

Production of Granular NPKs in Ammonium Phosphate Plants

Some Important Differences

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by James J. Schultz

International Fertilizer Development Center

Preface

The plant design and operating parameters required for producing agglomerated compound (NPK) fertilizers, especially urea-based and other temperature-sensitive and hygroscopic granular products, are often quite different from those required for the production of conventional ammonium phosphate fertilizers, i.e., diammonium phosphate (DAP) or monoammonium phosphate (MAP). These differences should be carefully considered when adapting a DAP/MAP plant for the production of NPKs. The plant design and operating criteria described in this bulletin are intended to serve as a "check list" that may be used to help guide those involved in the planning and design of new NPK projects or the modification of existing units.

The data and recommendations contained in this bulletin are the distillation of a broad international base of experiences and results collected and formulated over a number of years. The author is grateful for the valuable insight offered by the many production, engineering, and research/development organizations and individuals who candidly shared their experiences and knowledge, offered suggestions, and otherwise stimulated and supported the preparation of this publication.

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Introduction

Conventional ammonium phosphate granulation plants (DAP and MAP) equipped with atmospheric or pressure tank-type preneutralizers are often not ideally suited for the production of granular NPK fertilizers, especially those NPKs that contain relatively large amounts of urea or other very soluble, hygroscopic, and temperature-sensitive salt mixtures. As a result, many combination DAP/NPK plants, although well suited for producing DAP or MAP, often have difficulty in achieving the owner's expectations when producing NPKs. This bulletin describes the fundamental differences between the granulation of DAP/MAP and that of most NPKs and discusses the plant design features most often needed for routine production of high-quality NPKs. In general, it is less difficult to produce DAP or MAP in a plant designed to produce NPKs than to do the opposite, provided, of course, that the NPK plant is equipped with systems for neutralizing large quantities of phosphoric acid and recovering ammonia.

The NPK fertilizer granulation plant design and operating parameters discussed in this bulletin are intended to describe, in general terms, the mechanical and process conditions that should be met to achieve an optimum level of plant performance and NPK product quality. None of the indicated criteria are absolute; there may often be much latitude for modification/variation, depending upon the specific requirements with respect to (1) product formulations (grades and ratios); (2) raw material quality and related physical and chemical properties; (3) skill of the plant operators; (4) expected operating rate (capacity utilization); (5) expected product quality and related regulatory criteria; (6) method of packaging, storage, and use; (7) length of storage between production and use; and (8) a host of site-specific, and often variable, factors including climatic conditions, infrastructure, environmental impact criteria, cultural practices, and market requirements.

An examination of selected papers indicated in the bibliography together with numerous other literature sources cited in these papers will provide a useful complement to this bulletin.

Importance of Granule Formation Mechanism

The method of granule formation has a pronounced impact on the design and layout of the process equipment. Therefore, a good knowledge of the primary mechanism of granule formation, growth, and consolidation is essential in determining the design features of the plant. Although a more compre-

hensive description of the mechanisms of granule formation can be found in the literature, the following is a brief description of the two major granule formation mechanisms, excluding drop formation (prilling), encountered in most fertilizer granulation processes.

Agglomeration-Type Processes

With most granular NPK products (excluding the slurry-based nitrophosphate-type processes), agglomeration is the principal mechanism responsible for initial granule formation and subsequent growth (Figure 1). In most NPK formulations, 50%-75% of the raw materials are fed as "dry" solids. These solid particles are assembled and joined into agglomerates (granules) by a combination of mechanical interlocking and cementing—much as a stonemason fashions a stone wall by using stones of varying size and shape and mortar as the cementing agent. The cementing medium for fertilizer granules is derived from salt solutions, for example, a preneutralized ammonium phosphate slurry and/or the dissolution of salt on the surface of the soluble solid particles. The size, shape, surface texture, strength, and solubility of the solid particles vary widely (Figure 2) and have a major influence on the granulation characteristics of the mixture.

Accretion-Type Processes

The slurry-type granulation processes (DAP, MAP, TSP, and some nitrophosphates) are quite different from the processes used for most NPKs with respect to the mechanism of granule formation and growth. As a result, the required process parameters for optimum operation of these slurry-type plants are also often quite different. With a slurry-type granulation process, a relatively thin film of moist slurry is repeatedly applied, dried, and hardened to a relatively firm substrate consisting of granules that are often product size and/or nearly product size. Granule growth is primarily by accretion, the process in which layer upon layer of new material is applied to a particle, giving the final granule an "onion-skin" structure (Figure 1). In the process, of course, some agglomeration also occurs, but this is not the predominant mechanism.

The recycle-to-product ratio required for accretion-type granule development is normally higher than that required for agglomeration-type processes. Accordingly, for a given production rate, the material handling capacity of the equipment must be larger for accretion-type granulation plants than for most agglomeration-type plants. However, because of particular temperature-related processing requirements for some agglomerated NPKs, certain equipment,

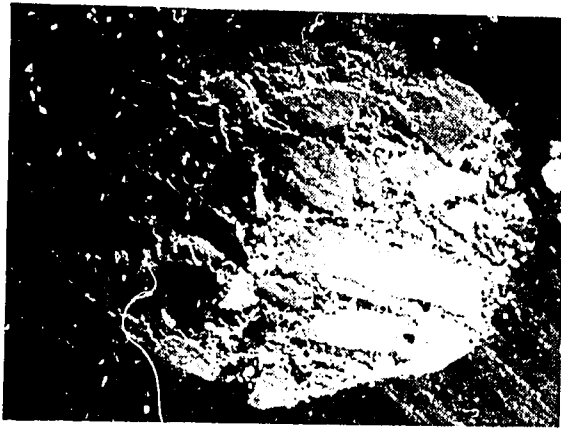


Photo of Actual Fertilizer Granule (Agglomeration)

Scale: 1 mm

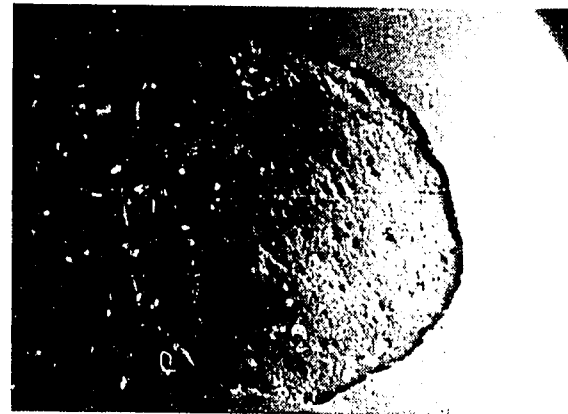
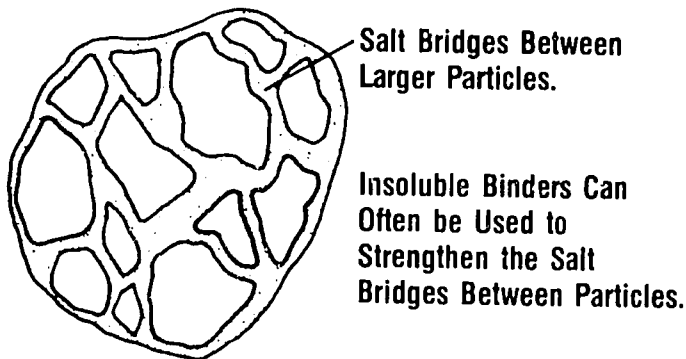
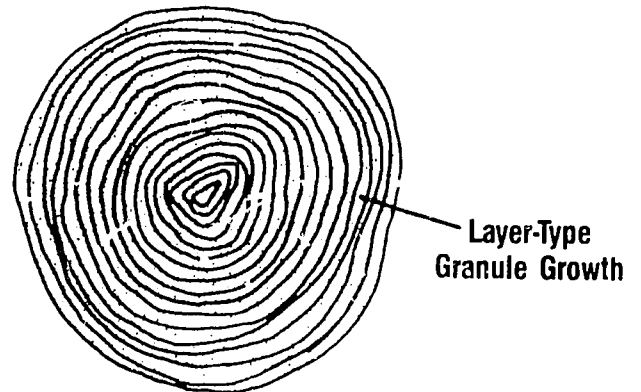


Photo of Actual Fertilizer Granule (Accretion)

Scale: 1 mm



Granule Formed by Agglomeration



Granule Formed by Accretion

Figure 1. Principal Mechanisms for Granule Formation.

especially the dryer and cooler, may actually be larger in some agglomeration-type plants to achieve the same production rate as in the accretion-type processes. This is discussed in greater detail later.

Granules formed by accretion are almost always harder, more spherical, and more durable than those formed by agglomeration. For example, a typical well-formed DAP or TSP granule produced mainly by accretion-type granulation may have a crushing strength of about 4-5 kg, whereas the crushing strength of an agglomerated granule may not only be less (often less than 3 kg) but also more variable depending upon its raw material composition and a number of specific factors related to granule formation. Some examples of the variability in granule strength for a number of fertilizers are shown in Table 1.

Equipment and Operating Parameters Unique to Agglomerated NPKs

A discussion of the key plant design and processing parameters required for the production of agglomerated NPK products follows. Specific reference is made to the special features needed for the production of most urea-based NPKs and other NPKs that exhibit similar high solubility, temperature sensitivity, and critical relative humidity (CRH) characteristics. The major deviations from the recommended equipment and operating criteria normally found in conventional DAP/MAP plants are discussed.

1. Critical relative humidity is the ambient relative humidity below which a material loses moisture to the atmosphere and above which the material absorbs moisture from the atmosphere. The CRH of a material varies with temperature.



Figure 1. SEM images of the particles.

Figure 1 shows the SEM images of the particles. The particles are spherical and have a smooth surface.

3.1. Morphology and Particle Size

The morphology and particle size of the particles were investigated by SEM. The particles are spherical and have a smooth surface. The particle size distribution is shown in Figure 2. The particles have a narrow size distribution with a mean diameter of approximately 1.5 μm.

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3.2. Elemental Particle Size

The elemental particle size of the particles was investigated by SEM. The particles are spherical and have a smooth surface. The elemental particle size distribution is shown in Figure 3. The particles have a narrow size distribution with a mean diameter of approximately 1.5 μm.

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Table 2. Typical Particle Size Data for Commercially Available Materials Frequently Used to Produce Granular NPKs

Material	Percent Retained on Indicated Mesh ^a					
	4 (4.75)	8 (2.36)	16 (1.00)	28 (0.60)	48 (0.30)	100 (0.15)
Ammonium sulfate (crystalline)	0	0	1	7	75	98
Diammonium phosphate ^b (granular)	0	22	98	100	100	100
Monoammonium phosphate (nongranular)	0	1	7	30	65	90
Potassium chloride (standard)	0	0	6	55	90	99
Potassium chloride (special standard)	0	0	0	5	35	90
Potassium sulfate (standard)	0	0	15	75	95	100
Single superphosphate (run-of-pile)	3	11	25	36	52	76
Triple superphosphate (run-of-pile)	7	14	19	26	51	80
Urea (prilled) ^b	0	15	92	95	100	100

a. Tyler mesh, opening size in mm indicated in parentheses.

b. Crushing of these materials is preferred to obtain a more uniform (homogeneous) NPK product.

Table 3. Solubility of Common Fertilizer Salts in Water^a

Fertilizer Salt	Approximate Concentration of Saturated Solution at Indicated Temperature		
	0°C	20°C	100°C
Ammonium nitrate	54	66	90
Ammonium sulfate	41	43	51
Diammonium phosphate	30	41	58
Monoammonium phosphate	18	27	63
Potassium chloride	22	25	36
Potassium nitrate	12	24	71
Potassium sulfate	6	10	19
Urea	41	52	88

a. Values indicated are for pure salts.

300 kg/tonne of product is about optimal for most agglomeration-type NPK formulations. Of course, it should be appreciated that liquid phase, while important in granule formation, is only one of the criteria that must be carefully evaluated when estimating the granulation characteristics of a particular formulation.

Table 4. Liquid Phase Factors for Selected Materials Frequently Used in NPK Granulation (Agglomeration) Formulas

Material	Liquid Phase Factor (kg/kg)
Anhydrous ammonia	0.50
Ammonia/ammonium nitrate solutions (various compositions)	1.00
Ammonium nitrate (prills)	0.30
Wet-process phosphoric acid	1.00
Sulfuric acid	1.00
Superphosphoric acid	1.00
Water or steam	2.00
Ammonium sulfate (crystalline)	0.10
Single superphosphate (run-of-pile)	0.10
Triple superphosphate (run-of-pile)	0.20
Potassium chloride (coarse or granular)	0.30
Potassium chloride (standard)	0.00
Diammonium phosphate (granular)	0.25
Monoammonium phosphate (nongranular)	0.20
Urea (prilled)	0.30

To obtain the total weight of the liquid phase in a formulation, multiply the weight of each raw material in the formula (kg) by the appropriate liquid phase factor. A total liquid phase weight value of about 300 kg/tonne is considered optimal in many cases.

Heat of Chemical Reaction

The level of liquid phase is also closely allied with another criterion, i.e., the expected amount of heat created by various chemical reactions in a given NPK formulation. The amount of heat generated, particularly within the granulator, can have a marked effect on the amount of liquid phase formed and, therefore, the resulting granulation characteristics of the mixture. In general, to achieve optimum granulation, the calculated total liquid phase for a formulation, using

added to the granulator, for example, an ammonium phosphate slurry and/or solutions of urea or ammonium nitrate, and (2) dissolution of a small portion of material on the surface of the soluble raw material and recycle particles. This dissolution is caused by the combination of heat and water contained in the above solutions or by steam or water injected into the granulator. Solubility data for some of the more common fertilizer salts are given in Table 3. Liquid phase control is the key to achieving the desired level of granulation efficiency and product quality. Ideally, after drying, the liquid phase (salt solution) forms strong crystal bonds (salt bridges) between the particles of the agglomerate that are mechanically well-fitted and interlocked—again, the concept of a stone wall.

Estimating Liquid Phase Values

Experience has shown that there are considerable differences in the amounts of liquid phase generated by the various materials normally used in the production of agglomerated NPKs. Several years ago (during the 1960s), the Tennessee Valley Authority (TVA) examined a wide variety of NPK production formulations that were known to perform well and devised a numerical value to express empirically the "apparent" liquid phase contribution that could be expected from a number of materials commonly used to produce NPKs. These "liquid phase factors" are shown in Table 4. Experience has shown that, when these values are used as a guide, a liquid phase of about

the data in Table 4, should be lowered if the formulation produces a large amount of chemical heat of reaction. However, the optimum relationship between liquid phase and heat of reaction for a specific formulation must be learned from actual operating experience.

The most important heat-generating chemical reaction in most NPK plants is the neutralization of acidic materials with ammonia. The approximate amount of heat released when ammonia reacts with some common fertilizer materials is shown in Table 5. As with liquid phase, experience has shown that if the amount of heat released in the granulator is equivalent to about 45,000-50,000 kcal/tonne of product, conditions are generally good for obtaining optimum granulation. Of course, like liquid phase, the proper level of heat is just another one of the many critical criteria that must be met to obtain optimum granulation efficiency.

Insoluble Binders

In some cases, the mechanical and crystal (salt bridge) bonding of particles can be greatly improved by adding about 5%-15% of a finely divided insoluble binder powder, for example, kaolin clay, to the granulating mixture. The binder powder helps to fill the many small voids between the particles and acts much like a saturated wick in helping to join the particles together (Figure 1). This concept works particularly well with NPKs containing large amounts of crystalline ammonium sulfate, potassium chloride, potassium sulfate, and/or kieserite (magnesium sulfate monohydrate) and relatively low levels of suitable soluble salts or solid binders such as ammonium phosphate or superphosphate. It is important to note, however, that some insoluble binders (clay, for example) have the capacity for retaining moisture thus making subsequent drying more difficult.

Liquid Phase Control

In all NPK formulations, most of the liquid phase is obtained from materials that are introduced to the process at a fixed rate to achieve a final product with the

desired chemical analysis. The resulting liquid phase can, of course, be adjusted within rather specific limits through the selection of raw materials or by controlling the free water content and/or chemical composition of the slurry (for example, the $\text{NH}_3:\text{H}_3\text{PO}_4$ mole ratio as shown in Figure 3). However, once this is established (optimized), the flow rates of the liquids must remain constant to ensure the correct analysis of the final product. For this reason, all agglomeration-type formulations should allow for a moderate degree of liquid phase "tuning" performed by the operator using steam and/or water fed directly to the granulator. The discretionary use of a small amount of steam and/or water by the operator helps to compensate for variations in granulation efficiency caused by changes in the temperature of the materials, quantity and particle size of the recycled material, and minor (but normal) upsets within the overall processing system. This fine tuning of the process by the operator is the basis for the observation: "NPK granulation by agglomeration is more of an art than a science." The unique skill of an experienced granulator operator often greatly overrides the effectiveness of the most costly and sophisticated process design and engineering skill.

Acid/Ammonia Neutralization Methods

As indicated earlier, the acid/ammonia neutralization reactions create heat that contributes to the overall liquid phase conditions in the granulator and the efficiency of the granulation process. Thus, the method used for neutralization (reacting ammonia) can significantly influence the overall performance of the plant. A brief discussion of the most common methods used for neutralization in agglomeration-type NPK granulation plants follows.

Direct Neutralization in Granulator—This was one of the most common methods used for reacting ammonia in the many NPK granulation plants that were operated in the United States and elsewhere during the 1960s and early 1970s. Direct neutralization in the granulator is particularly well suited for NPK grades containing large amounts of superphosphate (SSP or TSP) and a relatively low level of nitrogen. With direct

Table 5. Approximate Amount of Heat Released When Ammonia Reacts With Various Materials Commonly Used to Produce Granular NPKs

Material Reacted With Ammonia	Reaction Product (solid)	Heat Released	
		NH_3 Gas (kcal/kg NH_3 reacted)	NH_3 Liquid
Wet-process phosphoric acid (54% P_2O_5)	Monoammonium phosphate (MAP)	1,890	1,370
Wet-process phosphoric acid (54% P_2O_5)	Diammonium phosphate (DAP)	1,510	590
Monoammonium phosphate (MAP)	Diammonium phosphate (DAP)	1,130	610
Triple superphosphate (TSP)	Ammoniated TSP	1,580	1,060
Single superphosphate (SSP)	Ammoniated SSP	1,460	940
Sulfuric acid (100%)	Ammonium sulfate	2,165	1,645

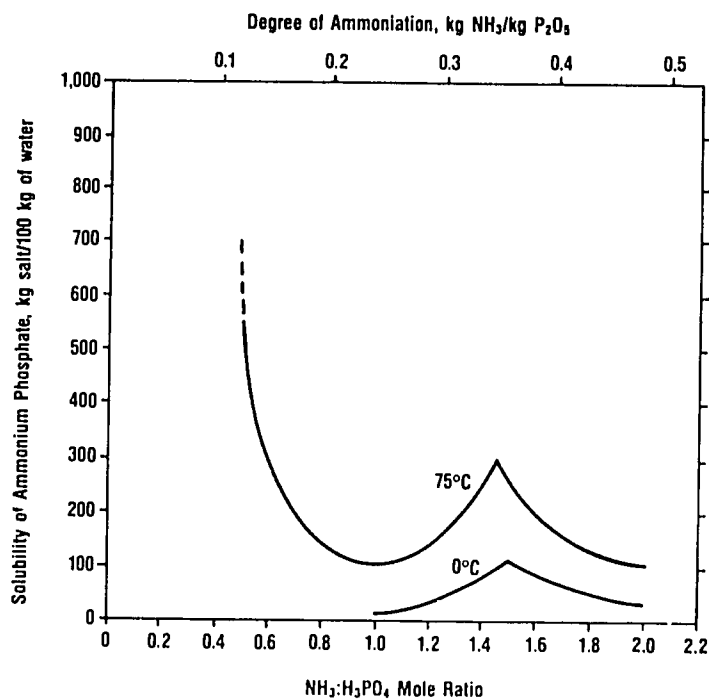


Figure 3. Effect of Mole Ratio on Solubility of Ammonium Phosphate.

neutralization, the best operation is usually obtained if the amount of ammonia reacted in the granulator does not exceed the equivalent of about 50 kg/tonne of product.

In the direct neutralization process, ammonia is distributed beneath the bed of material in the granulator. If sulfuric acid is used, it too is usually distributed beneath the bed of material while the phosphoric acid, if used, is most often sprayed or dribbled on top of the bed. When sulfuric acid is used, precautions should be taken to ensure that the acid is added at a particular location with respect to the ammonia to ensure quick and uniform neutralization and thus minimize the unwanted reaction of sulfuric acid with potassium chloride that most often is also present in the formulation. This reaction causes the formation of very corrosive hydrochloric acid, which reacts rapidly with ammonia to form a dense fume of ammonium chloride that is very difficult and costly to collect in the plant's emission control (scrubbing) system.

Tank-Type Neutralizers—The use of an atmospheric or pressurized tank-type neutralizer offers maximum flexibility in managing the acid/ammonia reactions and obtaining the critical heat/liquid phase criteria needed for good granulation when producing a wide variety of NPK grades. Because the acid/ammonia reactions are only partially completed in these tank-type neutralizers, they are often referred to as "preneutralizers." Such preneutralizers are commonly used in the majority of today's DAP plants.

When a preneutralizer is used, large amounts of acid can be partially reacted with ammonia. The

degree of reaction performed in the preneutralizer is determined by a number of factors; however, the most important criteria are the production of a fluid slurry that is easy to transport (pump) to the granulator and uniformly distribute onto the rolling bed of material in the granulator. The fluidity of the preneutralized slurry is maintained through careful control of the NH₃:H₃PO₄ mole ratio, temperature, and free water content of the reacted slurry. The neutralization reactions that are only partially completed in the preneutralizer are completed in the granulator where additional ammonia is added beneath the rolling bed of material.

When sulfuric acid is reacted in combination with phosphoric acid in the preneutralizer, special precautions must be taken in the selection of construction materials that will resist the more corrosive environment caused by the sulfuric acid. Also, at the higher mole ratio and pH (for example, about 1.5 and 6.8, respectively), the presence of ammonium sulfate crystals tends to thicken the slurry and make pumping difficult; thus, operation at a lower NH₃:H₃PO₄ mole ratio and pH (about 0.4 and 2.0, respectively) is often preferred.

Pipe-Type Reactors—In the mid-1970s, TVA demonstrated the feasibility of replacing a conventional tank-type preneutralizer with a novel device referred to as a pipe reactor. This type of reactor was a radical departure from the conventional tank-type preneutralizer normally used to react large amounts of ammonia with phosphoric acid. The pipe reactor consists basically of a length of corrosion-resistant pipe (about 3-6 m long) to which phosphoric acid, ammonia, and often water are simultaneously added to one end through a piping configuration resembling a tee, thus the name "tee reactor." The acid and ammonia react quite violently, pressuring the unit and causing the superheated mixture of ammonium phosphate slurry ("melt") and water to forcefully discharge from the opposite end of the pipe that is positioned inside the granulator. Uniform distribution of the "melt" on top of the rolling bed of material in the granulator is achieved by varying the configuration and orientation of the discharge opening of the pipe. A major advantage of the pipe reactor over conventional preneutralizers is that it more effectively utilizes chemical heat of reaction to evaporate unwanted water from the relatively dilute acid.

Later, the tee reactor was modified by TVA to also accept an additional flow of sulfuric acid through another pipe inlet located opposite the phosphoric acid inlet, giving the unit a "cross" configuration and thus the name "pipe-cross reactor" (PCR).

Use of the PCR makes it possible to react a wide variety of phosphoric/sulfuric acid mixtures with ammonia. This capability is particularly useful in NPK granulation plants and allows a greater choice in the selection of

raw materials to improve granulation and optimize the overall cost of production.

In general, the mixture discharged from the PCR does not require further reaction with ammonia in the granulator. In some cases, however, the level of reaction in the PCR may be altered (decreased) to minimize the escape of ammonia or to obtain improved granulation characteristics of the "melt" when it is combined with the solids in the granulator.

Several variations of pipe-type reactors (and materials of construction) are currently used in NPK, DAP, and MAP plants, sometimes in combination with conventional tank-type preneutralizers. Perhaps one of the greatest advantages offered by the use of pipe reactor technology in the NPK industry is that it provides an opportunity to effectively use a greater variety of raw materials including, for example, larger quantities of dilute acids and scrubber liquor. This added flexibility in raw material choices can often result in more favorable production costs and at the same time provide a method for

disposing of certain "problem materials" such as excess scrubber liquor. It should be noted, however, that the technology does not fit all situations equally well. Therefore, its potential should be carefully examined with regard to the particular circumstances.

Preparing the Production Formulation

According to the foregoing discussion, a large number of raw material and process variables must be considered when developing NPK production formulations. As with the operation of an NPK plant, formulation too requires a considerable amount of skill and an element of "art" to ensure that the particular formulation will yield the desired results in a given plant.

A given NPK fertilizer can be formulated in many ways depending upon the available raw materials and specific equipment system. Table 6 shows some examples of NPK production formulations that have been

Table 6. Examples of Typical Commercially Proven NPK Production Formulas in Which Agglomeration is the Principal Mechanism for Granule Formation and Growth^a

Material as Fed to Process ^c	Direct Ammoniation in Granulator			Pipe-Cross Reactor (PCR) ^b		Tank-Type Preneutralizer (PN) ^b		Urea Solution/Steam (No Chemical Reaction)		
	3-9-18	5-20-20	13-13-13	8-24-24	13-13-13	15-15-15	17-17-17	12-12-17-1.2 Mg	14-6-21-2.4 Mg	16-0-30
	(kg/tonne finished product) ^d									
Anhydrous ammonia—82% N	37	52	-	66 (90% to PCR)	85 (100% to PCR)	127 (75%-80% to PN)	82 (65%-70% to PN)	-	-	-
Ammonia/ammonium nitrate solution—46% N	-	-	145	-	-	-	-	-	-	-
Urea (prills)—46% N	-	-	-	-	-	105	231	115	153	240
Urea solution—35% N	-	-	-	-	-	-	-	155	204	156
Ammonium sulfate (crystalline)—21% N, 24% S	-	50	205	121	300	-	-	-	-	-
Sulfuric acid—variable % H ₂ SO ₄	63 (93% H ₂ SO ₄)	-	64 (78% H ₂ SO ₄)	40 (78% H ₂ SO ₄)	192 (78% H ₂ SO ₄)	261 (96% H ₂ SO ₄)	108 (96% H ₂ SO ₄)	-	-	-
Wet process phosphoric acid—54% P ₂ O ₅	-	170	63	443 (90% to PCR)	250 (85% to PCR)	292 ^e	330 ^e	-	-	-
Single superphosphate (ROP)—18% P ₂ O ₅ , 12% S	508	332	216	-	-	-	-	-	-	-
Triple superphosphate (ROP)—46% P ₂ O ₅	-	124	-	-	-	-	-	-	-	-
Monorammonium phosphate (powdered)—10% N, 50% P ₂ O ₅	-	-	-	11	-	-	-	-	-	-
Diammonium phosphate (crushed granules)—18% N, 46% P ₂ O ₅	-	-	130	-	-	-	-	87	-	-
Phosphate rock (ground)—32% P ₂ O ₅	-	-	-	-	-	-	-	247	191	-
Potassium chloride (standard)—60% K ₂ O	-	342	221	402	223	255	289	276	353	500
Potassium sulfate (standard)—50% K ₂ O, 18% S	320	-	-	-	-	-	-	-	-	-
Sulfate of potash-magnesium (standard)—22% K ₂ O, 11% Mg, 22% S	110	-	-	-	-	-	-	-	-	-
Magnesium sulfate (kieserite)—16% Mg, 22% S	-	-	-	-	-	-	-	-	150	-
Magnesium oxide—50% Mg	-	-	-	-	-	-	-	25	-	-
Insoluble binder	-	-	-	-	-	-	-	110	-	130
Micronutrient mix (various nutrients as required)	10	-	-	-	30	-	-	10	-	-
Conditioning agent (coating on product)	-	-	10	-	10	15	15	15	10	15
Subtotal	1,048	1,070	1,054	1,083	1,090	1,055	1,055	1,040	1,061	1,241
Evaporation	-48	-70	-54	-83	-90	55	-55	-40	-61	-41
Total (product basis)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

a. Examples intended to partially illustrate large number of formulation possibilities depending upon specific process equipment system, available raw materials, agronomic requirements, product composition guarantees, and other local factors

b. Flows of acid and ammonia to PCR and PN may vary, indicated flows typical for commercial practice. The addition of steam and/or water to the granulator is generally required to optimize granulation efficiency

c. All materials are fed directly to granulator unless otherwise noted. Indicated composition is typical of industry practice

d. Values rounded for simplicity

e. Phosphoric acid is first fed to fume scrubbing system and then onward to PN

successfully used in commercial practice. Because the performance of these formulations in a given plant will depend heavily upon a number of factors as described in this bulletin, these examples are offered only to illustrate the variability that should be taken into account in the planning and design of an NPK production facility.

Dry Raw Material Feed System

The chemical analysis of the finished product from granulation plants that use significant quantities of solid raw materials in the formulation depends heavily upon careful control of the solid raw material feeds to ensure that they are in the correct proportion and that their flow rate is closely matched with the flows of the fluid materials (for example, preneutralized slurry and ammonia) fed to the granulator.

Some granulation plants use individual belt-type weigh feeders to measure the continuous flow of each solid material to the process. Other plants, particularly those in the United States and Brazil, use a combination batch weighing/continuous feed (stream-out) system.

A common problem with using individual belt-type weigh feeders for each material is that it is often difficult to maintain accurate control on a continuous basis because of lumps and other variations in the flow properties of the nongranular solid materials. Belt-type weigh feeders can be particularly troublesome in NPK plants where a large number of grades are produced and/or when lumpy, damp, or finely textured raw materials are used. For example, inadequately cured superphosphate, some forms of byproduct ammonium sulfate, and some dry but finely textured materials such as potash and kieserite often cause problems because they tend to bridge in the weigh feeder surge hoppers. In many cases, mechanical vibrators that are attached to the surge hoppers and designed to overcome these problems actually increase the tendency of the material to compact and bridge.

Variability in the raw material feed characteristics may lead to erratic performance of the continuous belt-type weigh feeders and increase the need to frequently change (adjust) the feed rates on the basis of the chemical analysis of the product. Correctly adjusting the raw material feed rates on the basis of product analyses is also very difficult because of the lag time in the granulation plant system. For example, several hours are required for a change in the raw material feed rate to become fully evident in the final product (Figure 4). Unless the lag time in the plant is well known and the sampling program is carefully synchronized with this lag time, the analytical findings will be quite misleading and will thus result in a pro-

gram of constantly changing the feed rates without achieving the desired goal. The lag time also varies with the raw material; for example, a change in easy-to-granulate ammonium phosphate slurry will show up in the product much quicker than a change in a difficult-to-granulate material such as sulfate of potash. Furthermore, in most NPK formulations, the recycle material has a very different chemical composition from that of the final product; thus, a considerable amount of time (often 3-6 h) is required to achieve equilibrium after making a change in the feed rate of a raw material. However, in a slurry-type process, such as DAP granulation, the neutralized feed and recycled materials are essentially the same in chemical composition and equilibrium is more quickly established.

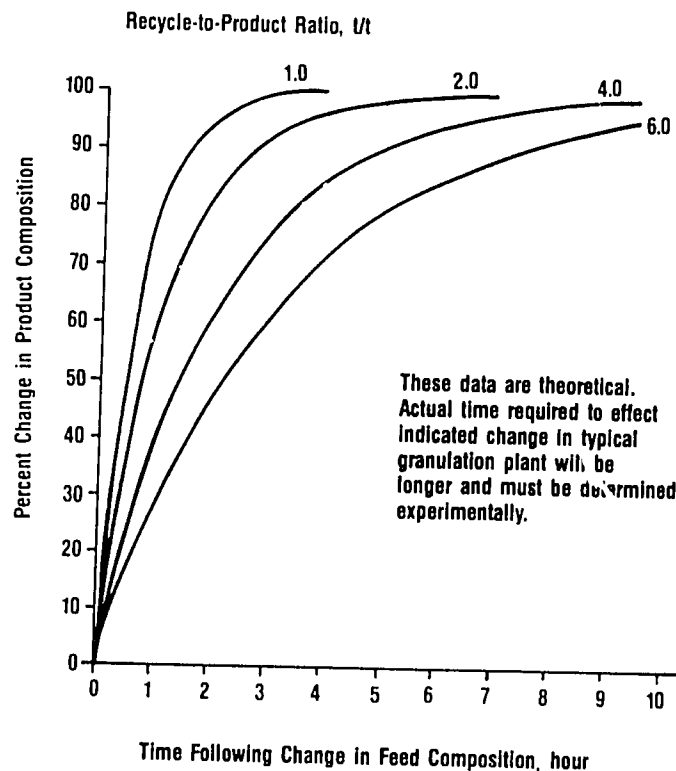


Figure 4. Relationship Between Time and Change in Product Composition in Granulation Plant at Various Recycle-to-Product Ratios.

Most of the problems with individual belt-type weigh feeders and their possible adverse effect on the chemical analysis of NPKs can be almost completely avoided by using a combination batch weighing/continuous stream-out feed system (Figure 5). The batch weighing system avoids the problem of uncertain weighing accuracy caused by lumps and other variations in the dry raw material flow characteristics. With this system, a precisely weighed batch of dry materials (usually a 2- to 4-t batch) is discharged into

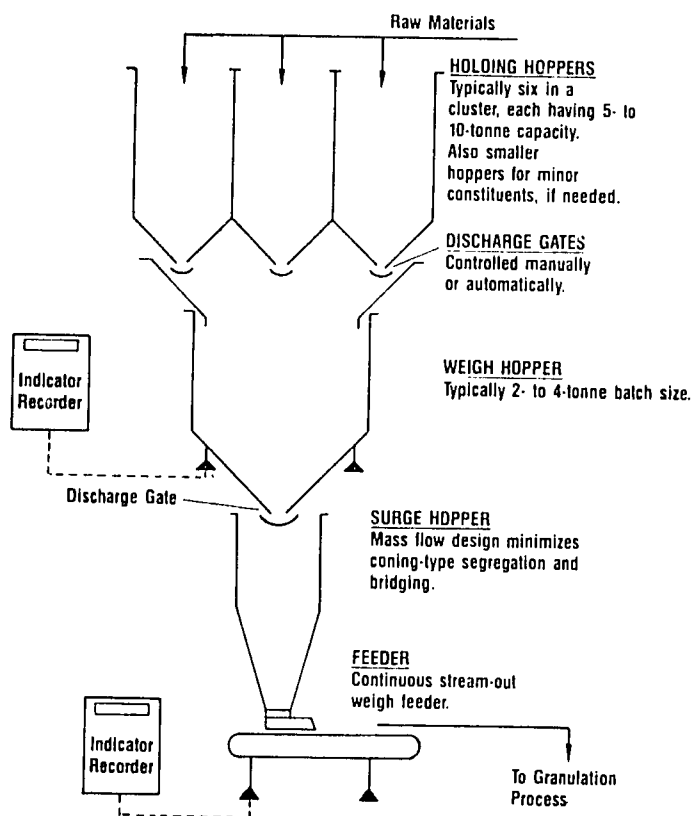


Figure 5. Batch-Type Raw Material Weighing Unit With Continuous Feed System.

a surge hopper equipped with a belt-type weigh feeder (stream-out feeder). In some plants, a variable speed screw-type conveyor is very effective, especially if the feed material is very fine and free flowing. The rate of this feeder is synchronized with the flow rate of slurry from the preneutralizer (or pipe-type reactor) and other fluids fed to the granulator. This system is quite simple, and the operator can check the accuracy of the stream-out feeder by simply using a stopwatch to check the time required to feed a batch of known weight. The operator can do this as frequently as necessary (usually about twice per work shift) to ensure accurate feeding and proper matching of the dry feed with the slurry and other fluids fed to the process.

Certain formulations may require a large number of dry raw materials, which may vary widely in both quantity and physical properties. In this case, the uniformity of the analysis of the individual granules of final product and the consistency of the granulation step can be improved by mixing the weighed batch of raw materials before it enters the hopper supplying the stream-out feeder. In this case it is also important, after mixing, to avoid subsequent segregation caused by the material "coning" in the feeder hopper. A relatively tall, slender cylindrical hopper with a long tapered conical bottom, described in the literature as a "mass flow hopper," will minimize "coning" and ensure uniformity of the material entering the stream-out feeder.

Figure 6 depicts an example of such a system in which a combination weigh-hopper/paddle-type mixer is used, followed by a mass flow-type surge hopper supplying the stream-out feeder. Ribbon-type blenders or rotary drum-type mixers can also be used. If a rotary drum-type mixer is used, a separate weigh hopper offers a more practical and reliable mechanical design. Of course, the separate weigh-hopper design also works well with any type of mixer and may be preferred because of its mechanical simplicity compared with the combination weighing/mixing units. This more elaborate and more costly version of the batch-type weighing concept (Figure 6) is usually needed only if many nutrient guarantees are required (for example, micronutrients), if the size and surface characteristics of the materials differ greatly from each other, or when a high degree of uniformity in each product granule is required. Such a system is especially helpful in obtaining uniform distribution of small quantities of insoluble binders or other materials that may be used to promote granulation.

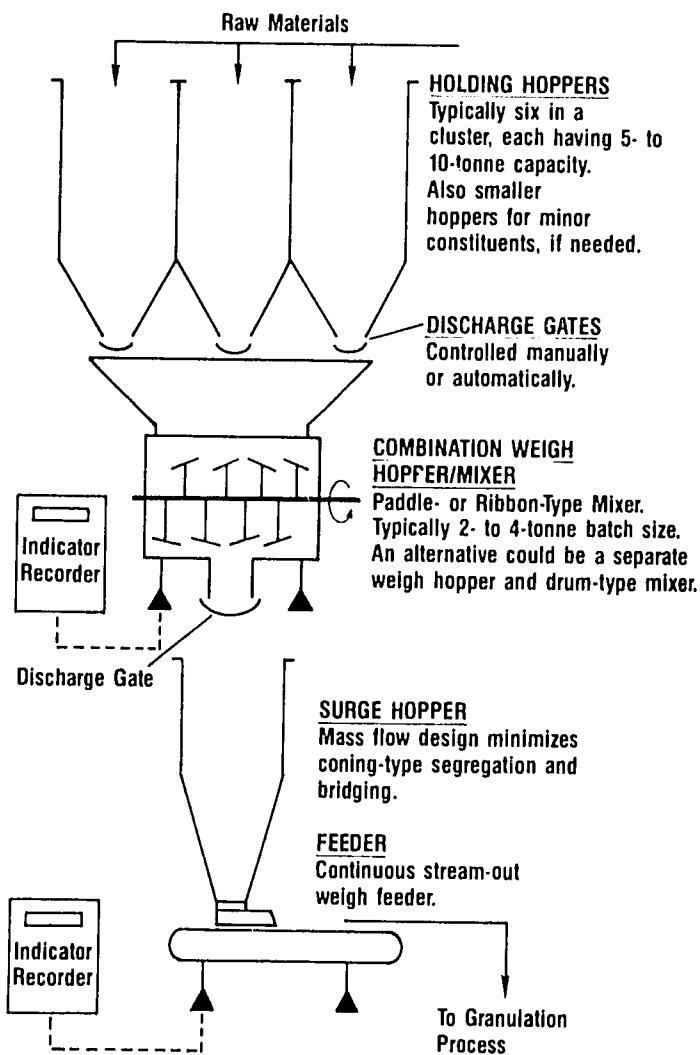


Figure 6. Batch-Type Raw Material Weighing/Mixing Unit With Continuous Feed System.

If it is not practical to modify an existing continuous belt-type weigh feeder system to the batch-type feed method, then it is important to devise some method for frequently checking the feed rates from the individual belt-type weigh feeders and using these check results as a basis for adjusting the rates. This method of feed rate adjustment is more accurate and more rapidly responsive than are adjustments made on the basis of product-sampling because it avoids the complications and uncertainties caused by system lag, difficulty in collecting representative samples, and other uncontrollable variables. In NPK plants where the agglomeration of solid materials is the principal granulation mechanism, it is extremely important to base any change in feed rate(s) on a representative product sample collected (composited) over a period of at least 4 h. Adjustments in feed rates made on the basis of frequent "grab" samples can be very misleading even if the feed rate(s), sampling technique, and analytical work are precise.

Solids Recycle

Unlike most slurry-type/accretion granulation processes, NPK processes based on agglomeration seldom recycle a significant quantity of product-size material to the granulator; only undersize material is normally recycled. The use of a recycle control system for controlling (optimizing) conditions in the granulator is one of personal choice and is often of limited value except during periods of startup or when changing grades. In most cases, a "floating" recycle system is preferred in agglomeration-type NPK plants. However, the relative merits of floating and controlled recycle are often a topic of debate among NPK and DAP plant operators.

In agglomeration-type granulation, particles will agglomerate only if they can first be attracted to each other. This attraction is then followed by interlocking and bonding. Raw material and recycle fines will often not agglomerate into product-size granules if they are too large. They will simply repel each other and accumulate, eventually overloading the system. Therefore, a facility for crushing a portion of the "large" fines is recommended if coarse-grade raw materials and/or large-size product (and therefore large-size recycle fines) are anticipated. Also, the efficient crushing of oversize material is essential to ensure that the particle size distribution, and therefore surface area, of the material recycled to the granulator is reasonably uniform. The relationship between particle size and surface area is shown in Table 7. For this reason, it is recommended that the material discharged from the crushers be recycled to the screens to ensure that only fine material is returned to the granulator. Many crushers are less than 50% efficient

on a single pass; therefore, the need for recirculation of the material from the crusher back to the screens should be carefully examined. This is discussed in more detail later.

Table 7. Relationship Between Particle Size and External Surface Area

Particle Size		
Diameter (mm)	Nominal Tyler Screen Size	External Surface Area ^a (m ² /kg)
0.106	150	43.4
0.250	60	18.5
0.500	32	9.27
1.00	16	4.62
2.00	9	2.31
4.00	5	1.16
4.75	4	0.971
6.70	3	0.688
8.00	2.5	0.577
15.00	-	0.307

a. Theoretical, assuming perfect spheres having a density of 1.3 g/cm³.

Granulator

A longer-than-normal rotary drum granulator is preferred (length-to-diameter ratio of 3 or more) for granulation by agglomeration. The longer granulator is needed to (1) provide sufficient room for the uniform distribution of slurry, acids, solutions, ammonia, and steam, (2) promote intimate mixing of the solids and fluids, and (3) provide time for initial agglomeration (granule formation) and consolidation of the granules to occur in view of the operator before the material disappears into the dryer. The "art" of granulation implies that the granulator operator should be able to see what is happening and make the often subtle adjustments needed to avoid inefficient granulation and the resulting problems caused by upsets in the recycle equilibrium (mass flow and particle size distribution). Some plants that depend heavily upon steam and recovered scrubber liquor as the source of liquid phase very effectively utilize a premixing unit (using, for example, a pugmill-type mixer) located immediately upstream from the rotary drum granulator. This added step ensures uniform distribution of the liquid phase and initiates agglomeration; thus, it affords the operator another opportunity to optimize the granulation process.

Cocurrent Dryer

General—With agglomeration-type granulation, the moisture (usually about 2%-6%) in the material fed to the dryer is distributed quite evenly throughout the granule structure; this situation is very different from that prevailing in the slurry-type processes, for example, DAP, in which a moist film covers a relatively hot

and dry particle core. In either case, a cocurrent (parallel flow) dryer is preferred because with such a flow configuration the hot inlet air first contacts the moist fertilizer and thus allows operation at a higher overall temperature difference between the drying air and the moist fertilizer while minimizing the risk of overheating and melting the fertilizer, which becomes more temperature sensitive as it dries.

With the agglomerated granules, the diffusion of moisture from the core of the granule to the outside surface and then to the drying air must be quite carefully regulated—too much heat, applied too quickly, may melt the surface of the particles and cause “case hardening” resulting in granules with a soft, moist center caused by entrapped moisture. Sometimes “melting” may lead to excessive agglomeration and/or fouling of the dryer internals. In still other cases, too rapid evaporation may cause the granule to “explode.” Furthermore, if evaporation occurs before proper consolidation of the granules is achieved (promoted by the rolling and tumbling action in the dryer), the granules may be too porous and therefore quite weak.

With agglomeration, the inlet portion of the dryer should be viewed as an extension of the granulator because a considerable amount of final granule formation and consolidation occurs here. Therefore, optimal performance of most NPK dryers requires an operator who is skilled and capable of exercising considerable judgment because the performance of the dryer is greatly influenced by the grade being produced and the characteristics of the individual raw materials.

Some experienced operators prefer to omit one or two rows of lifting flights near the inlet end of the dryer to give a section of smooth shell immediately following the forward-pitched throw (spiral) flights at the dryer inlet. The length of the smooth section usually equals about one-half diameter to one full diameter of the dryer. The lifting flights that follow immediately after the smooth shell section must be designed to provide full exposure of the moist particles to the drying air, yet not be too closely spaced to cause plugging or make cleaning difficult.

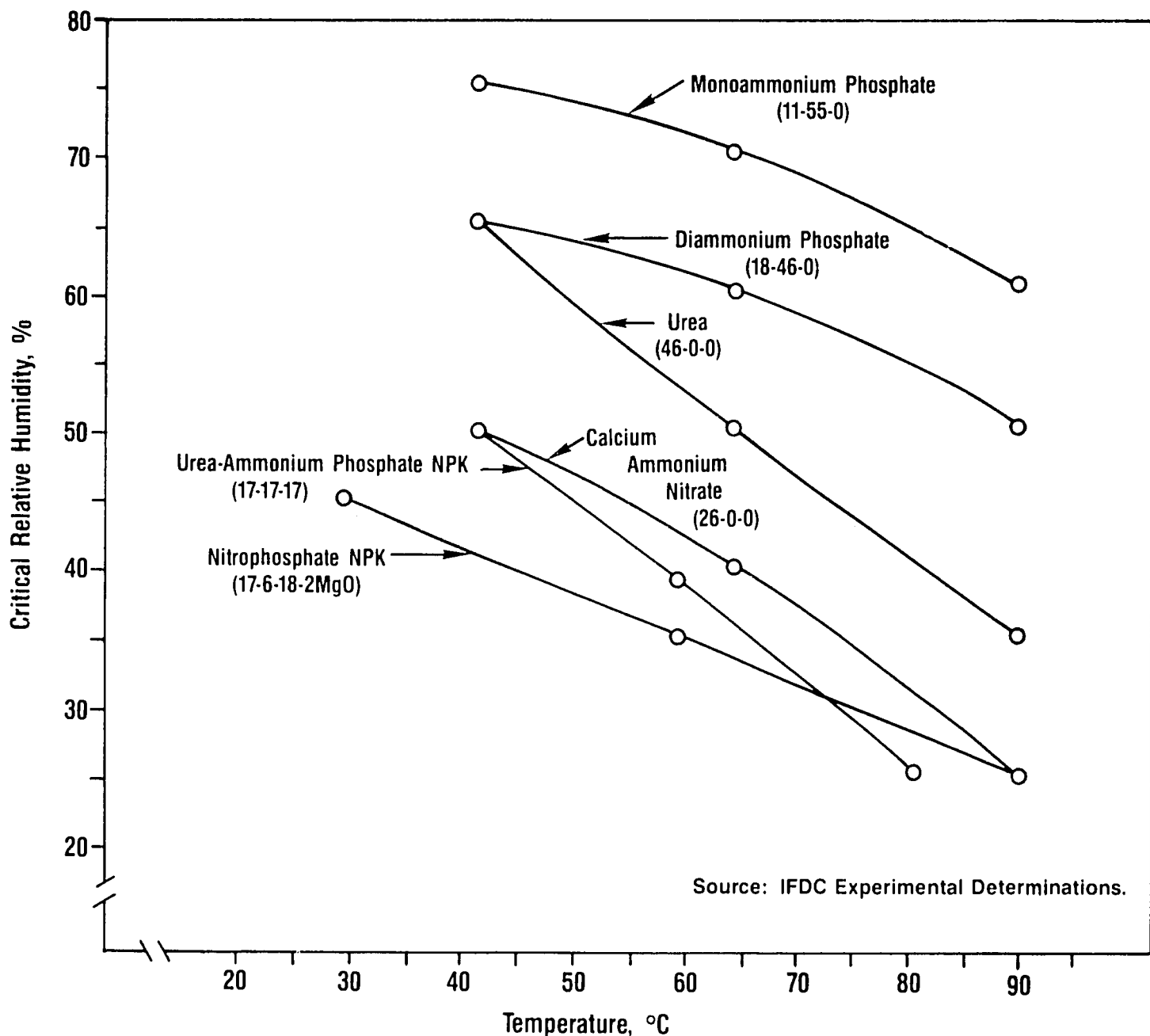
Temperature and Humidity Profile—In general, agglomerated products require relatively gentle drying. The temperature profile within the dryer is dependent upon the temperature sensitivity and the CRH of the material. With urea-based or highly soluble ammonium nitrate-based NPKs, the dryer outlet temperature (product) usually should not exceed about 74°C; if kieserite is also present or the N-to-P₂O₅ ratio is high, then a temperature of about 68°C is about maximum. The relative humidity (RH) of the dryer outlet air should be at least 10-15 percentage points below that of the CRH of the material at the dryer outlet temperature. Thus, for most urea-based NPKs, the RH of the air at its

outlet temperature (typically about 74°C) should not exceed about 20% because the CRH of the urea- or ammonium nitrate-based materials at this elevated temperature is usually about 30%, and sometimes even lower (Figure 7). The moisture-holding capacity of air at typical NPK drying temperature and RH conditions is shown in Figure 8. The unique RH, CRH, and temperature criteria required for drying many NPKs, especially the urea-based NPKs, translate into larger-than-usual process airflows. This results in the need for rotary dryers that are relatively large in diameter compared with those used to dry products such as DAP that are less sensitive with respect to temperature, humidity, and particle entrainment.

Air Velocity—The particle size distribution of most agglomerated NPKs entering the dryer is much wider than that of DAP. NPK granules are also relatively irregular in shape compared with well-formed DAP granules; thus, they exhibit a greater drag in the airstream. The effect of drag is clearly shown in Figure 9 where the actual entrainment of irregular potash granules is compared with theoretical values for perfect spheres. To avoid excessive entrainment of the smaller and more irregular particles (those less than about 1 mm) found in most NPK plants, it is necessary to operate the dryer at a lower air velocity than is customary for DAP dryers. This lower air velocity criterion for NPKs (about 2.0 to 2.5 m/s empty-dryer [superficial] basis, compared with about 3 to 4 m/s for DAP) often limits the drying capacity of DAP plants that are converted to the production of NPKs.

Retention Time—Because the drying process for agglomerated NPKs is mainly controlled by the rate of diffusion of moisture from the core of the particles, the point at which a longer retention time does not significantly promote further drying is more quickly reached with many NPKs (especially the very temperature-sensitive urea-based NPKs) than with DAP or other accretion-type granular products. The net result is that a long retention time in the dryer is often less important with NPKs and sometimes quite undesirable. The overriding factors are the temperature and RH profile in the unit (most importantly, the difference between the material CRH and the RH of the drying air). If the dryer is too long and the cooling effect of evaporation ceases, the product may begin to overheat and “melting” may occur near the outlet end of the dryer. This can result in a ring-like buildup of material on the inside of the dryer near the discharge end. This buildup will cause a bed of material to form in the dryer which, in turn, will cause less efficient drying, overloading of the unit, and a number of other problems, including overgranulation.

Condition of Product at Dryer Discharge—The physical condition of NPK products discharged from the dryer may vary widely depending upon the



Source: IFDC Experimental Determinations.

Figure 7. Effect of Temperature on Critical Relative Humidity of Selected Fertilizers.

(1) raw material characteristics, (2) formulation, (3) dryer temperature and humidity profile, (4) operator skill, and (5) the particular crystallization habit of the mixture. This last point (crystallization habit) is the least predictable. Although it is quite easy to accurately determine the expected free water content, it is only by experience (trial and error) that the crystallization (hardening) characteristics of a particular fertilizer formulation can be accurately determined. Impurities in the phosphoric acid and other raw materials, the type and source of potash, the temperature and moisture content, and a host of other subtle and unpredictable factors often have a major influence upon the physical properties of the material dis-

charged from the dryer. At times the product may be crisp, hard, and easily screened and crushed; then again, with all conditions "apparently" the same, it may be "dry" but quite soft and plastic—a condition that can quickly lead to screen blinding, upsetting of the recycle loop, and plugging of the crushers.

Countercurrent Process Cooler (Second-Stage Dryer)

The adverse effect of most of the transient and unpredictable operational problems described above can be largely eliminated by routing all of the dryer

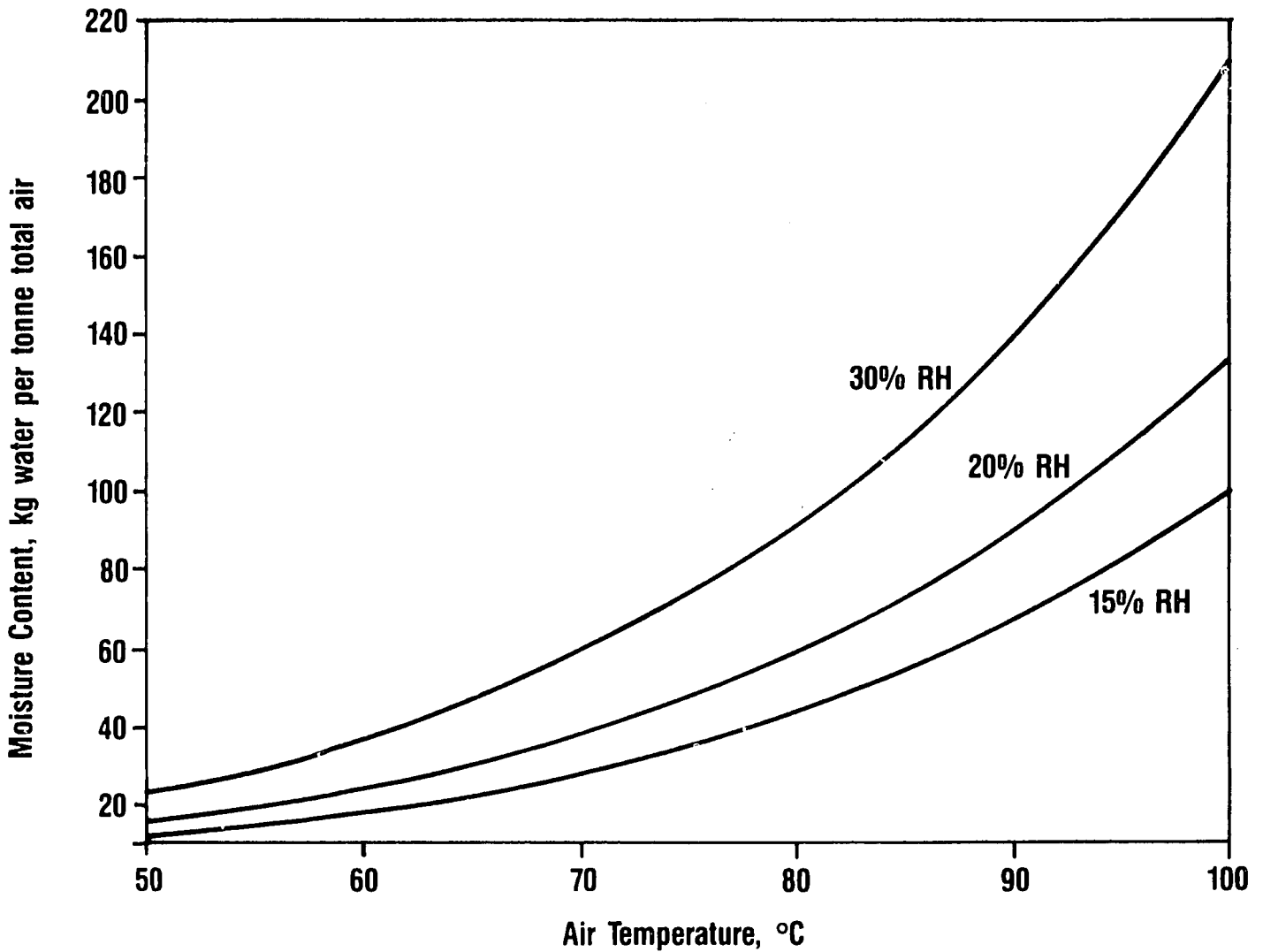


Figure 8. Effect of Temperature and Relative Humidity on Moisture Content of Air.

discharge material to a process cooler, which may be more properly referred to as a second-stage dryer. A countercurrent air-to-fertilizer flow configuration is preferred for maximum cooling in this unit. The transfer of fertilizer material from the dryer to the process cooler should be made by means of an inclined conveyor belt; a bucket elevator is not recommended because of the problems associated with the buildup of material in the buckets and discharge chute if the material is plastic or sticky or if a "slug" of "bad" material forms as a result of an upset caused by operator error, burner/air heater failure, or a number of other routine problems that commonly occur in most NPK granulation plants.

The heat transfer capacity of the process cooler should normally be about one-half to two-thirds that of the dryer. The cooler should also be equipped with an air heater to temper (heat) the inlet air if needed to decrease its RH and/or control the temperature profile in the unit. The addition of an air chilling unit with subsequent reheat to more carefully control the RH

and temperature of the inlet air may be needed in some locations; of course, the need for this feature would be dependent upon local ambient conditions and the NPK product characteristics. The process cooler serves the following useful functions:

- It allows drying to continue; typically, about 15%-25% of total drying occurs in the process cooler.
- It serves as a "safety valve" to accommodate process upsets. It makes the entire system more "forgiving".
- It adds time at a slightly reduced (and controllable) temperature profile to allow the material to crystallize and harden before it is subjected to screening and crushing. As a result, the screens are more likely to remain clean (free from blinding), and the crushers will perform more efficiently because the oversize particles are harder and therefore will fracture more easily. Material

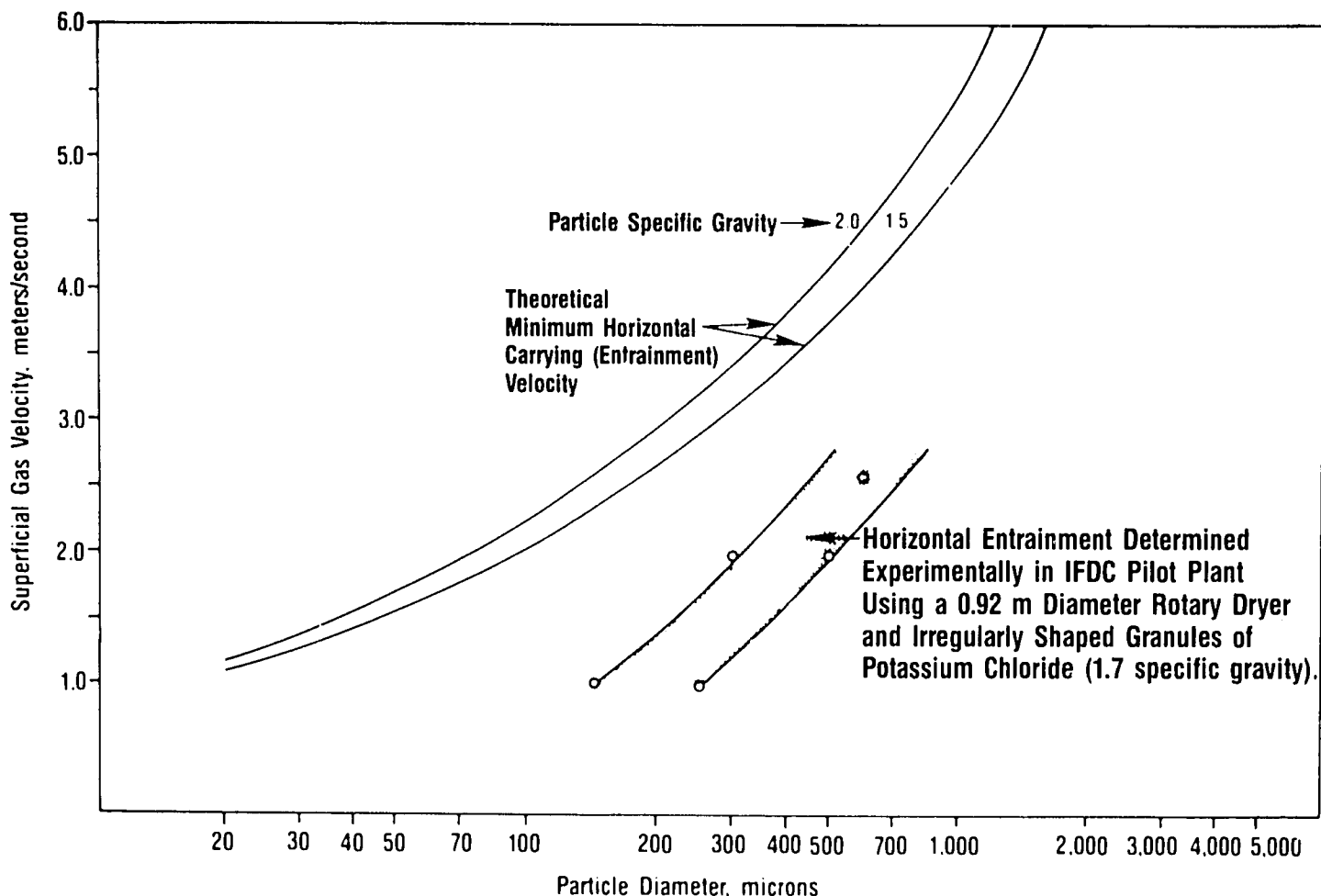


Figure 9. Effect of Particle Size and Gas Velocity on Entrainment of Particles.

plasticity and the resultant plugging of the crushers, screens, and downstream chutes are largely eliminated.

Screens

A key element in NPK granulation is precision screening to ensure that the bagged product will have good long-term storage properties. This is especially applicable to high-nitrogen grades manufactured from either ammonium nitrate or urea. If the process screening system is well designed, it is usually not necessary to install additional downstream screening facilities (for example, polishing screens after final product cooling or before bagging). Of course, such additional screening will be helpful, but the relative merits and need for such polishing-type screening should be determined on the basis of the design and performance of the basic process screening system and the specific product characteristics. The following process screening system is recommended for most NPKs especially those containing high levels of ammonium nitrate or urea.

- Square-mesh wire screen (stainless steel) should be used to ensure the production of well-rounded (minimum surface area) granules. Well-formed granules are of key importance to minimize surface contact points and residual dust and small particles that cause caking during long-term storage. The screening action on a square-mesh wire screen is more likely to "scrub" the granules and more effectively remove bits and pieces of fines. This is especially true if a horizontal gyratory-type screening machine is used. Stainless steel screen wire is recommended because its resistance to corrosion results in a smoother wire surface that resists build-up of solids and plugging.
- Product granules should be relatively large, in the range of 2-5 mm or even larger, to minimize contact area and, therefore, caking. The production of such large granules will influence the particle size of the recycle and the resultant granulation properties. Even with a 2-mm recycle particle (maximum size), it is often not necessary to crush the recycle; however, this point must be carefully considered depending upon the overall size distribution of the

recycle fraction. The size distribution may change quite significantly from formula to formula even though the screen size range of the final product remains constant.

- Single-deck screens are recommended because they allow easy access for inspection and cleaning without interrupting the process. In addition to ensuring the production of fertilizers with a minimum tendency to cake, clean screens are also of key importance in maintaining good process control.
- Horizontal gyratory-type screening machines are preferred over inclined units, especially for the product screens. The horizontal units are preferable because if they become blinded due to the lack of attention they will overload and stall; thus, they will automatically prevent "fines" from being discharged as product, a major cause of caking. If inclined screens become blinded, they continue to operate while discharging fines with product thus causing considerable problems with caking on the one hand and control of granulation on the other. Also, as previously mentioned, the horizontal-type units will more effectively "scrub" the granules to remove residual small particles and dust, thus decreasing the risk of caking.
- The ratio of the fertilizer material feed rate to the screening surface area should be quite low. For the oversize screen, about 10-20 tph/m² is recommended, whereas only about 5-10 tph/m² is recommended for the product screen with the smaller openings. Of course, the design of the screening machine and the screen open area (product size) have a major influence on the screening capacity under a given circumstance. However, it is important to note that many NPK plants often suffer from having too little screening capacity.

Oversize Crushers

Crushers are not 100% efficient in crushing oversize material on a single pass; an efficiency of about 50% or less is more likely. The crushing efficiency actually obtained, of course, depends on a number of factors, most importantly the required particle size distribution and the crushing characteristics of the material.

To avoid the risk of recycling a large amount of uncrushed or only partially crushed oversize to the granulator and upsetting the granulation process, which is very sensitive to particle size distribution, the material from the crushers should be recirculated to the oversize screens as shown in Figure 10. Although this procedure increases the capacity needed for the

screens and crushers, it ensures that the maximum particle size of the material recycled to the granulator will be smaller than the product and thus improves granulation control.

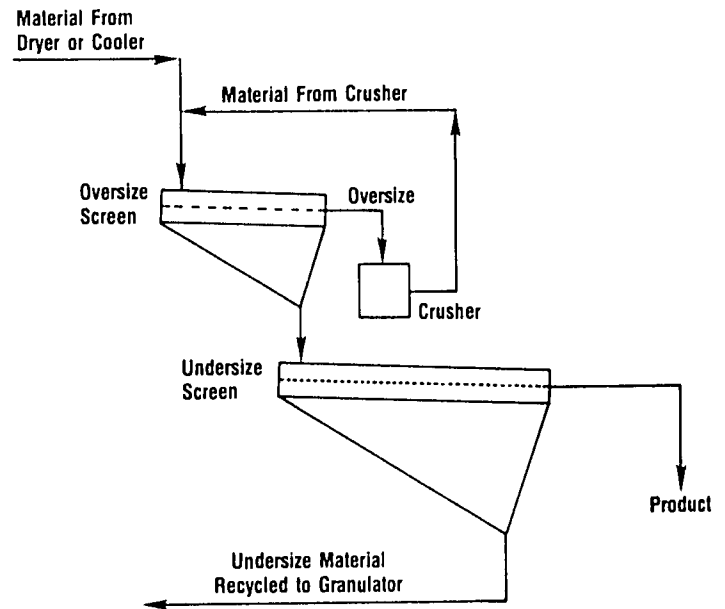


Figure 10. Closed-Loop Screening and Crushing System.

Because the size distribution of the solid particles is of such major importance in agglomeration-type granulation, extraordinary care should be taken in determining the optimum particle size characteristics required for good granulation. This type of information is learned best through testing in commercial-scale equipment. If such large-scale testing is not possible, smaller scale (pilot plant) studies can often be effectively used to provide valuable comparative data. These test data should then be used to determine the optimum design of the screening and crushing system.

Product Cooler

After screening, a conventional rotary- or fluidized bed-type product cooler is recommended. The perforated tray, countercurrent cascade-type cooler is also a good choice. Of course, the temperature and RH of the cooling air used in these units must be adjusted, depending upon ambient conditions, to effect cooling without wetting of the product. A final product temperature of about 43°C or slightly less is recommended. Excessive cooling is not recommended, especially in humid areas, because too much cooling could result in the absorption of atmospheric moisture by the material; this could lead to caking.

Conditioning

Many NPKs should be conditioned to add extra protection against caking. A kaolin-type clay is recommended. Usually about 0.5%-1.0% by weight is required; however, this depends heavily upon the NPK product characteristics and the properties of the clay. The benefit of using oil or wax to help bind the clay to the granules is not always clear; the oil or wax does, however, help to settle dust in bulk storage and bagging areas even if it does not always fully adhere the clay to the granule surface. If an oil-type binder is used, all conveyor belts downstream from the binder addition system should be "oil proof" to avoid ply separation and failure. Belting made from neoprene or polyvinyl chloride is not severely affected by oil-type binders or other organic-type conditioning agents.

The application of oil to NPKs, especially those produced by agglomeration, is often difficult because of the relatively unpredictable absorption characteristics of the granules from one grade to another. For those grades containing ammonium nitrate, especially in combination with potassium chloride, the use of oil should be avoided for safety reasons. A more detailed discussion of the potential safety hazards of mixing organic materials with nitrate-containing fertilizers can be found in the *Fertilizer Manual* and the references cited therein.

The most effective way to add solid conditioning agents to granular fertilizers is by use of a specially designed rotary drum application unit. The design parameters for such drums can also be found in the *Fertilizer Manual*.

Storage and Bagging

The recommended, and usually most practical, product storage and bagging system for hygroscopic NPKs consists of (1) a relatively small humidity-controlled bulk storage area (building) representing about 1 to 2 days' production. This bulk storage area should be divided according to the expected number of grades produced over a 1- to 2-day period; a minimum of two or three drive-in storage bays is recommended. This small and segregated storage method will also greatly facilitate changing of grades with a minimum of lost time. This method of bulk storage before bagging will minimize, and usually eliminate, the accumulation of "grade change" products that are so far off specification that they cannot be shipped. After a brief period of storage in bulk (overnight or perhaps a day or two) to allow for initial "pile set" and to certify the analyses, the product should be bagged in moistureproof bags. Bagging directly from the production unit or bulk storage of freshly made product in overhead bins is not recommended.

The optimum bag construction for long-term storage in humid areas consists of an open-mouth bag fitted with a loose polyethylene film liner that is at least 0.1 mm thick. The outer jacket should be constructed of woven polypropylene or some other strong and durable material. The liner should be tied, and the outer jacket should be stitched. The stitching should not penetrate the liner. Heat sealing of the liner is not recommended because if precautions are not taken such sealing usually entraps air that may result in pillow-shaped bags. Handling, especially stacking, such pillow-shaped bags is difficult. Venting entrapped air from such bags by piercing the film liner is a common practice but this should be avoided because such venting allows atmospheric moisture to seep into the bag, causing wetting and caking.

Process Plant Dehumidification

If hygroscopic NPKs are produced (especially those containing urea) and the ambient relative humidity at the plant site is in excess of about 50% for more than about 8 consecutive hours on a routine basis, it is essential that the process plant building (and bulk product storage building) be tightly enclosed and ventilated with low-RH air. Furthermore, if the temperature inside these enclosed buildings is excessive, then it will be necessary to cool and dehumidify the air to maintain comfortable and safe working conditions at an acceptable RH that will prevent "wetting" of the plant and equipment. Excessive "wetting" caused by the hygroscopic fertilizer material and dust accumulations will lead to excessive corrosion, electrical failures, safety problems (slippery floors and walkways), and a number of adverse process problems particularly with conveyor belt idlers, dust collection systems, screens, and air handling systems.

Recommendations Specific to the Production of NPKs Containing Urea

Urea-based NPKs are among the granular fertilizers that are most difficult to produce. On the basis of the foregoing general discussion and the particular characteristics of most urea-based NPKs, the criteria shown in the Appendix are recommended as a starting point for the basic design of a plant well suited for producing urea-based NPKs or other NPKs that exhibit similar characteristics such as excessive plasticity, low tolerance to elevated temperatures, and low CRH. These recommended design features are also applicable to the more tolerant NPKs. However, with these more tolerant NPKs, more latitude in the design and operating criteria may be allowed.

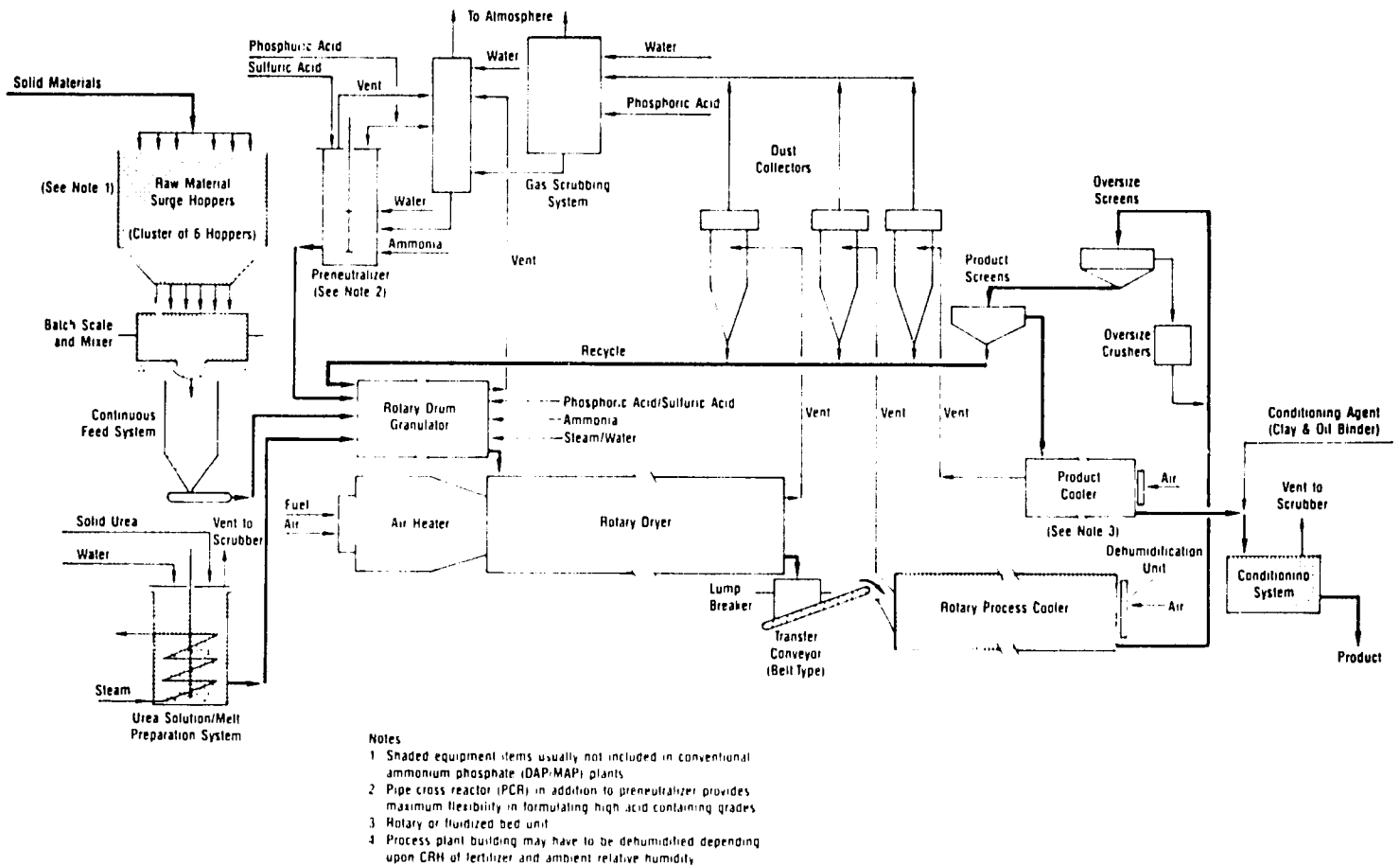


Figure 11. Recommended Process Flow Diagram for Maximum flexibility in Producing Granular NPKs Based on Agglomeration.

A process flow diagram of an NPK granulation plant embodying the recommended features is shown in Figure 11. Also indicated in Figure 11 are the features that are most often missing in a plant designed primarily for the production of DAP/MAP.

Verification of Recommended Plant Design and Operating Parameters

The recommended design and operating parameters for NPK granulation plants described in this bulletin are thought to be near optimum on the basis of data obtained from a number of IFDC pilot plant-scale trials and experience with several commercial-scale operations. However, because no two formulations (grades) or plants respond in exactly the same way to a given set of conditions, extrapolation and judgment are required when attempting to set the design basis for a "new" grade or plant.

Conclusion

The fundamentals of granule formation and processing for agglomerated NPK fertilizers differ markedly from those for DAP/MAP fertilizers. For this reason, many well-designed DAP/MAP plants experience difficulties when called upon to produce NPKs. The difficulties are most pronounced when the NPKs contain urea or other temperature-sensitive and hygroscopic ingredients. The plant design and operating criteria described in this bulletin are intended to guide those involved in planning new NPK plant projects or troubleshooting and modifying existing units. This bulletin may also be used as a checklist during the various stages of project development to help ensure that the special requirements for NPK plants are not overlooked.

APPENDIX—Design and Operating Criteria for Urea-Based NPK Granulation Plants

Solid Urea Feedstock—

Prilled urea is preferred because its small physical size helps to effect relatively homogeneous incorporation into the granule structure. Very small and broken prills are the most desirable.

Urea Solution—

If the urea content of formula is more than about 20%, it is often preferable to dissolve a portion of the urea to produce a hot (105°C) 75%-80% urea solution. The availability of urea solution adds considerable flexibility to the process. The solution is sprayed on top of the bed of material in the granulator. In most instances, a solution of urea is preferred over an anhydrous melt.

Other Solid Raw Materials—

Standard-grade materials are preferred. Nongranular run-of-pile (powdered) monoammonium phosphate and superphosphate are recommended. If superphosphate is used in combination with urea, it should be ammoniated to minimize unwanted reactions that result in the release of water of crystallization contained in the superphosphate. In general, the use of superphosphate in combination with urea is not recommended and should be avoided, even if the superphosphate is ammoniated. Standard grade muriate of potash is preferred because of its good flow characteristics and more optimum particle-size distribution. Good flow characteristics of all solid raw materials are desired to facilitate handling and accurate metering.

Preneutralizer—

A standard, atmospheric tank-type preneutralizer is preferred. An $\text{NH}_3:\text{H}_3\text{PO}_4$ mole ratio of about 0.5 to 0.6 is recommended in the preneutralizer to achieve a low free water content while still maintaining a fluid and pumpable slurry. This is especially important if a significant amount of sulfuric acid is also neutralized in the unit. The preneutralized slurry at a mole ratio of about 0.5 to 0.6 should be about 127°C and contain no more than 15% free water. The preneutralizer and its auxiliary equipment (agitator, pumps, and piping) should be constructed of corrosion-resistant materials to facilitate the use of a mixture of phosphoric and sulfuric acid, thus adding considerable flexibility to the process. In general, if a higher mole ratio (for example 1.5) is used, especially if sulfuric acid is also present, the free water content of the slurry will have to be higher to facilitate pumping.

Granulator (rotary)—

The length-to-diameter ratio should be at least 3. The greater length, compared with most DAP and many North American NPK plants, facilitates granule formation and gives the operator more flexibility in controlling the agglomeration process. The $\text{NH}_3:\text{H}_3\text{PO}_4$ mole ratio of the material discharged from the granulator may be quite variable depending upon the properties of the raw materials. However, a mole ratio between 1.0 and about 1.8 is expected to be optimum. The lower mole ratio will simplify operation of the scrubbing system and tend to improve the process control. The free moisture of the product discharged from the granulator will usually be in the range of about 2% to 3%. The recycle-to-product ratio is expected to vary from about 3 to 6. A ratio of 6 is recommended for design. If the process is based on a solid ammonium phosphate source (a preneutralized slurry is not used), then a design recycle-to-product ratio of about 3 is sufficient.

Cocurrent Dryer—

The length-to-diameter ratio of this rotary unit should not exceed about 6. The superficial velocity of the air (at outlet conditions) should not exceed 2.4 m/sec maximum (2.0 m/sec preferred). The maximum temperature of the outlet air should not exceed 80°C, and the RH at this temperature should not exceed 15%. An outlet air temperature of about 75°C at 20% RH is recommended as the design basis. The moisture of the material discharged from the dryer should not exceed 1.0%; a value of 0.8% is recommended for design provided a second-stage dryer (process cooler) is used. The temperature and humidity profile in the dryer is extremely important, and the optimum values will vary from product to product.

Countercurrent Process Cooler—(Second-Stage Dryer)

The length-to-diameter ratio of this unit should not be less than 6; 7 to 8 is preferred. The inlet air should be tempered (heated) and/or conditioned to ensure that the RH is 60% or less. The superficial air velocity should not exceed 2.0 m/sec. The low velocity is recommended because of the relatively large amount of minus 1.0 mm particles in the material. It is preferred that these small particles be removed (separated) by the screens rather than by the airflow/dust collection system. The unit should be designed to achieve a material (discharge) temperature of not more than about 54°C at a free moisture content of no more than 0.6%. Further cooling of the product fraction is performed in a separate operation.

Screening—

Single-deck horizontal gyratory-type units are recommended. The screen wire should be stainless steel and of the square-mesh style. If inclined, electrically (or motor) vibrated screens are used, they should be for oversize separation only, not for product screening. The hourly loading of the oversize screen should not exceed about 20 t/m², and the loading of the horizontal gyratory-type product screen should not exceed 50% of this value (25%-30% preferred).

Oversize Crushers—

Double rotor chainmill-type crushers or double row cage mills are preferred. The discharge assemblies of the mills should not be restricted and should be constructed of flexible rubber (conveyor belting) panels that can be flexed from the outside by an operator using a hammer. A flared-type discharge assembly for the crushers is recommended to help avoid the accumulation of solids. The crushed oversize should be recycled to the oversize screen on a closed-loop basis to ensure that only the fine-material fraction from the screens is returned to the granulator as recycle.

Product Cooling—

Either a rotary-drum or fluidized-bed unit is recommended. The single-pass, counter-current, cascade-type unit is also acceptable. The cooling unit should be located immediately ahead of the conditioning unit. The RH of the cooling air at inlet conditions should not exceed 50%. The temperature of the product discharged from the cooler should not exceed about 43°C. In all cases the temperature of the cooled product should be about 5°C above the average ambient temperature to avoid absorption of atmospheric moisture on the surface of the material.

Conditioning—

A standard rotary drum-type conditioning unit is recommended. Screw-type mixing units should be avoided as they tend to grind and break the product granules.

Bulk Storage and Process Plant Dehumidification—

If ambient conditions normally exceed about 50% RH for extended periods (more than about 8-16 h), provisions should be made to dehumidify the process plant and bulk storage buildings. Cooling and proper ventilation may also be necessary for worker comfort and safety. Adequate ventilation is especially important because all buildings should be tightly constructed and closed to maintain a dry inside environment (RH of 40%-50%).

Bagging—

The products should be bagged in moistureproof bags shortly after production. Direct bagging from the production unit is not recommended because off-specification product could inadvertently be bagged and because flexibility is lost in handling product during grade-change periods. In addition, bag set (caking) is minimized if the fresh product is allowed to "pile set" for a short period of time.

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