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Technology and Economics of Complex Fertilizer Production

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The combinations of ammonium phosphate with other materials such as urea and ammonium nitrate—made in processes that involve neutralization of phosphoric acid, addition or formation of the accessory material or materials, and granulation of the mixture—are being used increasingly in various parts of the world. Such high-analysis fertilizers make up much of the class indefinitely termed "complex fertilizers."[1]

The established practice for making the complex fertilizers had involved ammoniating acids in tank reactors, granulating the relatively dilute slurry by mixing with a mass of recycled solids several times the weight of product, and removing a relatively large amount of water in a dryer. To avoid these problems a new technology has been developed and is beginning to come into use.

Removal of Moisture

The traditional solids-drying step in finishing of fertilizers not only is expensive, both in investment and operating cost, but also is a problem in regard to maintenance and air pollution. Further expense is incurred in handling the large recycle tonnage, which has sometimes been over five times the production rate. Two major methods have been developed for coping with these problems; one involves water removal concurrent with granulation and the other removal before granulation, as compared with removal after granulation in the usual practice.

Drying Combined with Granulation—By spraying a slurry (or liquid reactants) onto small particles in motion and supplying heat at the same time, granulation and drying can be carried out simultaneously in the same vessel. The spray forms successive layers on the granules and builds them up to the desired size, a method that is claimed to give a superior product in regard to strength and sphericity.

The Scottish Agricultural Industries (SAI) "internal recycle" process accomplishes this type of operation in a double-drum assembly, one positioned within the other and the two turning as a unit. In the first version of the method, phosphoric acid and ammonia were introduced as the granules passed through the inner drum, thereby depositing ammonium phosphate on the solid particles. The coated granules fell into the outer drum (where nitric acid and ammonia were sprayed on), traversed it in the opposite direction, and were lifted by flights back into the inner drum; a small part of the total flow was removed at this point as product. Release of moisture from the thin layers formed on the granules was quite rapid and the heat of acid neutralization accomplished drying without need for a separate dryer. Moreover, the internal recycle was accomplished without need for the usual extensive screening and conveying equipment required in external recycling. Some external recycling was required but it was relatively small.

In a more recent version of the process (1), developed to increase production capacity, phosphoric and nitric acids are reacted with ammonia in a preneutralizing tank to remove part of the water before the double-drum granulator. The resulting liquor, containing about 10% water,

[1]Complex fertilizers are generally characterized as homogeneous, granular fertilizers made by a process that involves a major degree of chemical reaction—as opposed to mechanical mixing of granulated materials or granulation by wetting and drying. Hence ammonium phosphate - ammonium sulfate combinations and products based on ammoniated superphosphate fall in the class. These are older combinations, however; only nitric phosphates (which are primarily ammonium phosphate - ammonium nitrate combinations) plus ammonium phosphate - urea and ammonium phosphate - ammonium nitrate (with straight ammonium phosphate as the limiting case) will be discussed in the present paper.

Proc., Semin. Fert. Prod. Technol. New Delhi, India. (Dec. 14-16, 1969)

is introduced into the outer drum. Otherwise the operation is unchanged except that some heat must be added to the granulator air stream to give adequate drying. The method has been installed in the SAI plant in Edinburgh, Scotland.

The "Spherodizer" process (Chemical and Industrial Corporation) is another granulation-dryer type. Neutralized slurry is sprayed against a falling curtain of solid particles in a rotary drum; flights in the drum lift the particles and cycle them through the spray. Heated air for drying is blown in concurrently with the slurry. Since the granules cycle through the falling curtain many times before they leave the drum, a layering type of granulation and rapid evaporation of water are obtained. Although some external recycling is reqiured, it is much less than in conventional granulation systems. The process is in use in over 20 plants, 14 of which are located in Europe (2). The main use has been in production of nitric phosphate.

The most recent development in combination granulation-drying is fluid-bed granulation. Although old in the patent literature (as are most granulation methods), large-scale use is relatively new. Arzani (3) has described Montecatini work on the method. Acid and ammonia are reacted in a tank, the resulting solution further ammoniated and mixed with recovered dust in a second tank, and the slurry pumped to a "spouted-bed" granulator. The slurry is injected upwardly, concurrently with a current of hot gas for fluidizing the bed and drying the granules. Off-gas passes through dust-removal equipment and is then scrubbed by the incoming phosphoric acid to recover ammonia.

The conical spouted bed does not have a granule-supporting, gas-distributing plate. At the center, where the gas flow is at maximum velocity, the granules travel upward and form a small jet at the top of the bed. At the periphery they travel downward until the cone convergence brings them back into the gas stream. Thus, at the point where the granules are wet with incoming solution the travel is the fastest and sticking, therefore, is minimized.

Two plants of this type have been built by Montecatini, handling 100 and 250 tons per day, respectively, of raw materials containing 40% water. For the larger plant, the granulator is 42 feet high and the bed diameter is 8 feet. Power and fuel oil consumption are 50 kilowatt hours and 132 pounds, respectively, per metric ton of product (for diammonium phosphate production). Recycle ratio varies from 1:1 to 1:2 depending on the product. The process is said to be applicable to a wide range of products (including superphosphate) and to raw materials, such as filter-grade phosphoric acid, that contain large amounts of water.

Fluid-bed granulation is also used in the United States. Struthers Nuclear and Process Company has built three plants for granulating ammonium sulfate; presumably the method could be used also for complex fertilizers.

Melt Granulation—The combination granulator-dryer methods have the disadvantages that moisture disengagement from the granules is sometimes difficult, the dust entrained with the drying gas can cause a pollution problem, and power is required for the solids cycling within the granulator. These problems are reduced or eliminated by the various melt granulation techniques that have been developed.

The term "melt granulation" implies removal of essentially all the water, in some type of evaporator, before the granulation step. Thus, the liquid or slurry granulated is a melt containing only a percent or so of water (often as low as 0.3%). Since removal of water in the granulator is not required, no flow of drying gas is needed and the amount of solids recycled is relatively small. Moreover, water removal is simpler and thermally more efficient bacause of using a liquid evaporation system rather than a wet solids-drying type.

Melt granulation has been practiced for some time, of course, in production of nitrogen fertilizers such as ammonium nitrate and urea. Product solutions are evaporated to a very low moisture content and then normally finished by prilling, one form of melt granulation. The method has not been generally applied in production of complex fertilizers, mainly because of the higher melting point and melt viscosity of such mixes and the insoluble, nonmelting compounds often involved. The combination of ammonium nitrate and ammonium phosphate, however, has been found amenable to melt granulation because ammonium nitrate in a sufficient amount reduces the melting point of the ammonium nitrate -

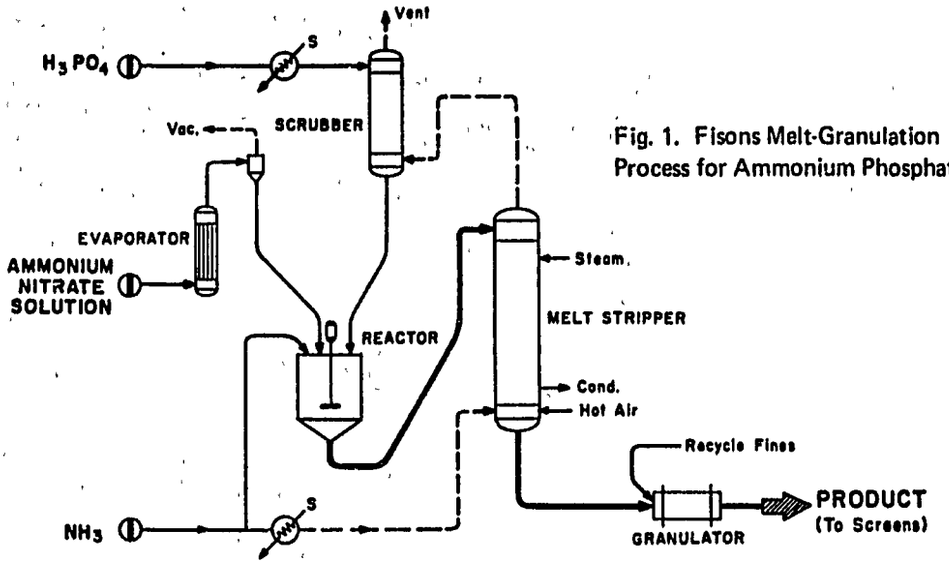

Fig. 1. Fisons Melt-Granulation Process for Ammonium Phosphate-Nitrate

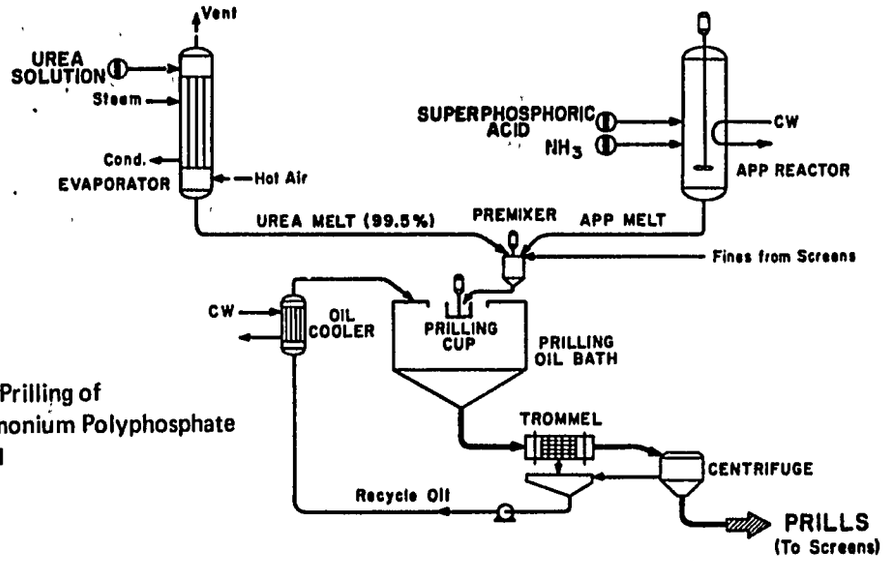

Fig. 2. Oil Prilling of Urea - Ammonium Polyphosphate in a Pugmill

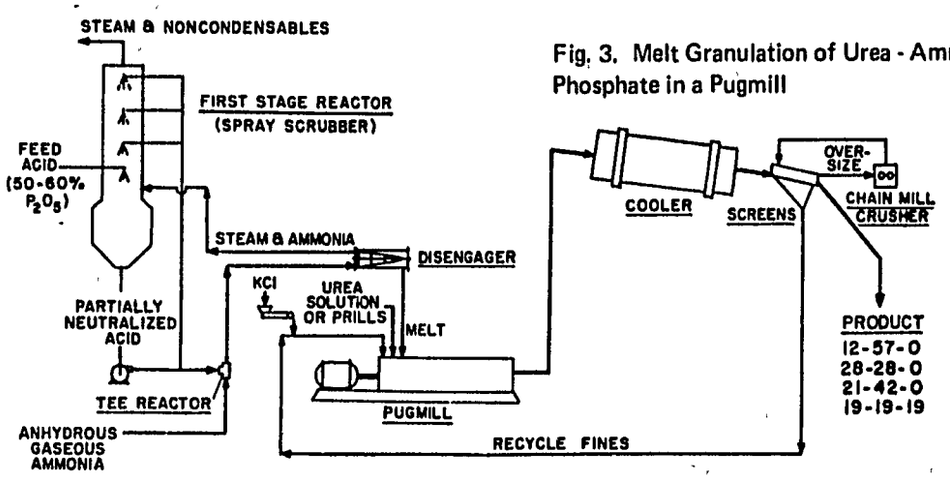

Fig. 3. Melt Granulation of Urea - Ammonium Phosphate in a Pugmill

ammonium phosphate mixture to a workable level. Moreover, such melts can carry a considerable amount of solids such as potassium chloride or dicalcium phosphate (in the case of nitric phosphate) without becoming too viscous for good operation.

In early TVA work (4), bench-scale tests were made of a method in which nitric acid, phosphoric acid, and ammonia were introduced into a packed tower. The water from the acids was evolved by the reaction heat and escaped from the top of the tower, and an anhydrous melt of ammonium nitrate and monoammonium phosphate flowed from the bottom. The melt could be granulated by any of the standard methods such as prilling, flaking, and pugmill of drum granulation. The minimum $N:P_2O_5$ weight ratio for good operation was 1:3.

NV Nederlandse Staatsmijnen (DSM) has done extensive development work on melt granulation of ammonium phosphate nitrate combinations, both with and without potash (5). One problem with mixes containing potash is that the chloride may sensitize the ammonium nitrate and cause deflagration at the elevated temperature involved. It was established in the DSM work, however, that only mixes in a certain proportion range (such as 1:1:2 and 2:1:2) presented any hazard, either in production or in later handling; grades such as 1:2:2, 1:1:1, and 1:2:1 could be granulated (prilled) and handled safely.

Fisons has developed the ammonium phosphate nitrate process shown in Fig. 1 (6). Early research on the method, begun in 1959, showed that the eutectic between ammonium nitrate and monoammonium phosphate melted at a temperature considerably below even that of ammonium nitrate and that the viscosity of the melt was relatively low. Therefore, granulation was no problem; the need was an efficient method for obtaining the ammonium phosphate nitrate melt. This was accomplished by reacting wet-process phosphoric acid (50% P_2O_5) with ammonia in stirred tanks, with addition of 92% ammonium nitrate solution. The $NH_3:H_3PO_4$ ratio was kept below that for monoammonium phosphate, thereby preventing ammonia loss. Impurities precipitated in the large volume of liquor without scaling the equipment. In the second stage, ammoniation to monoammonium phosphate was completed and the water evaporated (by a current of hot air) in a countercurrent, grid-packed stripping column. The off-gases were cooled and excess ammonia recovered by absorption in the incoming phosphoric acid. The melt from the column, containing only 0.2 to 0.3% water, could be granulated in any of the usual types of granulating equipment.

Fisons uses the melt process in a large plant. A rotary drum granulator is used, with the melt sprayed onto a rolling bed of fines or fines plus potash. Recycle ratio is reported to be about 1:1. Typical grades are 24-24-0, 30-10-0, 17-17-17, and 15-15-23. An $N:P_2O_5$ ratio as low as 1:1.5 is said to be possible.

In the United States, Monsanto Company, Spencer Chemical Company (now Gulf Oil Corporation), and C and I/Girdler Inc. have been active in development of melt granulation methods for ammonium phosphate nitrate. Limited amounts of grades such as 29-14-0 and 23-23-0 have been made by various fertilizer producers.

Urea - ammonium phosphate combinations can also be made by melt granulation but the thermal instability of urea makes a different technique necessary. TVA is working on two such processes, one involving oil prilling and the other pugmill granulation. In the oil-prilling version the objective is to make urea - ammonium polyphosphate rather than the orthophosphate; the product is expected to be a desirable raw material for liquid fertilizer production and therefore polyphosphate is needed to give high solubility. The process involves reaction of superphosphoric acid (furnace type) with ammonia (Fig. 2) to give a melt of ammonium polyphosphate directly (since there is no water in either raw material). Urea solution from urea plant decomposers is concentrated separately in a standard evaporation system to about 99.5%; because of the evaporator type used, the evaporation can be accomplished rapidly and with little urea decomposition. The two melts are then mixed just before entering the prilling basket, from which the droplets fall into a pool of cooled oil. Thus the urea and phosphate are in contact at high temperature for only a very short time, thereby minimizing urea decomposition. The oil is separated by screening and centrifuging and the product sized. The recycled fines (about 0.25 lb./lb. of product) serve the triple purpose of recovering off-size material, cooling the melt, and nucleating the prills to accelerate crystallization.

The oil-prilling technique was selected because polyphosphate crystallizes so slowly that prills falling though an air-prilling tower might not be hard enough to avoid deformation on striking the bottom. The oil cushions the fall, chills the droplets rapidly, and holds the prills until hard enough for further handling.

In the second TVA process (Fig. 3), orthophosphoric acid (wet-process type) is ammoniated in two stages under conditions such that the heat of reaction is conserved. If the acid concentration is 53% P_2O_5 or higher the heat of reaction is sufficient to evaporate the water introduced with the acid (acids of lower concentration can be used if supplemental heat is added by methods such as preheating the feed acid or ammonia). Moreover, enough polyphosphate (15-25% of the total P_2O_5) is produced, by dehydration of orthophosphate, to make the product molten and flowable at the temperature level generated.

In the pugmill, recycled fines are introduced at the front and followed by spraying urea melt onto the moving bed, thereby cooling and solidifying the urea. The ammonium phosphate melt is then fed to the mill and provides the bed plasticity required for granulation. This separation of the urea and ammonium phosphate melts until the urea has cooled avoids the problem of urea decomposition.

This method, now being tested in a pilot plant, appears to be a good one for situations in which a high polyphosphate level is not required. For high polyphosphate, there is the difficulty that a large amount of recycle would be required to cool and crystallize the polyphosphate.

The viscosity of the ammonium phosphate melt from the TVA reactor is low enough to allow prilling without addition of ammonium nitrate or urea. Thus the method makes it possible to finish ammonium phosphate by melt granulation processes, including prilling, in the same way as for urea or ammonium nitrate.

The third major class of complex fertilizers, nitric phosphates, can also be produced by melt granulations. This has been restricted mainly to the Odda type, where a major portion of the calcium is removed before the phosphoric acid - calcium nitrate solution is ammoniated and granulated. Norsk Hydro-Elektrisk Kvaelstofaktieselskab, for example, operates a plant of this type. The mixed-acid type, in which all the calcium remains in the product, can have a high viscosity in the molten form; it is normally finished by conventional granulation followed by drying or by a combination granulation-drying method, particularly the spray drum (Spherodizer) type. However, if the combination of nitric and phosphoric acids is used, the acidulate composition can approximate that of Odda-type solution after calcium removal. In early TVA pilot plant work (7), mixed-acid nitric phosphate of this type was melt granulated in a pugmill.

Economics

Both melt granulation and combined granulation-drying give the major advantages of eliminating the usual drying step and reducing the amount of external recycling required; both of these effects reduce investment, energy requirement, and atmospheric pollution. Higher granule strength and density are other desirable features. Melt granulation is particularly beneficial in urea - ammonium phosphate production because the contact time at high temperature between urea and ammonium phosphate is minimized and urea decomposition is thereby reduced.

As between melt granulation and combined granulation-drying, the melt type requires less power, dust evolution is lower, and heat of reaction can be used more advantageously in evaporating water (as in the TVA "low-polyphosphate" process). As to investment, the combination of granulation and water removal in the granulation-drying system is desirable but the units are very large and relatively expensive. Adequate information is not available for a good comparison with melt granulation.

The principal disadvantage of these newer methods probably is that the degree of phosphoric acid ammoniation is reduced as compared with the older process of granulation followed by drying, in which diammonium phosphate can be made without difficulty. Because of the high temperature in the melt process and the high gas flows common in the granulation-drying combinations, ammoniation beyond the monoammonium phosphate ratio is difficult. There have been some proposals to carry out the operations in an atmosphere of ammonia to increase ammonia absorption; for example, Arzani

(3) describes production of diammonium phosphate in a fluidized granulator-dryer by injecting excess ammonia into the liquor stream entering the granulator and carrying it with the exhaust gases back to the acid scrubber. Porter (6) infers that the Fisons melt process can be adapted to diammonium phosphate. In most of the processes reported, however, ammoniation very far beyond the monoammonium phosphate ratio is seldom attempted.

The merits of high ammoniation are difficult to evaluate. The advantages to be expected are (1) higher concentration, (2) upgrading of more ammonia to the solid form, (3) more heat of reaction for water removal, and (4) better physical condition (than for intermediate degrees of ammoniation). In the United States, diammonium phosphate has become a very popular material for these reasons, but there are some indications of a trend to lower $N:P_2O_5$ ratio in order to get higher phosphate concentration (to reduce shipping cost) and allow use of more low-cost direct-application ammonia. In Europe, there has never been any major effort to achieve high degrees of ammoniation.

Melt granulation methods also have less versatility in formulation. Drying after granulation makes it possible to granulate almost any formulation and grade. Drying during granulation is less versatile but is still more adaptable to a wide range of conditions than prilling.

With all these complications it is quite difficult to estimate the relative costs of the three methods. A major study would be required, and it appears that no one has made such an effort. The several advantages of melt granulation, however, make it the indicated choice except where the formulation is not conducive to formation of a melt with adequately low viscosity.

The economics of complex fertilizers can also be compared on the basis of product type—ammonium phosphate nitrate, urea - ammonium phosphate, and nitric phosphate. The main points of comparison are (1) ammonium phosphate nitrate is easiest to make, (2) urea - ammonium phosphate has the highest nutrient content, and (3) nitric phosphate uses the least amount of sulfuric acid (or none at all). TVA cost estimate (8) comparing the three showed that, for the same return on investment, Odda-type nitric phosphate could be sold at a price (per unit of nutrient) lower than for ammonium phosphate nitrate, urea - ammonium phosphate, or mixed-acid nitric phosphate, even at sulfur cost as low as $15 per long ton. Mixed-acid nitric phosphate, however, had an advantage over the ammonium phosphate types only at a sulfur cost of over $33 per long ton. Ammonium phosphate nitrate and urea - ammonium phosphate were about the same and their relative position was not affected, of course, by the cost of sulfur.

The advantage of Odda nitric phosphate was quickly lost when costs of shipping and distribution were included. The lower nutrient content of the Odda type made freight and retailer's handling cost important considerations, as such costs are a function of weight and are the same for a low-analysis fertilizer as for a more concentrated one. For an assumed sulfur cost of $26 per long ton, overall cost applied to the soil became the same for Odda nitric phosphate and urea - ammonium phosphate when freight and handling costs reached $9.50 per ton of product. Higher sulfur price, of course, was favorable to the Odda product; for each $1 per ton increase in cost of sulfur, the Odda process gained an advantage equivalent to about $0.68 in freight and handling costs.

Urea - ammonium phosphate, with its higher analysis, drew away from ammonium phosphate nitrate as shipping and handling costs increased. Therefore, urea - ammonium phosphate and Odda nitric phosphate were the only products in contention, the Odda type more economical up to a certain level of such costs, which increased with price of sulfur, and urea - ammonium phosphate the economic choice at higher levels. The estimate was based on 20-20-0 nitric phosphate; for higher analysis Odda grades such as now made (up to 23-23-0), the Odda type would be the most economical over a wider range.

There have been recent efforts to improve nitric phosphate economics, mainly by using recycled sulfate to remove calcium (9) and solvent extraction to separate phosphoric acid from calcium nitrate (10). Neither process has been applied in large-scale production.

Granulation Technique

The three methods of water removal are versatile in that several granulation techniques can be used

with each. The granulation methods generally associated with each moisture-removal arrangement are given below. Most of these combinations are in actual use; others are presumed to be applicable to complex fertilizers because they have been used successfully for ammonium nitrate or urea.

Method of moisture removal	Applicable granulating system
Evaporation before granulation (melt type)	Prilling tower
	Flaker
	Spray drum
	Drum (conventional)
	Pugmill
	Pan
Drying during granulation	Double drum
	Spray drum
	Fluid bed
Drying after granulation[a]	Drum (conventional)
	Pugmill
	Pan

[a]All the other methods are applicable also, of course, if some moisture is left in the material being granulated, as in the older practice. However, this is generally considered uneconomical.

Prilling—The main requirement in prilling is that the melt have a viscosity low enough to flow readily through the spray heads or rotating bucket. In making NPK fertilizer from ammonium nitrate, ammonium phosphate, and potash, for example, viscosity increases with amount and fineness of the potash but decreases with retention time because of reaction between ammonium nitrate and potash (5). The proper combination of conditions must be worked out for each grade. The dicalcium phosphate formed when nitric phosphate acidulate is ammoniated also affects viscosity; normally only acidulates from which much of the calcium has been removed are finished by prilling.

The choice between rotating bucket and spray heads is an important consideration in prill tower design. There does not seem to be any consensus on the point. Buckets, particularly conical ones, are said by some to be less affected by variations in pressure and viscosity, simpler to clean (since a clean bucket can be quickly swung into place to replace one taken out of service for cleaning), and capable of better prill size control (by variation of rotation speed to adjust for changes in operating conditions during a run) and better distribution in the tower. On the other hand, spray heads allow a wider variation in particle size from one run to another (by varying the pressure); some producers change from standard prills to microprills merely by increasing melt pressure, whereas for the bucket technique a separate bucket is required for microprills.

Removal of the prills from the tower bottom has given rise to some problems. The usual design is a cone bottom which is supposed to bring the prills to a central point for discharge but the prills sometimes stick and fail to roll down the slope. Some prefer a flat bottom with a rake to remove the prills. In a recent design, a fluidized cooler forms the bottom of the tower. The prills fall into the fluid bed, which performs the double function of cooling and of collecting the prills without sticking.

The various parameters in prill tower design—tower height and diameter, volume and velocity of cooling air, bucket shape and size, and number and size of holes—make the design somewhat complicated, too much so to cover in this paper. The subject has been treated by Steenwinkel and Hoogendonk (5).

Prilling has the general advantages of melt processes and in addition requires the least recycle. The amount depends on closeness of product sizing, of course, but seldom exceeds 10% of the unscreened material from the tower. Prilling also normally gives the most nearly spherical product. All the other methods, except flaking, involve impingement of melt onto existing particles, a technique that is much more likely to produce irregular granules than the drop formation in prilling.

Prilling (air type) also is limited in regard to the upper range of particle size. Large prills, 10 mesh or larger, are difficult to produce because the prills tend to deform in fall. Oil prilling helps in this respect because the prill strikes a yielding surface rather than a rigid one.

Flaking—Two plants in the United States, one urea and the other ammonium nitrate, use flaking as the granulation method. Solution is evaporated to the melt state and then flowed onto a cooled surface where it hardens to a cake form. The cake is broken up, screened, and the offsize recycled.

As far as is known, flaking has never been used for complex fertilizers although presumably it

could be.[2] One of the main drawbacks is the irregular shape of the granules, which, in the United States at least, has been generally considered to reduce the attractiveness of the product and consequently put it at a disadvantage in a competitive market. Moreover, economics of scale are poor; a large plant would require a large number of flaking units.

Spray Drum—C and I/Girdler has developed the spray drum (Spherodizer) method of granulation (see earlier description). Most of the application has been in nitric phosphate plants but Cominco Ltd. (Canada) has adapted the method to ammonium nitrate and urea production (12). In nitric phosphate operation a relatively dilute solution has been generally used because the nitric phosphate plants involved were of the mixed-acid type. In the Cominco work, however, a melt was used successfully and cooling air rather than hot gas was passed through the drum. Therefore, the method presumably could be used for complex fertilizer formulations that form an acceptable melt.

For melt operation, the spray drum has several advantages over prilling. Larger granules can be made (-6 +10 mesh, for example, or even -4 +6 mesh) which is an important consideration in U. S. bulk blending practice; ammonium nitrate and urea prills are generally smaller than the other constituents of the blend and therefore tend to segregate. Large urea granules are also desirable for sulfur coating, a slow-release technique being developed by TVA.

The spray drum granules are also said to be much harder than prills, to have a rougher surface which holds conditioner better, and to have better storage properties. However, the granules are not as spherical as prills.

These advantages have led to use of the spray drum method for urea and ammonium nitrate in at least five plants in the United States and Canada. Except for nitric phosphate, however, application to large-scale complex fertilizer production appears to be limited.

Drum (Conventional)—The rotary drum granulator is one of the older granulating devices but is still quite widely used, particularly for processes involving granulation of a slurry or moist solid followed by drying. It is especially useful when chemical reaction is combined with granulation, as in the TVA ammoniation-granulation process which is now the basic method in the diammonium phosphate industry. TVA work has shown that complex fertilizers such as ammonium phosphate nitrate and nitric phosphate can be made in the same way and several plants are in operation in various parts of the world.

For moist solid granulation, the rotary drum has the advantage that a wide range of formulations is feasible and ammoniation can be carried to the diammonium phosphate level. Drying of the product is required, however, and recycle is relatively high—more for the purpose of adjusting the liquid:solid ratio in the granulator than for recovering offsize.

For melt granulation, the rotary drum has been shown to be suitable in the Fison's work. Close control of the bed temperature is necessary to ensure envelopment of the granules with melt but without agglomeration; temperature control is accomplished by cooling the recycled fines. Recycle rate is about 1:1.

Pugmill—The paddle mixer, usually called a pugmill or blunger, is also widely used in granulation of slurries or moist solids. Originally, the pugmill was used more in processes involving a slurry feed, a relatively wet mix in the granulator, little or no chemical reaction in the granulator, and a very high recycle rate (to give a layering type of granulation). Conversely, the drum was used more for formulations in which solids made up the major part of the feed and granulation was accomplished by sticking the solid particles together—by wetting in the older practice and later by use of chemical reactions to increase temperature and thereby develop an adequate amount of liquid phase by dissolution of the soluble salts present.

These differences have tended to disappear and today drums and pugmills are used somewhat interchangeably in granulator-plus-dryer installations. Both perform well and comparison is difficult. In general, the pugmill can tolerate a wider range of liquid phase and therefore can handle more dilute slurries and is less likely to give trouble from operator error; the positive action of

[2]TVA studied flaking of ammonium phosphate nitrate in early work (11) but a dryer was required because the solution was evaporated only to 5% moisture in order to maximize ammonia retention.

the pugmill paddles or blades gives a positive control not available in the drum. In addition, the pugmill is said to be capable of a wider range of particle size (13). On the other hand, many hold that chemical reactions such as ammoniation can be carried out more efficiently in the drum (although at least one plant makes diammonium phosphate in a pugmill) and that the rolling action in the drum gives a more rounded granule. Much depends, probably, on how the pugmill is operated; Dorr-Oliver, Inc., for example, turns the blades so rapidly that the bed is in a fluidized state (the pugmill is 30 to 36 in. deep), a condition that is claimed to improve ammoniation and which is quite different from the more common kneading action in pugmills.

For melt granulation, no particular advantages are apparent between the two types.

Pan Granulation—The inclined pan granulator, first used in Germany for granulation of superphosphate, has been adapted to granulation of both straight nitrogen materials and complex fertilizers. The development work has been done mainly at TVA, where a large-scale ammonium phosphate nitrate plant is now in operation. The process involves a dryer but presumably melt granulation would also be feasible; TVA has successfully pan granulated urea melt on a pilot plant scale.

One of the main advantages of the pan is the self-classifying action, by which small particles are held in the unit until they grow to acceptable size. Recycle requirement therefore is considerably lower than for the drum and pugmill systems. However, the pan is not well suited to ammoniation and the dust problem is relatively severe.

Economics—As several of the granulation techniques can be applied to any one of the moisture-removal methods, it is preferable to consider granulation economics separately.

Adequate studies do not appear available on the relative economics of the various granulation systems. Many of the factors, such as size, shape, strength, and density of particles, are not amenable to cost estimation, and others, such as recycle rate and operating difficulty, depend heavily on the grade and on the particular raw materials used.

Production capacity is, of course, an important economic factor. In this respect prilling has some advantage, for capacity per unit is almost unlimited; Eimers and Rohr (Uhde) (13) give 1200 to 1500 metric tons per day as the practical upper limit. The spray drum is somewhat limited unless the drum is site fabricated, as the diameter becomes quite large at high capacities. The rotary drum, pan, and pugmill granulators also have size limitations, although 1000 tons per day of diammonium phosphate is produced in some rotary drum granulators.

There is no clear-cut advantage to any system in regard to investment. Vernede (Continental Engineering NV) (14) states that prilling is a little more expensive than drum or pugmill granulation for potash-containing grades such as 16-16-16 and 20-11-11, but is slightly less expensive for 22-22-0. However, this assumes drying after granulation; no figures are available for melt granulation in drums or pugmills but it seems likely that cost of the evaporator would be less than for the dryer and the equipment to handle the higher recycle. Venkatesham and Murty (15), for example, point out that melt granulation of urea in a pan granulator can be considerably less expensive than prilling. This estimate, however, is for a relatively small plant; Vernede states that small plant size penalizes prilling.

C and I/Girdler (12) reports that a Spherodizer installation is slightly more expensive than the prilling type. However, the Spherodizer of necessity has a built-in dust-removal system whereas prilling installations do not.

Eimers and Rohr (13) have compared the economics of the various granulation techniques for a variety of products and grades. Again, however, melt granulation was covered only for the prilling system. The data given serve to indicate that formulation and grade have more effect on investment and operating cost than does the particular granulation technique.

Summary

The complex fertilizers, a class including the modern fertilizers such as ammonium nitrate - ammonium phosphate, urea - ammonium phosphate, and nitric phosphate, are growing in importance because of their high nutrient content, homogeneity, and applicability to high-capacity

production units. The main problems have been cost of drying, product decomposition during drying, cost of the relatively high recycle rate required in granulation, and dust evolution in the drying, screening, and recycling operations. New techniques have been developed, however, that eliminate the conventional separate solids-drying step and reduce or eliminate recycling. These new methods are coming into use and are expected to become predominant in the future.

Combination of the granulation and drying steps is one of the new techniques. Devices such as the double drum with internal recycle, spray drum, and fluid-bed granulator all accomplish this. Melt granulation is also a new and perhaps more promising method; all the water is removed before granulation, thereby eliminating wet-solids drying completely and greatly reducing recycle. No special equipment is required for granulation, as the melt can be granulated in devices such as prill towers, spray drums, rotary drums, pugmills, and pan granulators. In addition to lower cost and less pollution, the new methods give a better product—rounder, stronger, and more dense.

Of the various complex fertilizer types, Odda-type nitric phosphate appears to be the most economical unless the relatively low analysis is penalized excessively by shipping and handling costs. The high nutrient content of urea - ammonium phosphate makes it superior when high distribution cost per ton of material is involved.

Comparison of the various granulation methods is difficult because many of the factors involved are qualitative and those that are quantitative depend heavily on formulation and product grade. In general, prilling gives the lowest recycle, the most attractive product, and the least pollution. However, granule size is limited, some product types cannot be made, and investment may be higher than for melt granulation by the other methods, particularly for small plants. It is concluded that selection of granulation method should be the subject of a special study for each new installation, with due attention to plant size, product type, raw material economy, pollution situation, and customer preference in regard to product characteristics.

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