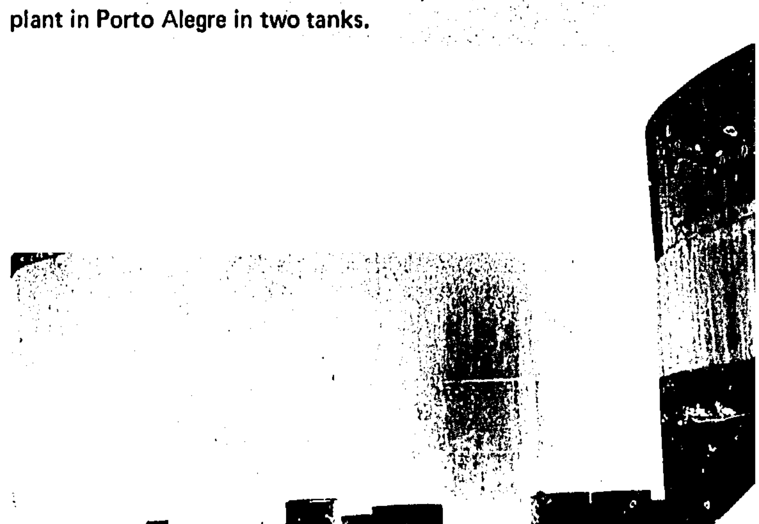


Figure 3. Magnetic flowmeter

Feeding of Ammonia-Urea Solution to Process—A mild steel centrifugal pump is used to feed the solution to the ammoniator-granulator through a 5-cm (2-in.) mild steel pipe. In the plant, a rotameter with a teflon float and pyrex sight glass is used to meter the solution. Since the pump and meter are sometimes used for only water (granulation of NSP), the pump is equipped with a valve system for changing the feed.

In the United States a magnetic flowmeter as shown in figure 3 is the most frequently used meter for metering nitrogen solutions in ammoniation-granulation plants. This meter operates on the principle that a conductive fluid will generate an induced voltage when flowing through a magnetic field. The amplitude of the voltage, thus produced, is directly proportional to the flow rate of the

Ammonia-urea solution is stored at the plant in Porto Alegre in two tanks.



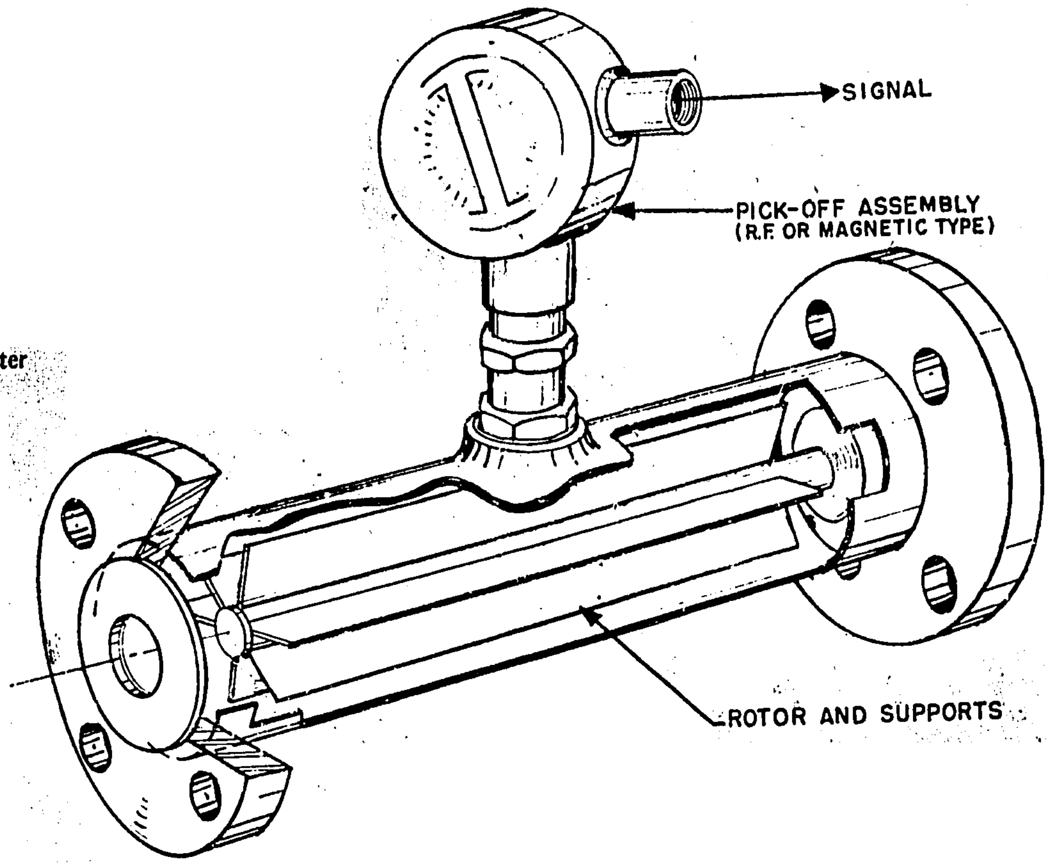


Figure 4. Turbine flowmeter

metered fluid. This voltage is used for indicating and can be used to control the flow.

Another type of meter used for nitrogen solutions is the turbine flowmeter (figure 4). The fluid passes through the metering area causing an internal rotor to turn at a speed directly proportional to flow velocity. The rotor spin is translated into an electrical signal through a radio frequency pick-off coil or a magnetic pick-off. This meter can also be used to control fluid flow; however, many companies report this meter is very complex and requires considerable maintenance.

A meter shown in figure 5 operates on the principle of vortex shedding. The flow of a fluid against a bluff or a nonstreamlined body is detected by sensors mounted in the bluff. These sensors are electronically self-heated resistance elements whose temperatures (resistances) vary as a result of velocity variations on the front face. These signals are converted electronically into readout or control devices. This type of meter is being used to meter nitrogen solutions in a few ammoniation-granulation plants. The plants report the meter is accurate and requires little maintenance. Its investment cost is significantly less than the conventional magnetic flowmeter.

Steam from the boiler is not metered. Water is sometimes used in a few grades and is added in overbed spargers. This water is also metered with a rotameter.

Solid Raw Materials—Solid raw materials used in the plant are typical of those available to any plant. The

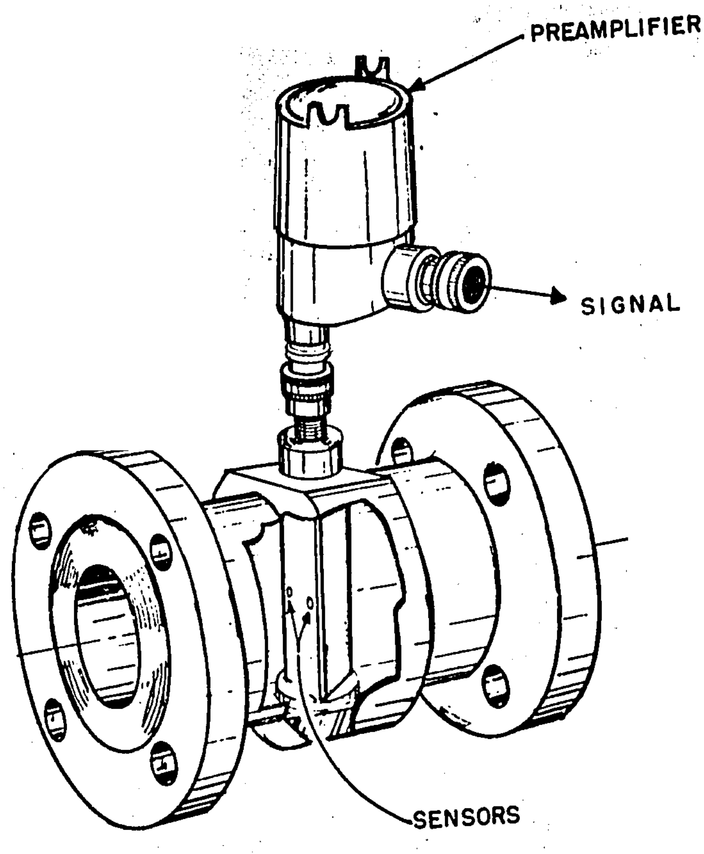
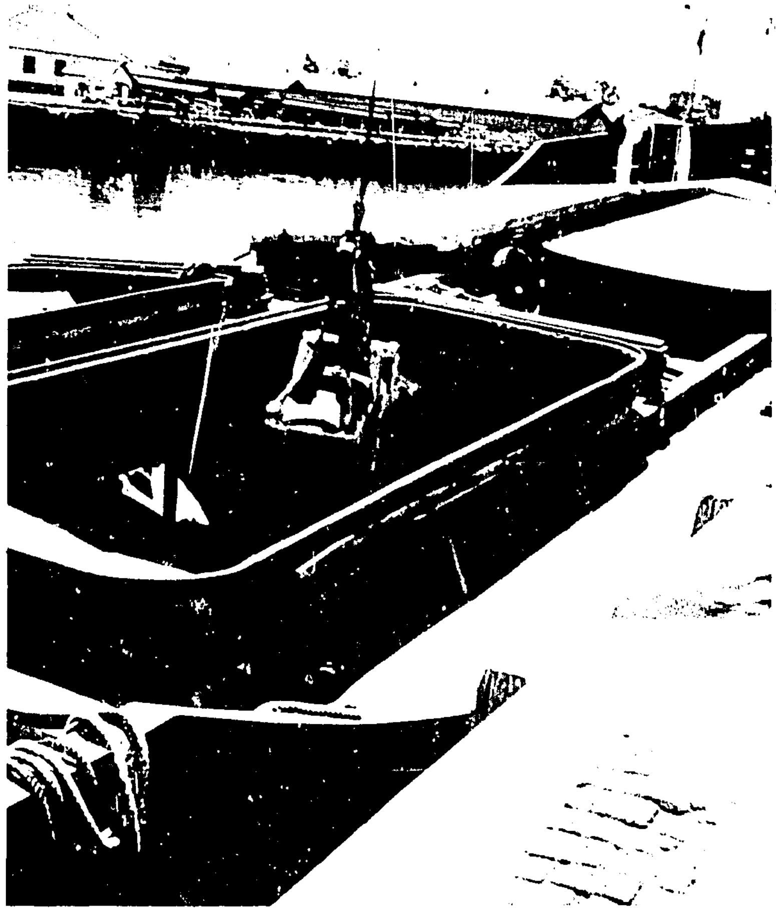


Figure 5. Vortex shedding flowmeter

Table 1. Composition of solid feed materials used in ammoniation-granulation plant

Material	Total N	Total P_2O_5	Citrate-[a] soluble P_2O_5	K_2O	H_2O humidity
NSP (0-20-0)	–	21.3	19.4	–	7.5
TSP (0-46-0)	–	47.2	45.2	–	4.0
DAP (18-46-0)	18.0	47.9	47.6	–	5.0
KCl (granular)[b]	–	–	–	61.6	0.5
KCl (powder)[c]	–	–	–	62.0	0.0

[a]Neutral ammonium citrate.
[b]98% of this material is +16-mesh and 71% is +8-mesh (Tyler).
[c]1% of this material is +16-mesh and 92% is +60-mesh (Tyler).



Solid raw materials such as phosphate rock, TSP, DAP, and KCl are transported via river barge from Rio Grande to Porto Alegre.

composition of the materials is given in table 1. At this plant two size ranges of KCl were available which differed greatly from the usual "standard" KCl. The larger KCl was 71% plus 8-mesh (Tyler). Use of this material alone caused the product to have individual particles of KCl visible in it. The powdered KCl was 92% plus 60-mesh (Tyler) which was difficult to meter accurately in the volumetric feeders. In most tests a 50:50 mixture of large:fine KCl was used.

The feed system for the solid raw materials is shown in figure 6. This system consisted of raw feed hopper equipped with an adjustable gate and fixed belt. This hopper is filled with a front-end loader. Material from this hopper flows to an elevator which lifts the material to an oscillating screen to remove lumps. Lumps are broken by a hammermill and returned to the screen. Material through the screen feeds to an inclined conveyor which feeds a

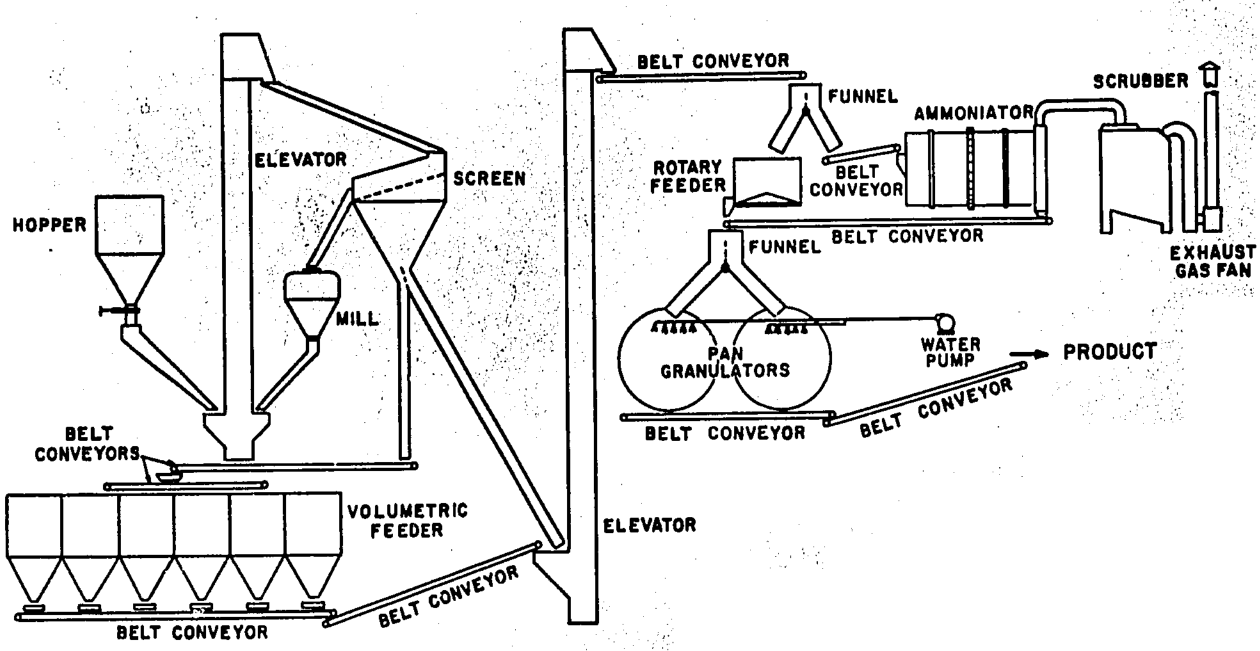


Figure 6. Solid feed system

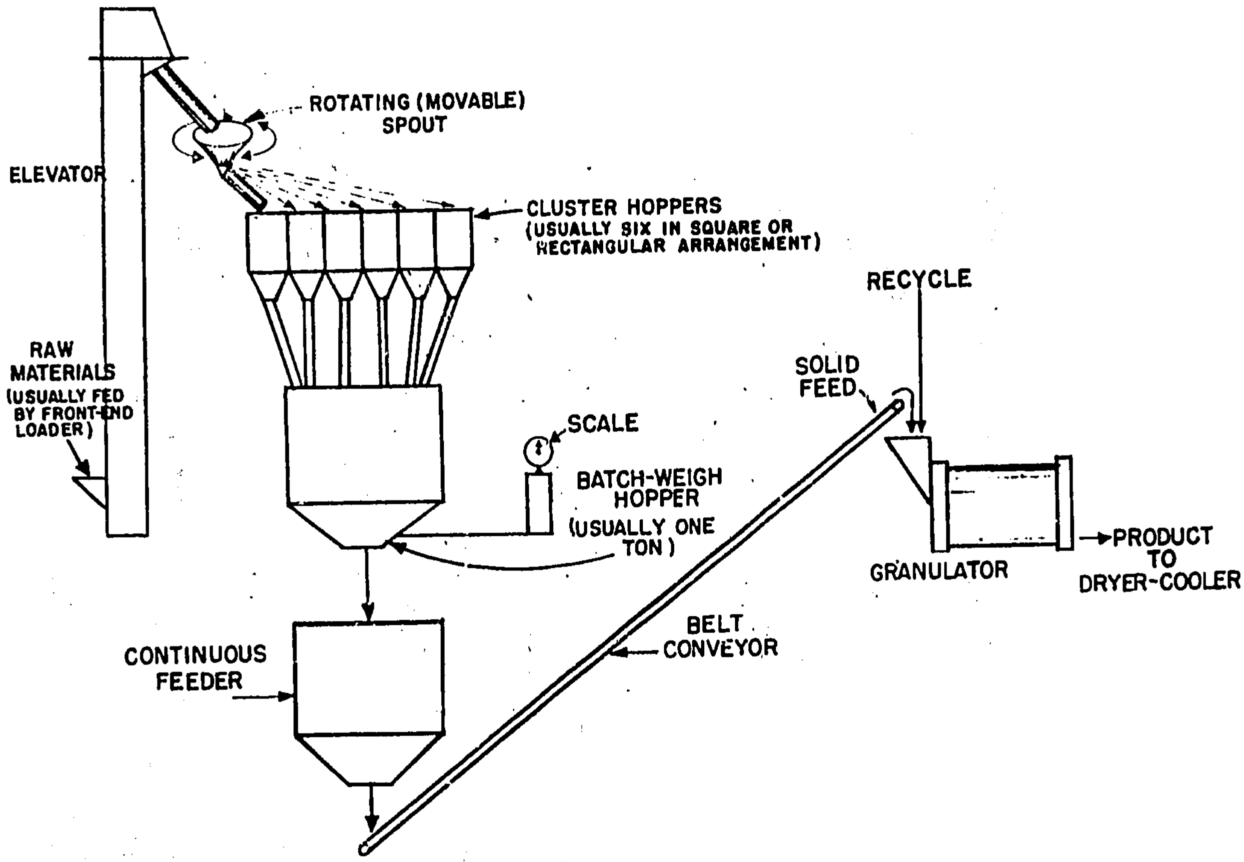


Figure 7. Solid feed system using a batch-weigh hopper

shuttle conveyor. This shuttle conveyor is used to fill the hoppers of the belt feeders. Material not requiring screening was placed directly into the hoppers of the belt feeders with a front-end loader. All powdered materials, such as NSP, TSP, and KCl, required screening. Each belt feeder could be operated independently. Material was metered by adjustment of a gate which allowed material to drop onto a constant-speed belt. Another system of bucket elevator and conveyors feeds solid materials to the granulator. Some difficulties were encountered with these feeders as originally designed. Baffles in the bottom of each hopper were not properly designed and powdered materials tended to "bridge." New baffles were installed. Also, vibrators were installed to aid in feeding powdered materials. Fresh material was used and material was not allowed to remain in the hoppers for extended periods.

One of the most popular and accurate methods of feeding solid materials is the batch-weigh hopper. It consists of a coarse grating which allows material to fall into a bucket elevator; a front-end loader is used to fill the elevator. Each material is elevated to a cluster hopper (usually six). Each hopper is equipped with a quick-opening gate at the bottom; the gate often is operated hydraulically. A batch-weigh hopper (usually 1-ton capacity) is filled with the proper amount of each material based on the formulation. The amount added is weighed and, after each material

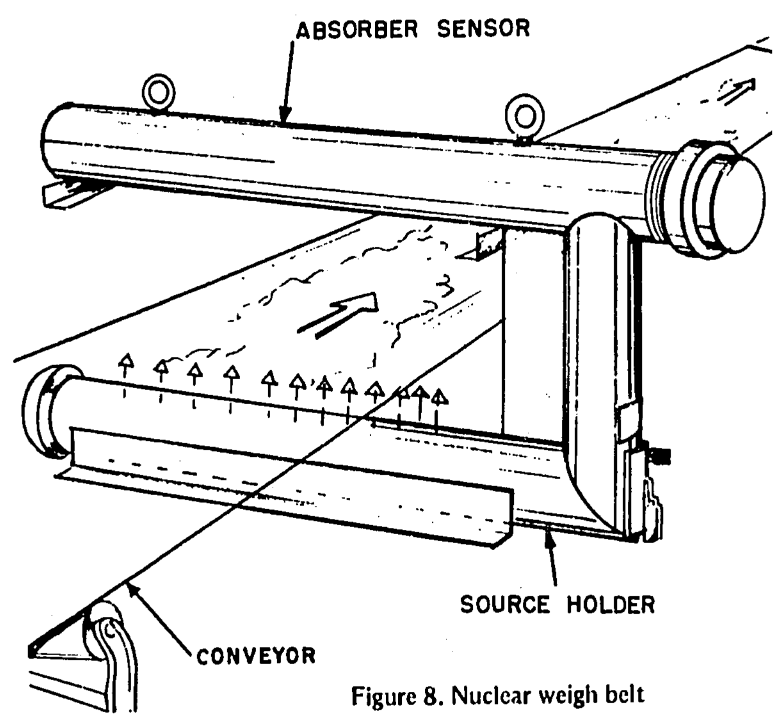


Figure 8. Nuclear weigh belt

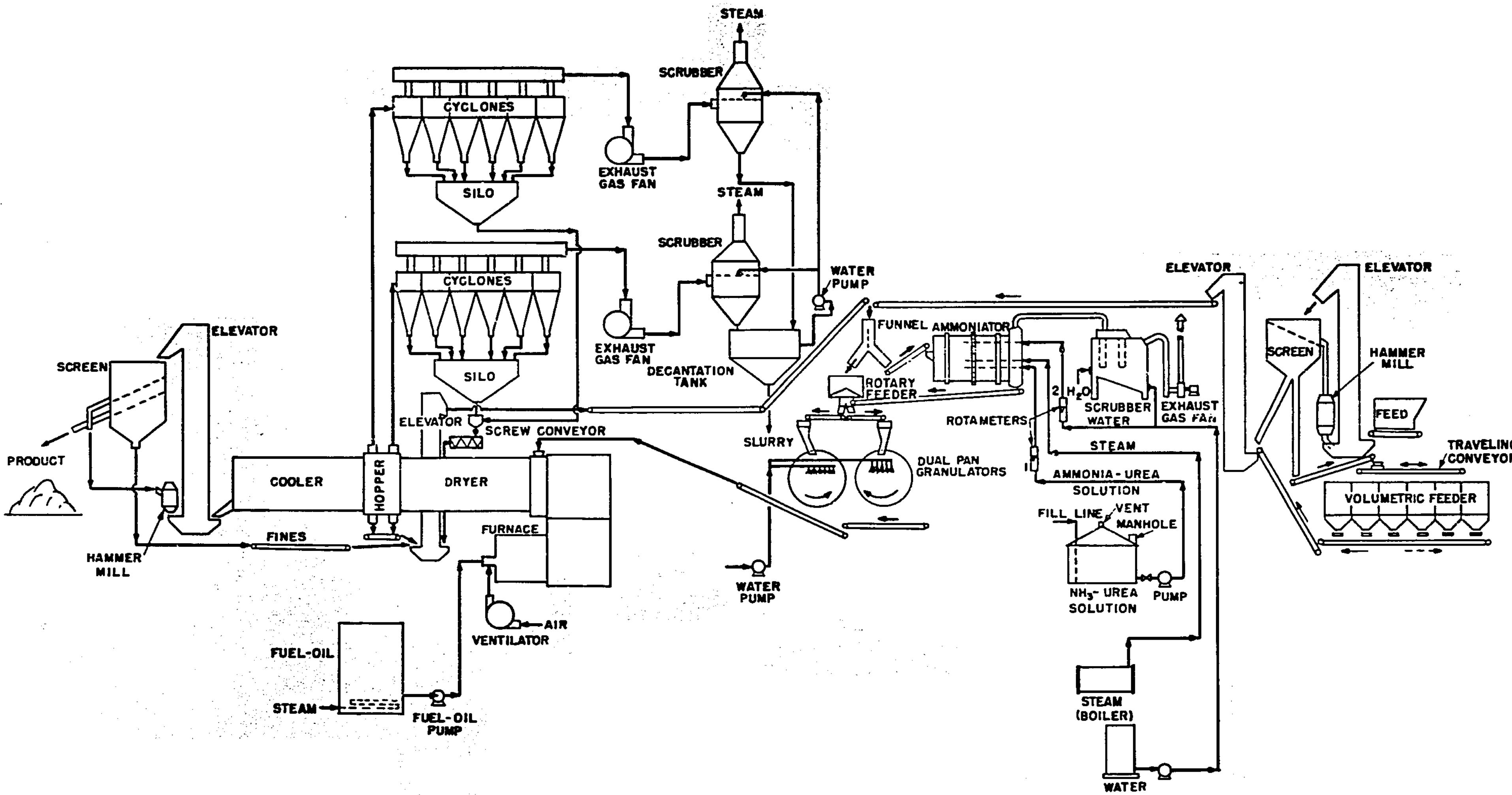
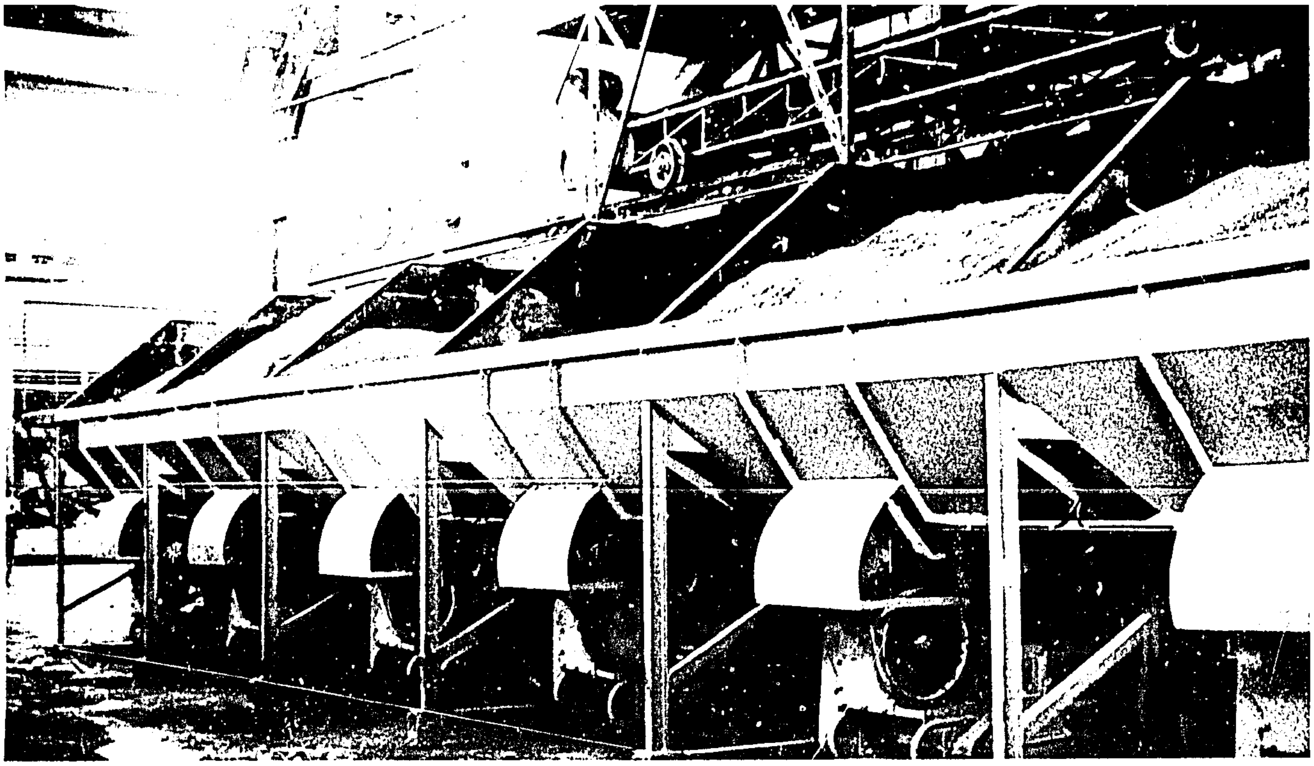


Figure 9. Flow diagram for CRA ammoniation-granulation unit



Volumetric belt feeders, such as these, are relatively simple to operate.

has been added, the batch dumps into a volumetric or belt-type feeder. The weighing sequence is started over again. The volumetric feeder is adjusted so that it empties just as the next batch dumps; the belt is allowed to run empty for about 0.6 m (2 ft) between batches. Even though the material is batch weighed, feed to the granulator is continuous. Figure 7 shows a sketch of this feed system.

Another type of feeder which could be utilized (figure 8) consists of a weigh belt or metering-type belt. One type of metering belt utilizes the principle of the absorption of nuclear radiation to measure conveyor loading. One arm of the unit containing a radioactive (gamma) source is mounted under the conveyor. A second unit mounted above the conveyor contains a measuring cell which converts nuclear radiation into electrical current. The radiation from the source passes upward through the conveyor and the material being weighed. As the weight of material varies, the amount of the absorbed radiation varies. The remainder of the radiation reaching the top arm is detected and produces a change in electric current. The signal can be made to record and control.

Granulation System

The granulation system described in this report and shown in figure 9 evolved from equipment already installed and in use. The TVA drum ammoniator-granulator was installed ahead of dual pan granulators which had been used to granulate NSP and formulas using water as the granulating medium. Normally, the pans would not be used in a conventional granulation process. As will be pointed out later, it is felt that the pans actually improved the physical appearance of the product compared with product from the drum granulator alone.

In the original installation, granulation was carried out in two pans of diameter 3 m (9.8 ft) at 12 rpm (revolutions per minute) using water. This gave a high moisture content (12-18%) in product from the pans. Material was hard to dry and could only be dried to a moisture content of about 5% with the full capacity of the dryer. In this type of granulation, there is no heat of reaction and materials usually are fragile and dusty. With the two pans the maximum production rate was about 17 mt/hr.

The TVA ammoniator-granulator was installed above the pans and material discharged from the drum was conveyed, split, and transferred via chutes to the dual pans. The feed system, solid and liquid, to the drum was described in a previous section. Discharge from the pans drops onto a belt conveyor which carries the wet granules to the inlet of the dryer. The dryer is a cocurrent type which is fired with fuel oil. It is equipped with flights. Material flows through the dryer and at the end lifting flights discharge to a transfer chute which feeds the cooler. Some spillage of fine material occurs here which is returned as recycle. The cooler is the countercurrent type and is mounted on the same level with the dryer. The dryer and cooler have the same dimensions, 2.2 m diameter x 15 m (7.2 ft diameter x 49 ft). Each unit has cyclones and exhaust fan. Material falls from the cooler through a grating to an elevator which lifts the material to a dual set of oscillating screens. The top screen has openings

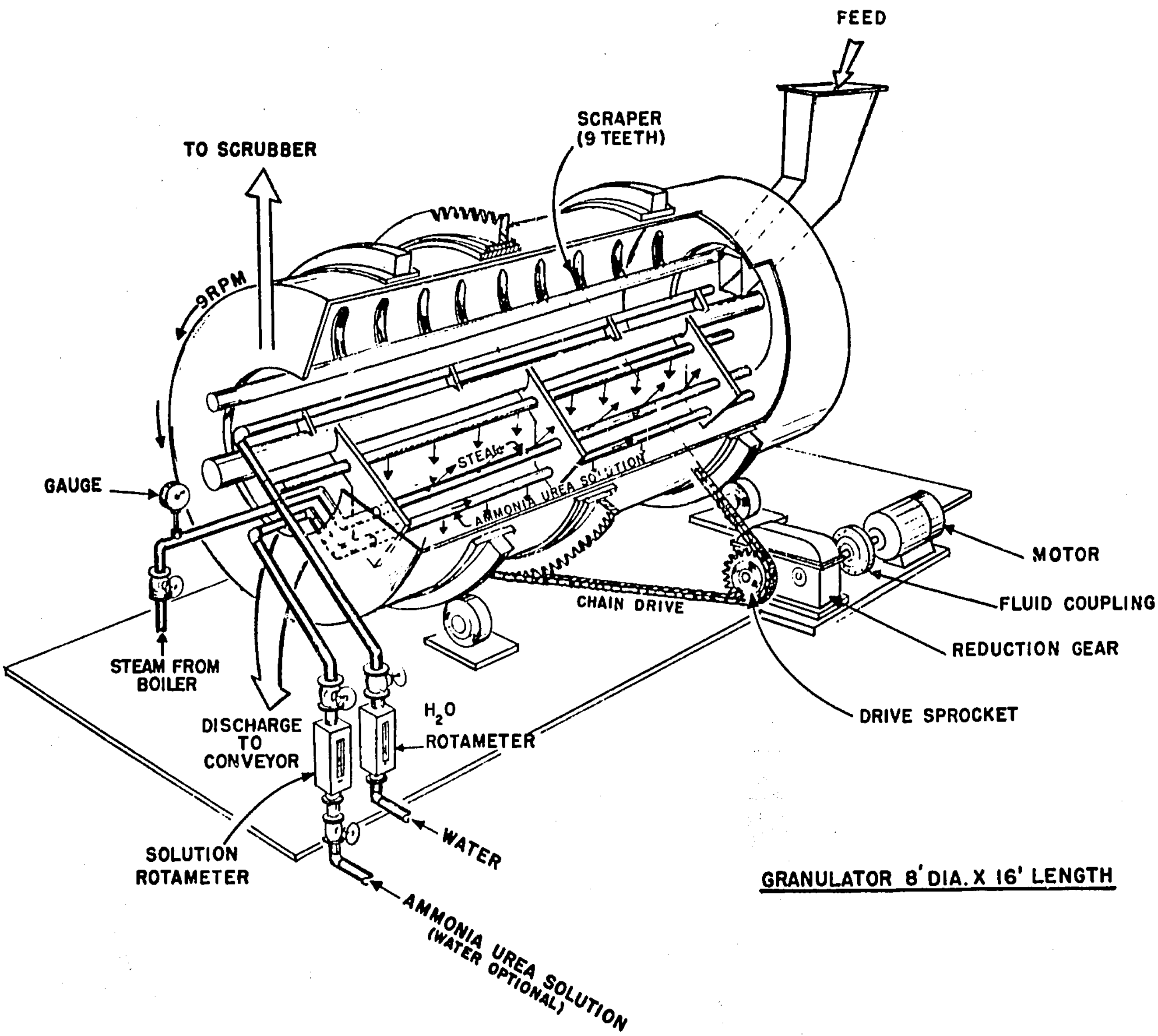
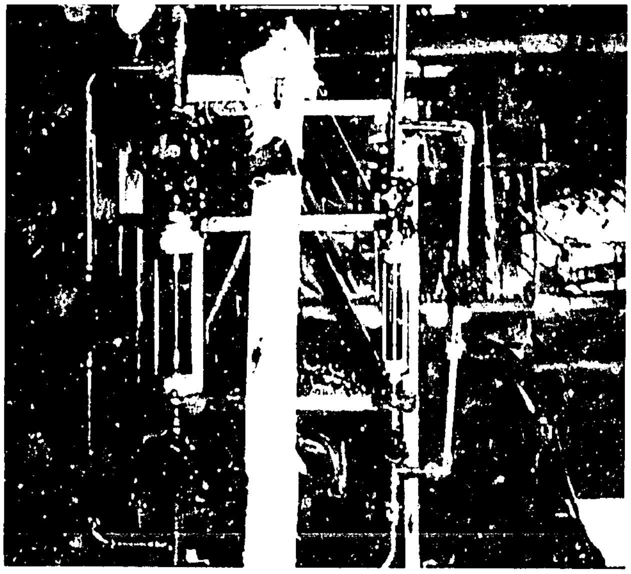


Figure 10. CRA ammoniator-granulator

of 5.5 mm (3.5-mesh-Tyler) and the bottom screen has 2.0 mm (9-mesh-Tyler). The screen area was reported to be [1.5 x 4.4 = 6.6 m^2 (71 ft^2)]. Oversize is crushed in a hammermill and lumps that are not crushed are returned to the screens by the bucket elevator. Product is allowed to drop onto a concrete floor and removed with a front-end loader to the bagging unit or to storage. Fines are recycled to the granulator.

The drum ammoniator-granulator is conventional design and made of mild steel. A sketch of the unit is shown in figure 10. The size is 2.4 m diameter x 4.8 m long (8 ft diameter x 16 ft long). Materials are added through a chute at the rear of the granulator. It is set at a slope of 2.1 cm/m (¼ in./ft). As material rolls through, it passes around two underbed spargers, the top sparger for steam and the bottom for ammonia-urea solution. These spargers are described below. The granulator is driven by a 75-hp (horsepower) motor in a counterclockwise direction. Power is transmitted through a fluid coupling, gear reducer, and drive sprocket which gives a rotation of 9 rpm. The rate of rotation is based on the formula:

$$\text{Rate (rpm)} = \frac{20 \text{ to } 27}{\sqrt{D}} \quad D \text{ in ft}$$



Controls for the ammoniator-granulator are within easy reach of the operator.

For a drum diameter of 8 ft, the formula indicates a range of 7.1 to 9.5 rpm. Most plants that have drum granulators 2.4 m (8 ft) in diameter operate well at rotational speeds of 8 or 9 rpm.

The sparger system consists of two underbed spargers, one for steam and one for ammonia-urea solution, and a dual parallel set of spargers overbed for water. In production of granular NSP, the underbed solution sparger is used for water. A description of these spargers follows:

No. 1–sparger (underbed) for ammonia-urea solution (water alternately). This is a 2.7-m (9-ft) length of AISI 316 schedule 40, 2.54-cm (1-in.) pipe containing 70 holes of 0.32-cm (1/8-in.) diameter. The holes are spaced 17 first 0.91 m (3 ft), 36 holes center 0.91 m (3 ft), and 17 holes last 0.91 m (3 ft). This sparger is located nearest the bottom of the drum granulator with the holes pointing downward; distance from the drum is about 5 in.

No. 2–sparger (underbed) for steam. This is a 9-ft length of AISI schedule 40, 1-in. pipe containing 52 holes of 1/8-in. diameter. The holes are spaced 17 first 3 ft and 35 last 3 ft (nearest to discharge end of granulator); holes in 3 ft of the pipe were closed by welding. This sparger is located on top of the ammonia-urea solution sparger with the holes pointing upward.

No. 3–sparger (2) (overbed) for water. This set of spargers consists of two 9-ft lengths of AISI 316 schedule 40, 1-in. pipe containing 17 holes of 1/8-in. diameter per pipe. Each sparger is mounted above the bed with the spray directed onto the top of the moving bed in the drum.

The granulator has an oscillating scraper which moves in a horizontal plane. The nine teeth are mounted so that they remain about 1-in. from the shell. The scraper is driven by a hydraulic pump. Various other scraper designs have been successfully used. TVA has utilized both the oscillating and the spiral-type rotary scraper that keeps about two teeth in close contact with the shell at any given time. Some granulators have mechanical "knockers" mounted on the outside of the shell to aid cleaning.

The discharge end of the granulator was easily accessible and remained open at all times. This allowed the operator to visually observe the rolling bed and make adjustments as needed. To aid in breaking lumps, a grate of 2.5-cm bars, 7.6-cm apart (1-in. and 3-in. apart) was mounted over the discharge chute; these lumps were broken by hand with a rod. Such an arrangement is usually necessary to prevent plugging of the discharge chute. A continuous retaining ring with a height of 40.6 cm (16 in.) is mounted on the feed end. A slotted ring of 35.6 cm (14 in.) is mounted on the discharge end; these slots help to cut material for quick removal.

Grades and Formulations Tested

Test production in Brazil was limited to several fertilizer grades which have a relatively high P_2O_5 to N weight ratio. The grades that were produced are summarized in the following table:

Grades produced (N-P_2O_5-K_2O)	P_2O_5/N wt ratio	Plant nutrient content, %	Feed materials used[a] AUS	NSP	TSP	DAP	KCl
0-20-0	–	20	–	x	–	–	1
5-22-10	4.4	37	x	x	x	x	x
8-24-12	3.0	44	x	x	x	x	x
6-30-12	5.0	48	x	x	x	x	x
10-30-15	3.0	55	x	–	x	x	x
9-36-12	4.0	57	x	–	x	x	x

[a]AUS = Ammonia-urea solution (30.5-0-0)
NSP = Run-of-pile normal superphosphate (0-20-0)
TSP = Run-of-pile triple superphosphate (0-46-0)
DAP = Granular diammonium phosphate (18-46-0)
KCl = Potassium chloride (0-0-60)

Table 2. Standard formulations[a] recommended for production of some grades in ammoniation-granulation plant

Grade	5-22-10	8-24-12	6-30-12	10-30-15	9-36-12
Feed materials, kg/mt (lb/st)					
Ammonia-urea solution (30.5% N)[b]	138(276)	174(348)	143(286)	100(200)	50(100)
Diammonium phosphate (18-46-0)[c]	50(100)	163(326)	100(200)	400(800)	425(850)
NSP (0-20-0)[d]	500(1000)	332(664)	100(200)	–(–)	–(–)
TSP (0-46-0)[e]	220(440)	225(450)	522(1044)	266(532)	356(712)
KCl (0-0-60)[f]	167(334)	200(400)	200(400)	250(500)	193(386)

[a]Assumed N loss of 2%, P_2O_5 loss due to reversion of 2%, and product moisture, 3%.
[b]Solution contained 17% NH_3, 36% urea, and 47% H_2O.
[c]Granular, assumed to be dry.
[d]Run-of-pile containing 7% H_2O.
[e]Run-of-pile containing 4% H_2O.
[f]Assumed to be dry.

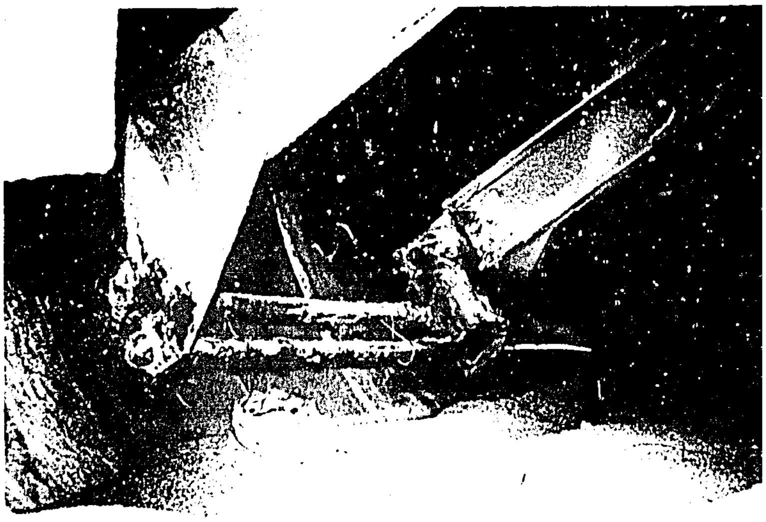
The above grades were produced by the TVA ammoniation-granulation process in sufficient quantities to demonstrate the technical feasibility of each grade and to determine typical operating conditions. Physical and chemical data were obtained to the extent possible. Basic testing was carried out with feed rates of 30 mt/hr.

Formulations for Above Grades

The grades given above were made with the ammonia-urea solution which contained only 30.5% nitrogen. During handling, transport, and storage, it became necessary to dilute the solution from the original nitrogen content of 33%. This was due to a special situation for tank testing and future shipments are expected to more nearly approach the 33% nitrogen content. Formulations in table 2 were actually tested in the granulation plant. In formulating these grades, a 2% nitrogen loss and a 2% P_2O_5 loss due to reversion were assumed. The product contained 3% moisture by weight.

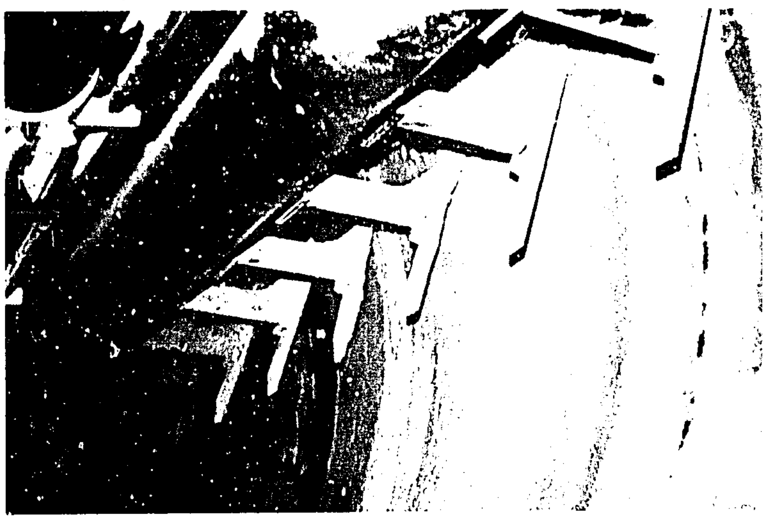
Typical Operating Conditions

Chemical heat generated during ammoniation of superphosphates with ammonia-urea solution does not heat the bed to a temperature comparable with that for the reaction of anhydrous ammonia and superphosphate or phosphoric acid. Some additional heat is required to raise the temperature of the granulation bed to a suitable temperature for optimum granulation. With the solution and superphosphates alone, a bed temperature of 60°C (140°F) can be expected, whereas with anhydrous ammonia and phosphoric acid a bed temperature of 82°C to 100°C (180° to 212°F) can be obtained. A temperature of 60°C (140°F) is not sufficient to form hard, strong granules. Therefore, in using the ammonia-urea solution for ammoniation of superphosphates, it is recommended that supplemental heat be added in the form of steam. A bed temperature of about



The ammoniator-granulator is equipped with two underbed spargers.

The oscillating scraper inside the ammoniator-granulator has nine teeth and is driven horizontally by a hydraulic system.



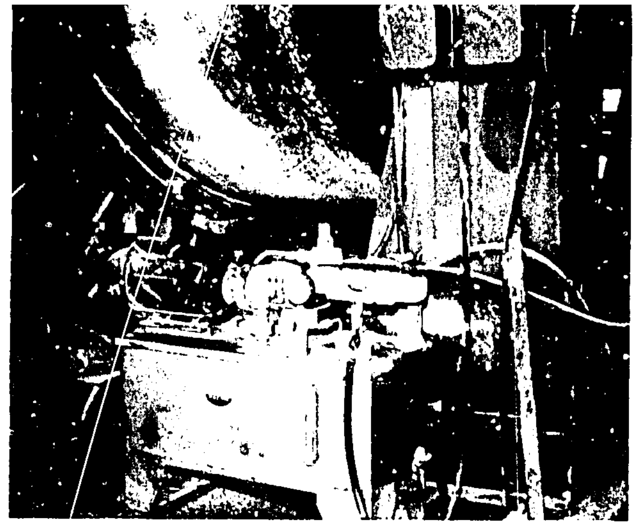
77°C (170°F) is sufficient for good granulation. The moisture content in the drum ranged from 9 to 12%. In this plant, further "rounding" and hardening of the granules is accomplished in the pan granulators following the drum. In some tests, the addition of a small amount of water in the form of a spray to the pans was helpful. In general, the moisture content of product sampled from the pans was nearly equal to that of drum product. The pan temperature was in the range of 54°C to 64°C (130° to 147°F) during production of the grades listed. Typical operating conditions are given in table 3. No facilities were available for measuring the quantity of recycle, but it was observed to be low during these tests.

Operating Procedure

Information given here is offered as a guide for consideration during plant operation. The exact procedure will depend on the particular characteristics of each plant. With this summary, however, one should be able to develop a detailed operating procedure for his individual plant.

Startup and Operation—For convenience, it is assumed that all mechanical problems have been identified and corrected and that the plant is ready for production. The procedure for cleaning the drum ammoniator-granulator is as follows:

1. Stop granulator and send personnel into granulator to remove any large lumps.



The scraper is driven by a hydraulic pump.

2. Empty drum by rotating it in a clockwise direction (opposite to the normal direction for granulation). A retaining ring having slots or offset sections is desired to aid in removal of product.
3. After the drum is about empty, it is stopped and the operator goes inside to punch out the sparger holes to make sure they are open. Any buildup of material on the spargers, supports, and scraper should be removed. Other rotary equipment--such as pans, dryer, and cooler--is emptied as completely as possible.

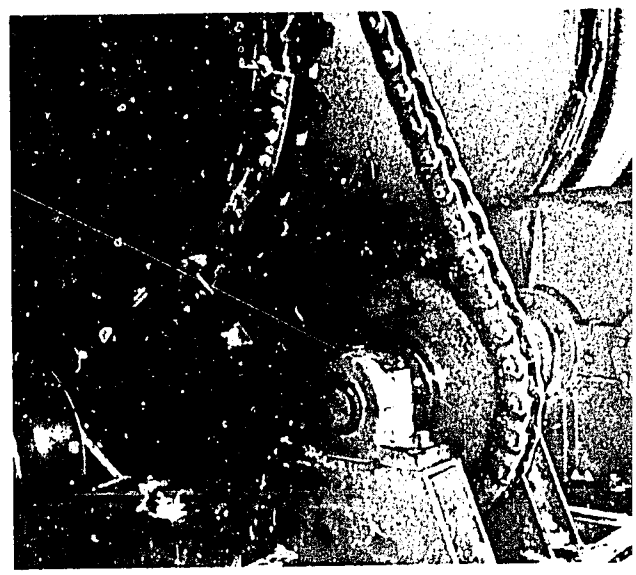
Table 3. Typical operating conditions for production of mixed fertilizer grades at 30 mt/hr

Grade	5-22-10	8-24-12	6-30-12	10-30-15	9-36-12
Feed rates, kg/min					
Ammonia-urea solution (underbed)[a]	69	85	72	50	25
NSP	250	166	60	0	0
TSP	110	113	261	133	179
DAP	25	81	50	200	212
KCl[b]	84	100	100	125	96
Average temperature, (°C) °F					
TVA drum	(75)168	(67)151	(72)162	(67)153	(70)158
Pan	(56)133	(55)131	(59)139	(61)141	(64)147
Dryer	(93)198	(69)157	(69)156	(71)159	(66)150
Cooler	(41)106	(50)122	(40)104	(62)143	(56)132
Average moisture[c], % H_2O					
TVA drum	12.2	11.6	12.1	8.9	11.0
Pan	13.0	11.4	15.0	8.7	10.0
Cooler	3.0	4.3	5.6	2.6	4.0
Steam underbed pressure[d], kg/cm²	5	0.5	2	4	7
Water overbed, l/hr	0	0	0	0	500

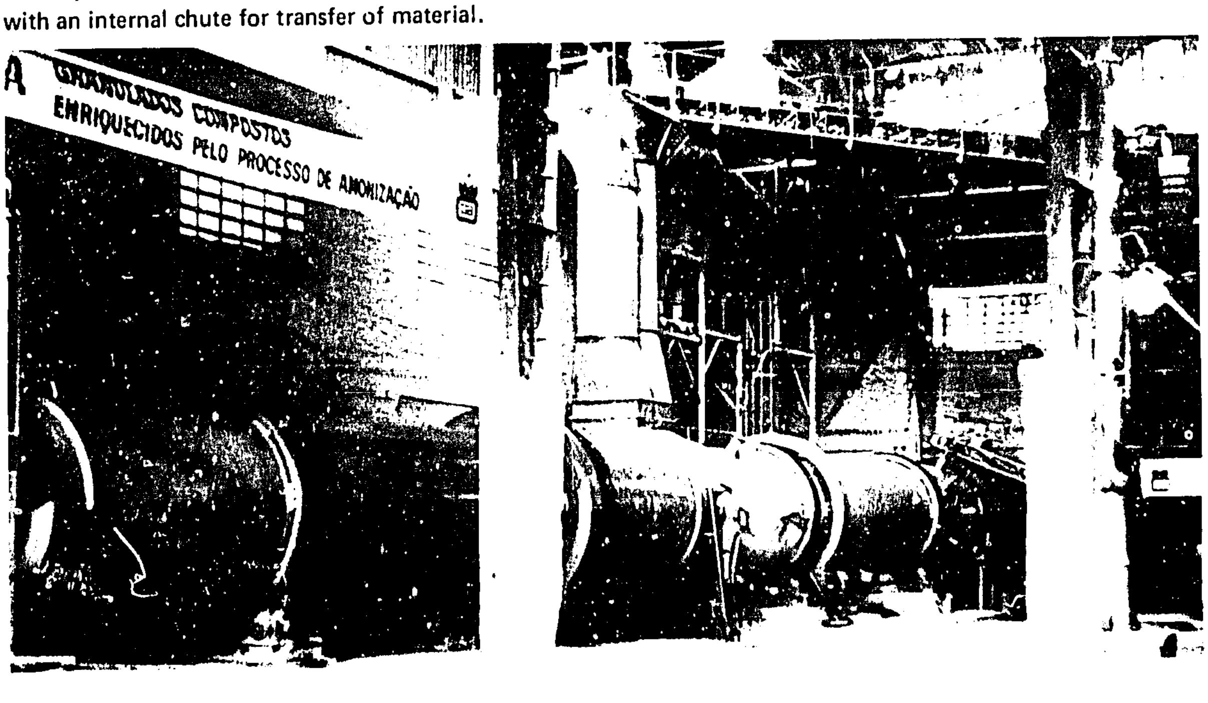
[a]Solution contained 30.5% N.
[b]A mixture of fine:coarse (50:50) KCl was used in most tests.
[c]Determined by drying crushed sample to constant weight.
[d]Actual steam consumption not metered.

A slotted retaining ring at the ammoniator-granulator discharge aids in removing material during emptying due to its cutting action.

The ammoniator-granulator is rotated with a chain drive.



The dryer and cooler at CRA are interconnected with an internal chute for transfer of material.



To start plant production, it is convenient but not necessary to use granular material of the grade to be made. Generally, 15 to 20 mt is sufficient. If available this material is placed in the feed hopper. The exact procedure will depend upon the type of solid feed system available. Other solid raw materials are placed in the feed hopper.

The following procedure is recommended for startup:

1. Start rotation of drum and pan granulators, dryer, cooler, and all conveying equipment.
2. Start all exhaust fans, scrubber-liquor recirculation, and all other blowers.
3. Make sure that liquid feed systems (ammonia-urea solution and water) and steam boiler are operative.
4. Fill the system with granular material and put on a recycle basis.
5. Light the burner of the dryer and control initially at about 400°C (752°F). Check the dryer exit temperature and control to obtain maximum temperature of about 90°C (194°F).
6. Steam is added to the drum granulator to warm the bed.
7. Start the solid feed system.
8. Continue adding steam and start the flow of ammonia-urea solution. As the solution reacts the bed temperature will rise. The bed should be carefully observed at this point to prevent "over wetting." Steam is adjusted to obtain good granulation.

The operator technique is the key to making a good granular product. Granulation control relies heavily on the experience and skill of the operator. He must observe the bed carefully at all times; disruptions in the feed system will require compensation of other flow rates. The operator must observe the drum granulator discharge and keep lumps broken and the chute open. It is estimated that material will have to be removed from the spargers about every 8 hours. This is done by the following procedure: Turn off steam, ammonia-urea solution, and solid feed. Stop granulator and reverse direction. While the granulator is rotating in opposite direction, use "pokerods" to break caked material away from spargers. When all clean, reverse rotation of granulator, start solid and liquid feed, steam, and water, if used. The operator should record pertinent data such as temperatures, feed rates, sampling times, and stoppages. The data sheet should be clear, concise, and provide an accurate record of production performance. A data sheet that might be used is shown in figure 11.

Shutdown of Plant—In any granulation plant, two types of shutdown are possible, normal and emergency. Developing countries sometimes have numerous power failures. Although there is no hazard due to power failure, certain operating precautions should be taken to avoid equipment damage.

A normal shutdown simply involves stopping solid and liquid feeds, steam, and emptying the equipment as low as possible preparatory to startup of a new grade.

In case of an emergency shutdown, usually all feeds will stop. The steam boiler should be a completely automatic type which will start and stop automatically. It is advisable to have emergency power available to the granulator so that it can be reversed to remove material. Hot material has a tendency to "set" as the temperature of the bed drops during a power failure. Failure to adequately breakup this solid mass will most likely result in severe damage to the spargers and possibly to the scraper mechanism. The operator should check completely the consistency of the material before operation is attempted.

Cleaning and Maintenance—The granulator should be cleaned as necessary to prevent buildup of solids on the wall. The scraper should be checked to be sure that it cleans evenly over the entire surface. It is not necessary to clean back to bare metal, but any buildup of ridges of material should be removed. Occasionally the outside of the drum should be "blown-down" with a pressure air line to remove dust. Also, the motor, coupling, and reduction gear should be cleaned. Dust buildup on the trunnions should be removed. As part of the granulation system, the scrubber should be inspected and cleaned periodically. Covers should be removed to allow inspection and any sludge collected should be removed.

The ammoniator-granulator is designed to be a rugged type of continuous equipment. Normally little maintenance is required if preventative maintenance is exercised. The bearings of the trunnions should be greased every 24 hours. Grease should be added to the "keepers" or horizontal thrust bearings when trunnion bearings are greased. Oil should be checked in the fluid coupling and gear reduction every 24 hours. During operation, the fluid coupling or the reduction gear should be stopped if it becomes overheated. The drive gear and chain should be lubricated heavily. The scraper mechanism should be lubricated periodically.

Figure 11. Typical format for production data sheet

Material Granular mixed Grade ______ ___ Operator __________ Date __________

	Rotameters						Feed rates, kg/min												
	N-solution Large meter (underbed)		Water Small meter (overbed)				Hopper number						[redacted]						
							Material in hopper												
															Temperature, °C				
Time	Reading X1000	Rate kg/hr	Reading	Rate l./hr	Steam pressure kg/cm^2	Motor current amps	1 NSP	2 NSP	3 TSP	4 DAP	5 KCl	6 MAP	Setting of screw	Feed rate kg/min	Drum	Pan	Dryer	Cooler	Remarks[a]

[a]Used to describe operating problems or stoppages.

Test Results, Chemical and Screen Analyses

Results of chemical and screen analyses for the five grades are shown in table 4. It will be noted that grade control in these preliminary tests was not as good as desired. This was due to some problems in obtaining accurate feed rates of solid raw materials. It is felt that with operating experience this grade deviation will decrease. Numerous changes were recommended for the feed system which should improve the accuracy. Two wide ranging sizes of KCl were available. A coarse material which was 71% + 8-mesh (Tyler) and a powdered material, 92% + 60-mesh (Tyler), was used generally in the ratio of 50:50. Use of 100% coarse material allowed visible KCl particles to remain in the product, and the powdered material was difficult to feed accurately. Some problem was encountered in feeding granular DAP as some lumps were usually present; when possible the feed system screen was used to remove these lumps. Fertilizer tolerance specifications are not very strict in Brazil as compared with the United States. Also, product moisture is usually higher in Brazil.

Products were screened to determine the quantity of material passing a 16-mesh screen. The range was from 0 to 22%; the fine material which passed the screen was granular and not a fine powder. It is believed that with additional time all grades could have been produced with little or no material passing a 16-mesh screen. The company was very pleased with the quality of the product. All products were hard, nondusty, and free flowing. At the present, storage in bulk or bag is not a problem, but it was recommended that storage tests be conducted in the future. Also, tests to determine relative hardness and fragility were recommended as described in the TVA booklet *Determining the Physical Properties of Fertilizers*. It is believed that no serious storage problems with these materials will be encountered, but experimental data are needed.

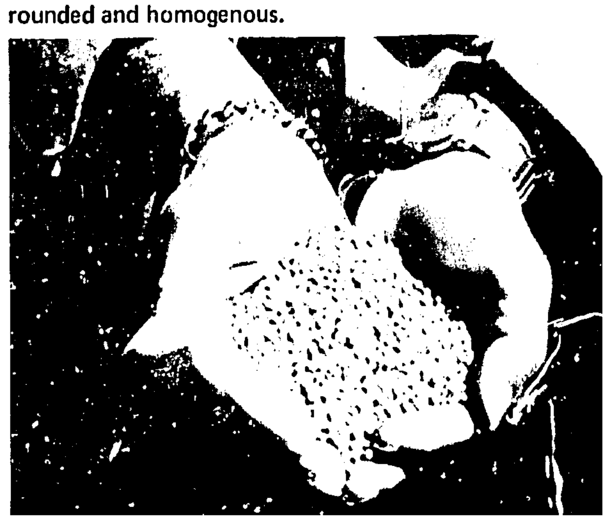
Table 4. Chemical and screen analyses of products made in ammoniation-granulation plant

Nominal grade	5-22-10	8-24-12	6-30-12	10-30-15	9-36-12
Product chemical analysis, %					
Total N	4.8	7.8	7.7	7.3	8.2
Total P_2O_5	22.9	24.0	28.1	33.8	34.0
Water-soluble P_2O_5	9.4	14.8	17.4	16.3	23.5
Citrate-soluble P_2O_5 [a]	20.4	22.1	26.4	31.9	32.7
K_2O	10.7	9.9	13.9	17.3	12.6
Free acidity	0.0	0.0	0.0	0.0	0.0
H_2O [b]	2.5	5.5	5.0	3.5	6.0
Actual grade	4.8-22.9-10.7	7.8-24.0-9.9	7.7-28.1-13.9	7.3-33.8-17.3	8.2-34.0-12.6
Product screen analysis, % *(Tyler)*					
+. 4	0	2.0	0.5	4.0	0
-4 + 8	76	32.0	59.0	40.0	28.0
-8 +16	24	56.0	39.0	53.0	50.0
-16	0	10.0	1.5	3.0	22.0

[a]Neutral ammonium citrate.
[b]Determined by heating a fine-ground sample to constant weight.

Products are shipped via rail and trucks, but mainly by trucks.

Products are hard, well-rounded and homogenous.



Economics of Process

Alternatives for Fertilizer Supply

In a developing country the fertilizer supply and marketing system usually has been developed through imported fertilizer materials. As the level of fertilizer consumption increases, a point is reached when some type of alternate supply system is justified. In order to arrive at an optimum supply situation at a given time, numerous and continuing studies are necessary. TVA in cooperation with such agencies as AID, IBRD (International Bank for Reconstruction and Development), UNIDO (United Nations Industrial Development Organization), IFC (International Finance Corporation), FAO (Food and Agriculture Organization), RRI (Rubber Research Institute), CIAT (Centro Internacional de Agricultura Tropical), and numerous private companies has conducted feasibility studies relating to fertilizer supply production, marketing, and use in 26 different countries since 1963. As a part of the overall objectives, these studies often include a survey of alternative supply or production methods that can be utilized in a particular situation to fill a specific and projected demand.

Table 5 indicates some broad areas that can be used to supply fertilizer. A developing country could progress and pass through the various alternatives and the supply scheme can be a combination of several alternatives.

For example, India continues to import fertilizer while operating some modern production units. Even large-scale, single-train units for ammonia are soon to come on stream. Many developing countries have reached the point where alternative production processes are under consideration. In some countries, a simple batch or continuous granulation process using water as a granulation medium is already being used. However, such granulated products often have poor physical properties. Procedures for improving these properties are known; however, these procedures need plant tests for further development. The production rate of a batch granulation plant is low (usually about 10 tons/hr). Water granulation is accomplished at a high moisture content since there is no heat of reaction. The process described in this report is intermediate between water granulation where there is no heat generated to that of granulation using ammonia and phosphoric acid or sulfuric acid where much heat is generated. Therefore, the moisture content during granulation is intermediate. Supplemental heat is provided by steam. This process then can be considered as a next step following water granulation of solid materials such as superphosphates to allow production until such time that anhydrous ammonia and acid become available. The ammonia-urea solution offers flexibility in that it can be used directly for ammoniation of superphosphates or acid or ammonia can be stripped out for ammoniation-granulation and the urea recovered by concentration. It can be readily transported even in developing countries which may already have production facilities for ammonia and urea but no transport facilities for anhydrous ammonia in pressure vessels.

One of the pitfalls that should be avoided in a developing country is the tendency to move too quickly into production facilities of high capital costs, such as large ammonia and urea plants. Efficient and economical operation of these plants depends upon operation at a high level of design capacity, as shown in figure 12. Low operating levels can be caused by many factors or combination of factors such as improper design, inadequate training, poor management, and unavailability of raw materials or a suitable market. In any plant. certain fixed costs must be borne whether the plant is not operating or operating at a low level. In a relatively low capital plant operating level does not affect production cost as significantly as shown in the figure. One big advantage of progressively increasing production capacity is that a cadre of trained personnel can

Table 5. Alternative schemes for supplying fertilizer

1. Import bagged materials
2. Import bulk materials and bag in-country
3. Import bulk raw materials (intermediates), and granulate with water—bulk blending of imported materials can be considered at this stage
4. Import ammonia-urea solution and bulk raw materials and granulate with steam
5. Import ammonia-urea solution and phosphoric acid and granulate
6. Import ammonia-urea solution and phosphoric acid; vaporize ammonia from solution and use in granulation and recover urea by concentration of solution
7. Import anhydrous ammonia and phosphoric acid and granulate
8. Produce anhydrous ammonia and urea; import phosphoric acid and granulate. At this stage alternate uses for ammonia such as ammonium nitrate would be considered; production of nitric acid would make nitric phosphate fertilizers an alternative.
9. Produce anhydrous ammonia and urea; produce phosphoric acid and granulate
10. Produce anhydrous ammonia and urea; produce phosphoric acid and react in a pipe reactor for production of solids, liquids, and suspensions

be developed with background in plant operation and maintenance. Also, simple plants allow the marketing systems and infrastructure to be developed prior to installation of high-capital plants.

Economics with Ammonia-Urea Solution and Superphosphate

In order to get an idea of costs for a process using ammonia-urea solution for ammoniation-granulation of superphosphates, a preliminary cost estimate is included in the appendix. The data were taken primarily from information contained in the TVA-AID report entitled *Technical and Economic Evaluation of Fertilizer Intermediates for Use by Developing Countries*. It is emphasized that this is only an estimate and actual decisions to be made for a particular location or situation should be examined in more detail. Actual quotes on plant equipment costs should be obtained from contractors. Actual costs and availability for raw materials and other inputs should be determined for a given location. No attempt was made to obtain actual plant costs from the cooperating company in Brazil and costs herein should not be construed as having been taken from actual plant files. Assumptions made in the estimates are given in the appendix.

The estimate was made for production of five grades, 5-22-10, 8-24-12, 6-30-12, 10-30-15, and 9-36-12 at an operating rate of 175,000 mt/yr. It is assumed that the ammonia-urea solution would not be available for captive use but must be imported and stored at the granulation site. Costs used for superphosphates reflect imported costs, although normal superphosphate or triple superphosphate could be produced for captive use. A recent study in Vietnam indicated that c.i.f. prices from the U.S. Gulf Coast were: DAP, $87.50/mt; TSP, $71.00/mt; and KCl, $36.00/mt. These prices are somewhat lower than those used in the estimate: DAP, $95.00/mt; TSP, $75.00/mt; NSP, $47.00/mt; and KCl, $52.00/mt.

A summary of the estimate using ammonia-urea solution is given in table 6 showing plant investment, capital investment, and production costs. It is estimated that the

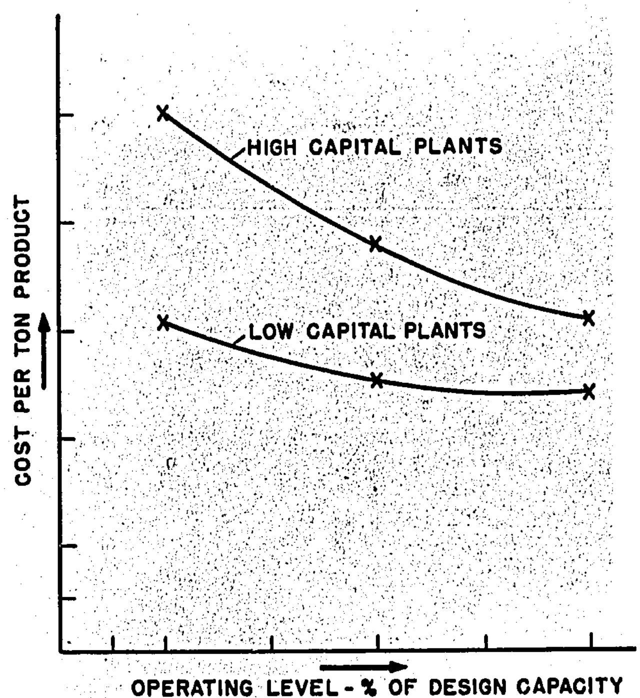


Figure 12. Effect of operating level on production cost for low- versus high-capital plants

Table 6. Summary of cost estimate using ammonia-urea solution and superphosphates

Grade (175,000 mt/yr)	5-22-10	8-24-12	6-30-12	10-30-15	9-36-12
Nutrient content ($N + P_2O_5 + K_2O$)	37	44	48	55	57
Plant investment, $	5,785,000	5,785,000	5,785,000	5,785,000	5,785,000
Working capital, $	4,283,000	4,685,000	4,908,000	5,192,000	5,402,000
Total capital investment, $	10,068,000	10,470,000	10,693,000	10,977,000	11,187,000
Raw material cost,[a] $/mt product	60.74	67.64	71.46	76.33	79.92
Fixed and variable cost, $/mt product	10.18	10.18	10.18	10.18	10.18
Production cost, bulk, (0% ROI), $	70.92	77.82	81.64	86.51	90.10
Bags and bagging, $	6.73	6.73	6.73	6.73	6.73
Interest on working capital, $	0.98	1.07	1.12	1.19	1.23
Production cost, bagged, (0% ROI), $	78.63	85.62	89.49	94.43	98.06
Return on investment (15%), $	8.63	8.97	9.17	9.41	9.59
Production cost, bagged, (15% ROI), $	87.26	94.59	98.66	103.84	107.65
Per unit nutrient, $/unit	2.36	2.15	2.06	1.89	1.89

[a]Ammonia-urea solution (30-0-0 @$53/mt); NSP (0-20-0 @ $47/mt); TSP (0-46-0 @ $75/mt); DAP (18-46-0 @ $95/mt); and KCl (0-0-60 @ $52/mt).

plant, including storage, could be installed with supporting facilities in a foreign country for $5.79 million. The production costs for bagged material with a 15% return on investment ranged from $87.26/mt for a 5-22-10 to $107.65 for 9-36-12 grade. The higher-analysis grades gave the lowest cost per unit of plant food. These production costs are highly influenced by the cost of raw materials. In reality a particular plant would produce only a predetermined quantity of each grade in order to fulfill the annual production. In addition, the equipment could be used to granulate a single material such as NSP or TSP which could be used for direct application or bulk blending.

The equipment can be easily modified by changing spargers to utilize anhydrous ammonia and phosphoric acid in the future if these raw materials become available. A pressure solution of ammonia-urea having a higher nitrogen content (40-45% N) could be used with the proper metering devices and sparger arrangement.

Economics with Anhydrous Ammonia and Phosphoric Acid

An additional estimate was made to determine the production cost of the above five grades using imported ammonia and phosphoric acid. These data are summarized in table 7 and given in more detail in the appendix. The data show that the use of anhydrous ammonia and phosphoric acid for production of the five grades would be more economical, except for the higher analysis materials, than the use of ammonia-urea solution and superphosphates at the values for raw materials assumed in the estimate. It probably then should be the objective to utilize anhydrous ammonia and phosphoric acid in the granulation facility as these materials become available. However, there are other alternatives which should be evaluated both technically and economically. For example, the ammonia-urea solution can be decomposed to yield anhydrous ammonia and a solution of urea which can be prilled or granulated alone. Phosphoric acid can be used to react with the ammonia or ammonia-urea solution to replace part or all of the superphosphates. Therefore, in a developing country a granulation plant should be designed for flexibility to utilize both available and potentially available raw materials within reasonable economic limits. At least, the plant should be designed such that units can be added with minimum cost and downtime.

Table 7. Summary of cost estimate using anhydrous ammonia and phosphoric acid

Grade (175,000 mt/yr)	5-22-10	8-24-12	6-30-12	10-30-15	9-36-12
Nutrient content ($N + P_2O_5 + K_2O$)	37	44	48	55	57
Plant investment, $	6,942,000	6,942,000	6,942,000	6,942,000	6,942,000
Working capital, $	3,946,000	4,426,000	4,899,000	5,290,000	5,689,000
Total capital investment, $	10,888,000	11,368,000	11,841,000	12,232,000	12,631,000
Raw material cost,[a] $/mt product	54.11	62.35	70.46	77.16	83.99
Fixed and variable cost, $/mt product	11.31	11.31	11.31	11.31	11.31
Production cost, bulk, (0% ROI), $	65.42	73.66	81.77	88.47	95.30
Bags and bagging, $	6.73	6.73	6.73	6.73	6.73
Interest on working capital, $	0.90	1.01	1.12	1.21	1.30
Production cost, bagged, (0% ROI), $	73.05	81.40	89.62	96.41	103.33
Return on investment (15%), $	9.33	9.74	10.15	10.48	10.83
Production cost, bagged, (15% ROI), $	82.38	91.14	99.77	106.89	114.16
Per unit nutrient, $/unit	2.23	2.07	2.08	1.94	2.00

[a]Ammonia @ $88.00/mt; phosphoric acid (54%) @ $95.15/mt; KCl @ $52.00/mt; and filler @ $3.00/mt.

Other Possible Formulations

Some additional formulations are given in table 8 which could possibly be used in preparation of the grades indicated. In these formulations, ammonia-urea solution reacts with solid raw materials, such as superphosphates, to provide part of the heat and the necessary steam requirement to give 160,000 BTU/short ton (st) is indicated. The quantity of ammonia-urea solution was limited to 450 lbs/st. In some grades such as 22-22-11, urea added from solution is 185 lbs and from the solid materials is 457 lbs for a total of 642 lbs. This is equivalent to 32% urea in the formulation which probably would not be practical to make in this granulation process. Part of the urea could be added in the granulator to prepare a lower $N:P_2O_5$ grade and the remaining nitrogen requirement as urea could be added by blending. This, of course, would not give a truly homogenous product. It is emphasized that none of these grades have actually been tested in pilot or full-scale operation and are given only as potential formulations.

The formulations would require actual testing to determine if they are feasible. Generally, it is not desired to add large quantities of ammonium sulfate to formulations as this material is somewhat difficult to formulate.

Table 9 gives possible formulations based on the use of anhydrous ammonia and phosphoric acid and other materials. Here the heat of reaction is about 200,000 BTU/st; the liquid phase is 600 or slightly higher.

TVA has developed a computer program which can indicate the optimum granulation formulation based on the cost of raw materials. This is referred to as a "least cost" formulation. In addition, other information–such as heat of reaction, liquid phase, and steam requirements–can be calculated. The data are based on that obtained from many granulation plants operating in the United States.

Conclusions and Recommendations

The use of ammonia-urea solution for ammoniation-granulation of superphosphates to make mixed homogenous grades of fertilizer having a relatively low $N:P_2O_5$ ratio was satisfactorily demonstrated in Brazil. By installation of solid and liquid feed systems, drum granulator and scrubber, and steam boiler, the company was able to significantly increase its production rate. At the same time, the output of a single granulated material such as single superphosphate was increased.

Products made during the testing program were hard, well-rounded, and less dusty than those previously made by water granulation. The grades were not as precise as desired since some difficulties were encountered in feeding solid raw materials accurately.

The potential for use of ammonia-urea solution for use in developing countries should not be overlooked. Use of this solution will allow granulation to be accomplished in areas where anhydrous ammonia is not available.

It is recommended that this solution be considered for use as a nitrogen source in studies for technical and economic evaluation of granulation plants in developing countries.

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Table 8. Possible formulations using various solid raw materials and ammonia-urea solution

Grade	16-16-8		13-13-13		18-9-9		18-6-6		22-22-11		20-10-10		6-24-24		10-30-10	10-10-10	4-12-12	5-20-20	10-20-10
Total nutrient ($N+P_2O_5+K_2O$)	40		39		36		30		55		40		54		50	30	28	45	40
Materials, lb/st																			
Ammonia-urea solution[a]	340	388	314	315	172	218	115	145	421	7	191	242	271	173	450	333	–	309	450
$(NH_4)_2SO_4$[b]	839	604	766	761	1119	891	1439	1287	48	–	846	593	–	–	49	448	389	–	264
MAP[c]	345	–	7	–	334	–	223	–	816	–	371	–	300	–	–	–	–	–	–
Urea[d]	–	156	–	3	84	235	6	107	457	594	275	442	–	–	–	–	–	–	–
DAP[e]	–	–	–	–	–	–	–	–	–	962	–	–	–	363	251	–	–	–	–
TSP[f]	297	710	568	577	–	399	–	266	–	13	–	444	706	701	1080	–	–	690	703
NSP[g]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1020	1224	452	423
KCl[h]	267	267	433	433	300	300	204	204	367	367	333	333	800	800	333	333	400	667	333
Steam,[i] lb/st	79	60	80	80	124	106	138	125	66	163	120	99	87	110	38	86	165	79	45
Evaporation,[j] lb/H_2O/st	167	183	168	169	133	149	124	134	174	106	136	154	164	148	201	221	178	197	219
Liquid phase	626	680	589	590	504	556	436	471	807	695	560	620	647	625	805	608	452	650	723

[a] 16% NH_3 and 44% urea; 33.4% N.
[b] 21-0-0.
[c] 11-55-0.
[d] 46-0-0.
[e] 18-46-0.
[f] 0-46-0.
[g] 0-20-0.
[h] 0-0-60.
[i] Steam (100%) required to provide total heat of 160,000 Btu/st.
[j] Water to be evaporated.

Table 9. Possible formulations using various solid raw materials, anhydrous ammonia, and phosphoric acid

Grade	16-16-8		13-13-13		18-9-6		22-22-11		20-10-10		6-24-24		10-30-10		10-10-10		4-12-12		5-20-20		10-20-10	
Total nutrient ($N+P_2O_5+K_2O$)	40		39		30		55		40		54		50		30		28		45		40	
Materials, lb/st																						
Anhydrous ammonia[a]	84	64	80	66	68	68	89	52	67	64	108	80	119	63	72	70	77	67	98	76	98	61
$(NH_4)_2SO_4$[b]	849	1027	951	853	1316	1316	–	104	887	930	48	–	60	–	690	680	87	17	101	–	587	289
Urea[c]	172	–	–	–	76	76	685	576	362	326	51	–	204	–	–	–	–	–	–	–	–	–
TSP[d]	431	–	201	–	–	–	216	–	80	–	876	550	1278	221	21	–	141	–	621	402	621	–
H_3PO_4[e]	238	331	320	342	351	351	360	269	310	331	161	172	44	225	360	360	333	346	227	227	227	316
DAP[f]	–	321	–	175	–	–	338	659	–	55	–	313	–	845	–	21	–	126	–	–	–	516
KCl[g]	267	267	433	433	200	200	367	367	333	333	800	800	333	333	333	333	400	400	667	667	333	333
Filler	–	29	61	172	33	33	–	–	–	–	–	118	–	342	569	581	1008	1086	332	446	180	521
Steam, lb/st	73	100	68	100	100	100	–	100	100	100	10	100	–	100	86	92	74	100	27	100	27	100
Water, lb/st	27	–	32	–	–	–	–	–	–	–	90	–	100	–	14	8	26	–	73	–	73	–
Evaporation, lb/H_2O/st	140	140	146	142	143	143	53	128	139	140	144	133	139	129	146	145	146	142	146	137	146	137
Heat of reaction Btu/st x 1000	200	191	200	196	200	200	186	165	194	192	200	200	200	178	200	200	200	198	200	200	200	185
Liquid phase	600	643	600	619	600	600	669	776	632	642	600	600	600	712	600	600	600	611	600	600	600	676

[a]82.3% N.
[b]21-0-0.
[c]46-0-0.
[d]0-46-0.
[e]0-54-0.
[f]18-46-0.
[g]0-0-60.

Appendix

Information on Nitrogen Solution

Ammonia-urea solution was obtained from Nederlandse Stikstof Maatschappij N.V., Sluiskil, The Netherlands, through an arrangement with Transammonia. The contact for the solution is Ir. J. A. Zeegers, Deputy Managing Director. A log was kept on the ship, *M. V. Anco Duke*, during the period January 23, 1972 to February 9, 1972, of the temperatures of the air, seas, and cargo tanks. A copy of this log is included in the appendix (table A-1). The maximum temperature recorded in the tanks was 32°C (89°F) when the ship was near the equator. Tank temperatures varied depending on location in the ship.

Literature data have been included on the systems NH_3-$CO(NH_2)_2$-H_2O (figure A-1) from Worthington, Datin, and Schutz [*Ind. Eng. Chem.* 44:910 (1959)]. From this information the salting-out point and vapor pressure at 32°C (90°F) can be predicted. For example, a composition of 16% NH_3, 44% urea, and 40% H_2O should salt out about 19°C (66°F), and would exert no gauge pressure at 32°C (90°F). Other compositions can be checked using the phase diagram.

Acknowledgement

The TVA engineers wish to express their sincere thanks to all CRA personnel who participated in the development and demonstration of the ammoniation-granulation process. Without the dedication and enthusiasm of CRA personnel it would have been impossible to achieve such success. A special thanks is extended to Dr. Shu Lin Peng who contributed greatly to the project. It was really he who envisioned the ammoniation-granulation process as being applicable to the CRA plant in Porto Alegre. He persevered to obtain the objective even though many problems had to be overcome.

A list of CRA personnel with whom the TVA engineers associated are given below. In addition, numerous personnel of the plant operating and maintenance staff contributed greatly.

CRA Personnel

Dr. Ubirajara de Jesus Pereira	Director Presidente
Sr. Erich H. Pudler	Director Superintendente
Sr. Delmar Silveira	Director Financeiro
Dr. Shu Lin Peng	Director Industrial
Sr. Horst Bals	Assistant to Directore Superintendente
Sr. Oscar R. Dietrich	Assistant to Director Industrial
Sr. Frederico R. Carvalho Mottolo	Engineer
Sr. Jorge Appel Soirefman	Engineer
Sr. Quintino Barchinski	Engineer
Sr. Julio Cesar Dexheimer	Engineer
Sr. Roberto Froes Pena	Engineer
Dono Oda Ludwig	Secretary

Table A-1. Log–*M. V. Anco Duke*–voyage 23/72–Sluiskil to Rio Grande–urea ammonia, voyage temperature record, °F

Date		Temps		Ullage space				2 Center cargo temps			4 Center cargo temps			6 Center cargo temps			8 Center cargo temps		
1972	Time	Air	Sea	2	4	6	8	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
1/23	0700	44	56					74	73	74	80	80	80	82	81	81			
1/23	1200	46	56					76	76	76	83	82	81	85	85	85			85
1/23	1700	39	55					74	74	73	81	81	81	84	82	83		82	82
1/24	0700	39	55					72	72	72	78	78	79	77	78	78	82	82	83
1/24	1200	40	54					70	71	70	77	77	78	78	78	77	82	81	82
1/24	1700	46	52					69	70	71	77	77	76	76	76	76	79	81	80
1/25	0700	44	45	60	65	66	68	78	77	76	75	75	74	75	74	74	74	74	75
1/25	1200	56	55	65	69	66	66	71	72	72	72	72	74	71	71	72	71	71	71
1/25	1700	53	54	60	64	68	68	71	72	73	72	72	72	71	71	72	70	70	71
1/26	0700	53	57	66	65	66	65	74	74	74	73	72	72	71	71	72	70	70	70
1/26	1200	59	57	66	65	63	63	73	73	72	71	71	71	72	71	71	71	71	71
1/26	1700	56	57	65	63	63	64	71	71	72	72	72	74	71	71	71	71	71	71
1/27	0700	58	61	72	68	74	70	81	81	81	77	76	78	78	77	78	76	75	76
1/27	1200	64	62	78	76	74	74	82	81	78	80	77	76	78	76	78	76	76	75
1/27	1700	63	62	76	72	77	74	84	83	81	79	78	79	78	78	77	77	76	74
1/28	0700	60	65	83	84	83	79	88	87	86	88	87	84	87	83	82	82	81	78
1/28	1200	66	65	84	82	78	78	88	87	84	86	82	78	85	83	80	79	79	78
1/28	1700	62	66	84	86	78	74	89	89	82	89	85	78	86	80	78	78	78	76
1/29	0700	63	70	79	75	74	72	89	86	80	85	82	78	84	80	78	76	76	74
1/29	1200	69	70	86	83	82	78	89	86	81	86	81	80	83	81	80	78	77	76
1/29	1700	70	70	81	79	78	77	89	85	82	87	81	79	83	81	78	77	77	76
1/30	0700	70	70	76	74	72	72	80	80	78	78	76	75	77	74	74	73	73	73
1/30	1200	75	71	77	75	72	72	79	78	77	77	77	76	75	75	74	73	73	73
1/30	1700	72	73	72	69	72	72	77	77	77	74	73	75	74	74	73	72	72	73
1/31	0700	70	74	70	71	68	71	75	75	757	73	73	73	72	72	72	72	72	72
1/31	1200	74	74	70	71	67	72	74	75	74	73	73	73	73	71	72	73	72	72
1/31	1700	78	76	71	70	68	72	75	75	75	73	73	73	72	72	73	72	73	73
2/1	0700	75	81	72	71	71	71	75	75	76	73	74	74	73	73	74	73	73	74
2/1	1200	83	81	75	72	73	74	75	76	76	74	75	75	73	74	74	75	75	75
2/1	1700	79	81	74	74	70	74	76	76	76	75	75	75	74	75	75	74	74	76
2/2	0700	76	83	75	74	77	74	76	77	78	76	77	77	76	76	77	76	77	77
2/2	1200	79	83	76	75	74	72	76	77	78	75	76	77	76	77	77	77	77	78
2/2	1700	78	83	75	75	75	77	77	78	78	77	77	77	76	77	77	78	78	78
2/3	0700	[illegible]	83	75	74	75	76	78	78	79	77	78	78	78	78	78	78	79	79
2/3	1200	84	83	74	77	78	78	78	79	79	78	79	79	78	79	79	79	79	79
2/3	1700	80	83	74	75	76	76	79	79	79	79	79	79	78	79	79	79	79	80
2/4	0700	79	80	73	75	75	80	80	80	80	74	80	80	79	80	80	80	80	80
2/4	1200	79	80	75	76	76	76	79	80	80	79	80	80	80	80	80	80	80	80
2/4	1700	88	83	78	78	77	81	80	81	81	80	80	81	80	80	81	81	81	81
2/5	0700	75	84	76	77	77	78	81	81	82	81	81	81	81	81	81	82	82	82
2/5	1200	88	85	77	78	78	81	81	82	82	61	82	82	81	82	81	82	82	80
2/5	1700	87	85	77	77	78	79	81	82	82	81	81	81	81	82	81	82	82	82
2/6	0700	83	85	80	80	79	82	82	82	83	82	82	82	82	82	82	83	83	83
2/6	1200	88	85	79	79	80	83	82	82	83	82	82	83	82	82	83	83	83	83
2/6	1700	84	84	78	79	79	81	82	83	83	82	83	83	82	83	82	80	83	83
2/7	0700	80	81	76	78	78	79	82	82	82	81	82	82	81	82	82	82	82	82
2/7	1200	88	83	87	83	79	80	83	82	83	82	82	82	82	82	82	82	82	82
2/7	1700	89	83	80	81	78	81	82	83	83	82	82	83	81	82	82	81	82	83
2/8	0700	79	80	80	79	78	79	82	82	83	82	82	82	82	82	82	82	82	82
2/8	1200	87	80	80	78	80	80	82	82	82	82	82	82	81	81	82	81	81	81
2/8	1700	90	82	76	76	78	80	82	82	82	82	82	82	81	81	81	81	82	82
2/9	1400	85	80	78	79	79	79	80	81	81	81	81	81	80	81	81	80	81	81

Figure A-1. Phase diagram for NH_3-$CO(NH_2)_2$-H_2O

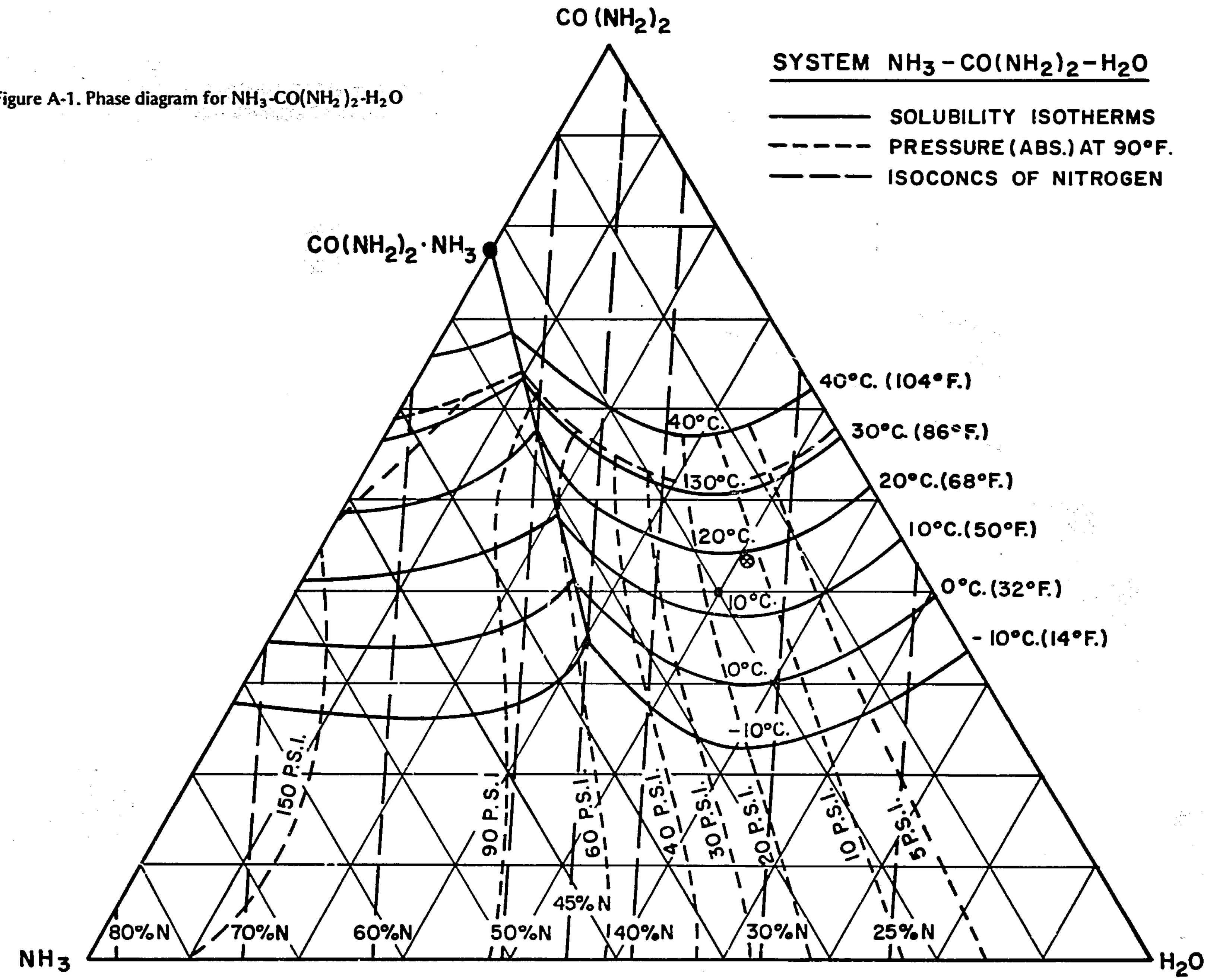

Table A-2. Investment cost for production of mixed granular fertilizer using ammonia-urea solution and superphosphates

Basis: One unit of 600 mt/day capacity of 198,000 mt/yr; operating rate 175,000 mt/yr	
Plant investment	
U.S. cost, battery limits	$1,976,000
Foreign cost, U.S. cost x 1.3	593,000
Auxiliary facilities (25% of plant cost)	642,000
Support facilities	
25% of plant cost	642,000
25% of auxiliary facilities	161,000
Bulk storage (1/3 of annual production) (58,300 x $11)	641,000
	$4,655,000
Ammonia-urea solution storage (10,000 mt)	250,000
Raw material storage	880,000
Total plant investment	$5,785,000

Table A-3. Estimated labor requirements for ammoniation-granulation

Manpower	Number/shift
Plant manager	1
Foreman	1
Front-end loader operator	1
Weigh operator	1
Drum granulator operator	1
Pan granulator operator (optional)	2
Laborers	3
Boiler operator	1
Shipping clerk	1
Chemist analyst	2
Maintenance	
Electrician	1
Machinist	1
Pipefitter	1
Helpers	3
Subtotal	20

For 8-hr shift = 8 hr x 20 men = 160 man-hr

At 30 mt/hr = 8 hr x 30 mt/hr = 240 mt

or $\frac{160 \text{ man-hr}}{240 \text{ mt}} = 0.667$ man-hr/mt

Assume $2.50/man-hr = 0.667 man-hr/mt x $2.50/man-hr = $1.67

Bagging and shipping	
Top operator (foreman)	1
Front-end loader operator	1
Baggers	5
Loaders	4
Subtotal	11

8 hr x 11 men = 88 man-hr

$\frac{88 \text{ man-hr}}{240 \text{ mt}} = 0.367$ man-hr/mt

Assume $2/man-hr = 0.367 man-hr/mt x $2/man-hr = $0.73

Table A-4. Estimated production cost of 5-22-10 grade from ammonia-urea solution and superphosphate

Operating rate	175,000 mt/yr
Plant investment	$ 5,785,000
Working capital	4,283,000
Total capital investment	$10,068,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Ammonia-urea solution	(0.138)	53.00	7.31
NSP (0-20-0)	(0.500)	47.00	23.50
TSP (0-46-0)	(0.220)	75.00	16.50
DAP (18-46-0)	(0.050)	95.00	4.75
KCl (0-0-60)	(0.167)	52.00	8.68
Subtotal			60.74

Fixed and variable costs	
Steam (50%) (211 lb x $0.50/1000 lb)	0.11
Labor (0.667 man-hr/mt x $2.50/man-hr)	1.67
Maintenance (5% of plant investment)	1.65
Supplies (20% of maintenance)	0.33
Electricity	0.10
Water	0.02
Taxes and insurance (2% of plant investment)	0.66
Depreciation (15 yr)	2.20
Fuel oil (3 gal/mt x $0.15/gal)	0.45
Interest (8% of ½ plant investment)	1.32
Overhead (100% of labor)	1.67
Subtotal	10.18
Total production cost, bulk	70.92
Bags (50 lb) (44 bags x $0.136/bag)	6.00
Bagging labor	0.73
Interest on working capital (8% of ½ working capital)	0.98
Production cost at 0% return on investment	78.63
Return on investment (15%)	8.63
Production cost at plant exit (15% ROI)	87.26
Production cost per unit plant food, bagged	(2.36)

Table A-5. Estimated production cost of 8-24-12 grade from ammonia-urea solution and superphosphate

Operating rate	175,000 mt/yr
Plant investment	$ 5,785,000
Working capital	4,685,000
Total capital investment	$10,470,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Ammonia-urea solution	0.174	53.00	9.22
NSP (0-20-0)	0.333	47.00	15.65
TSP (0-46-0)	0.225	75.00	16.88
DAP (18-46-0)	0.163	95.00	15.49
KCl (0-0-60)	0.200	52.00	10.40
Subtotal			67.64
Fixed and variable costs			10.18
Total production cost, bulk			77.82
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.07
Production cost at 0% return on investment			85.62
Return on investment (15%)			8.97
Production cost at plant exit (15% ROI, bagged)			94.59
Production cost per unit plant food, bagged			(2.15)

Table A-6. Estimated production cost of 6-30-12 grade from ammonia-urea solution and superphosphate

Operating rate	175,000 mt/yr
Plant investment	$ 5,785,000
Working capital	4,908,000
Total capital investment	$10,693,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Ammonia-urea solution	0.144	53.00	7.63
NSP (0-20-0)	0.100	47.00	4.70
TSP (0-46-0)	0.523	75.00	39.23
DAP (18-46-0)	0.100	95.00	9.50
KCl (0-0-60)	0.200	52.00	10.40
Subtotal			71.46
Fixed and variable costs			10.18
Total production cost, bulk			81.64
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.12
Production cost at 0% return on investment			89.49
Return on investment (15%)			9.17
Production cost at plant exit (15% ROI, bagged)			98.66
Production cost per unit plant food, bagged			(2.06)

Table A-7. Estimated production cost of 10-30-15 grade from ammonia-urea solution and superphosphates

Operating rate	175,000 mt/yr
Plant investment	$ 5,785,000
Working capital	5,192,000
Total capital investment	$10,977,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Ammonia-urea solution	0.100	53.00	5.30
NSP (0-20-0)	0.000	47.00	0.00
TSP (0-46-0)	0.267	75.00	20.03
DAP (18-46-0)	0.400	95.00	38.00
KCl (0-0-60)	0.250	52.00	13.00
Subtotal			76.33
Fixed and variable costs			10.18
Total production cost, bulk			86.51
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.19
Production cost at 0% return on investment			94.43
Return on investment (15%)			9.41
Production cost at plant exit (15% ROI, bagged)			103.84
Production cost per unit plant food, bagged			(1.89)

Table A-8. Estimated production cost of 9-36-12 grade from ammonia-urea solution and superphosphates

Operating rate	175,000 mt/yr
Plant investment	$ 5,785,000
Working capital	5,402,000
Total capital investment	$11,187,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Ammonia-urea solution	0.050	53.00	2.65
NSP (0-20-0)	0.000	47.00	0.00
TSP (0-46-0)	0.358	75.00	26.85
DAP (18-46-0)	0.425	95.00	40.38
KCl (0-0-60)	0.193	52.00	10.04
Subtotal			79.92
Fixed and variable costs			10.18
Total production cost, bulk			90.10
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.23
Production cost at 0% return on investment			98.06
Return on investment (15%)			9.59
Production cost at plant exit (15% ROI, bagged)			107.65
Production cost per unit plant food, bagged			(1.89)

Table A-9. Investment cost for production of mixed granular fertilizer using imported ammonia and phosphoric acid

Basis: One unit of 600 mt/day capacity of 198,000 mt/yr
Operating rate 175,000 mt/yr

Plant investment	
U.S. cost, battery limits	$1,976,000
Foreign cost, U.S. cost x 1.3	593,000
Auxiliary facilities (25% of plant cost)	642,000
Support facilities	
25% of plant cost	642,000
25% of auxiliary facilities	161,000
Bulk storage (58,300 x $11)	641,000
Ammonia storage (10,000 mt; $811,000 x 1.3)	1,054,000
Auxiliary facilities for ammonia (25%)	264,000
Phosphoric acid storage (24,000 mt; $745,000 x 1.3)	969,000
Total plant investment	$6,942,000

Table A-11. Estimated production cost of 8-24-12 grade from imported ammonia and phosphoric acid

Operating rate	175,000 mt/yr
Plant investment	$ 6,942,000
Working capital	4,426,000
Total capital investment	$11,368,000

Raw materials	t/mt	$/mt	Total cost $/mt
(inc. losses)			
Anhydrous ammonia	0.099	88.00	8.71
Phosphoric acid	0.445	95.15	42.34
Potassium chloride	0.200	52.00	10.40
Filler	0.300	3.00	0.90
Subtotal			62.35
Fixed and variable costs			11.31
Total production cost, bulk			73.66
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.01
Production cost at 0% return on investment			81.40
Return on investment (15%)			9.74
Production cost at plant exit (15% ROI, bagged)			91.14
Production cost per unit plant food, bagged			(2.07)

Table A-10. Estimated production cost of 5-22-10 grade from imported ammonia and phosphoric acid

Operating rate	175,000 mt/yr
Plant investment	$ 6,942,000
Working capital	3,946,000
Total capital investment	$10,888,000

Raw materials	t/mt	$/mt	Total cost $/mt
(inc. losses)			
Anhydrous ammonia	0.062	88.00	5.46
Phosphoric acid	0.407	95.15	38.73
Potassium chloride	0.167	52.00	8.68
Filler	0.413	3.00	1.24
Subtotal			54.11

Fixed and variable costs	
Steam	0.00
Labor	1.67
Maintenance (5% of plant investment)	1.98
Supplies (20% of maintenance)	0.40
Electricity	0.10
Water	0.02
Taxes and insurance (2% of plant investment)	0.79
Depreciation (15 yr)	2.64
Fuel oil (3 gal at $0.15/gal)	0.45
Interest (8% of ½ plant investment)	1.59
Overhead (100% of labor)	1.67
Subtotal	11.31
Total production cost, bulk	65.42
Bags (50 lb) (44 bags x $0.136/bag)	6.00
Bagging labor	0.73
Interest on working capital (8% of ½ working capital)	0.90
Production cost at 0% return on investment	73.05
Return on investment (15%)	9.33
Total production cost at plant exit (15% ROI)	82.38
Total production cost per unit plant food, bagged	(2.23)

[a]Ammonia cost, $50 + $30 (freight, handling, and storage) = $80/st or $88/mt.

[b]Phosphoric acid cost, $66.50 + $20.00 (freight, handling, and storage) = $86.50/st or $95.15/mt.

Table A-12. Estimated production cost of 6-30-12 grade from imported ammonia and phosphoric acid

Operating rate	175,000 mt/yr
Plant investment	$ 6,942,000
Working capital	4,899,000
Total capital investment	$11,841,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Anhydrous ammonia	0.074	88.00	6.51
Phosphoric acid	0.555	95.15	52.81
Potassium chloride	0.200	52.00	10.40
Filler	0.245	3.00	0.74
Subtotal			70.46
Fixed and variable costs			11.31
Total production cost, bulk			81.77
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.12
Production cost at 0% return on investment			89.62
Return on investment (15%)			10.15
Production cost at plant exit (15% ROI, bagged)			99.77
Production cost per unit plant food, bagged			(2.08)

Table A-13. Estimated production cost of 10-30-15 grade from imported ammonia and phosphoric acid

Operating rate	175,000 mt/yr
Plant investment	$ 6,942,000
Working capital	5,290,000
Total capital investment	$12,232,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Anhydrous ammonia	0.124	88.00	10.91
Phosphoric acid	0.555	95.15	52.81
Potassium chloride	0.250	52.00	13.00
Filler	0.147	3.00	0.44
Subtotal			77.16
Fixed and variable costs			11.31
Total production cost, bulk			88.47
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.21
Production cost at 0% return on investment			96.41
Return on investment (15%)			10.48
Production cost at plant exit (15% ROI, bagged)			106.89
Production cost per unit plant food, bagged			(1.94)

Table A-14. Estimated production cost of 9-36-12 grade from imported ammonia and phosphoric acid

Operating rate	175,000 mt/yr
Plant investment	$ 6,942,000
Working capital	5,689,000
Total capital investment	$12,631,000

Raw materials (inc. losses)	t/mt	$/mt	Total cost $/mt
Anhydrous ammonia	0.111	88.00	9.77
Phosphoric acid	0.667	95.15	63.47
Potassium chloride	0.200	52.00	10.40
Filler	0.117	3.00	0.35
Subtotal			83.99
Fixed and variable costs			11.31
Total production cost, bulk			95.30
Bags (50 lb) (44 bags x $0.136/bag)			6.00
Bagging labor			0.73
Interest on working capital (8% of ½ working capital)			1.30
Production cost at 0% return on investment			103.33
Return on investment (15%)			10.83
Production cost at plant exit (15% ROI, bagged)			114.16
Production cost per unit plant food, bagged			(2.00)