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International Workshop
Madras/Bombay, India
February 1988

NPK Fertilizer Production Alternatives

International Fertilizer Development Center

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Edited by
J. J. Schultz
E. D. Frederick

International Fertilizer Development Center

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International Fertilizer Development Center
P.O. Box 2040
Muscle Shoals, Alabama 35662

Phone No. 205-381-6600
TWX-810-731-3970 IFDEC MCHL
Telefax: (205)381-7408

General Editing: E. N. Roth
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About These Proceedings

Much discussion was generated throughout the many workshop sessions. The fact that such dialogue occurred was a good indication that the technical topics, points of view, and experiences were relevant to the interest and needs of the delegates. The intention of these proceedings is to present the information given by the speakers and delegates and provide a valuable reference on the complex subject of NPK fertilizer production and use.

The technical papers and recorded deliberations were edited to obtain the uniformity needed to facilitate reproduction. In the process of transcribing the tapes, editing, and reproduction, every effort was made to accurately capture and preserve the technical content and meaning. Any errors, oversights, or ambiguities that may exist are accidental. If you need additional information or clarification, we urge you to contact the respective authors or IFDC.

International Workshop—NPK Fertilizer Production Alternatives

Cosponsored by IFDC/FAI/FADINAP • Madras/Bombay, India
February 8-13, 1988

Workshop Directors

B. K. Jain
Director (Technical)
FAI

J. J. Schultz
Fertilizer Production Specialist
IFDC

A. G. Vaes
Team Leader
FADINAP/ESCAP

Workshop Coordinators

P. Hjortlund
Marketing Economist
FADINAP/ESCAP

R. S. Giroti
Training Administrator
N. D. Le
Chemical Engineer
IFDC

S. Seetharaman
Regional Executive
FAI

Acknowledgment and Thanks

The management of IFDC is grateful for the support and efforts of our cosponsors, FAI and FADINAP, in organizing and making it possible to carry out the workshop.

We are especially grateful to the large number of speakers and technical resource persons who freely gave of their time to participate in the workshop and share their experiences.

Finally, the workshop could not have been the success it was without the contributions of the many delegates who participated enthusiastically in the discussions on the technical information and data recorded in these proceedings.

International Fertilizer Development Center
December 1988

Donald L. McCune
Managing Director

Inaugural Session

The following opening remarks were made by Mr. J. J. Schultz, IFDC Fertilizer Production Specialist.

After more than a year of planning, organizing, and seeking financial support, we have finally assembled. It is most rewarding to reach this point and face a roomful of more than 50 enthusiastic delegates and invited speakers assembled from 14 countries, all with a common objective of sharing and learning more about the world of NPK fertilizers--their production and use. I look forward to meeting each of you and learning from you.

Before going further, let me introduce you to the cosponsors who, together with each of you, made this workshop possible. First, we have the Fertiliser Association of India (FAI). The FAI is expert in organizing technical meetings and transferring fertilizer technology throughout the Indian fertilizer and agricultural sector. We are most pleased that FAI so kindly agreed to arrange the facilities here at Madras and in Bombay and will continue to help throughout the week to make the workshop flow smoothly. FAI also coordinated the selection of Indian speakers and delegates. Mr. S. Seetharaman and Dr. S. Nand are representing FAI on behalf of Mr. B. K. Jain (Director, Technical) who, hopefully, will join us later in the week. Second, I am pleased to introduce to you Mr. A. G. Vaes, who is representing our other cosponsor, the Fertilizer Advisory, Development and Information Network for Asia and the Pacific (FADINAP). FADINAP's participation as a cosponsor has strengthened this workshop in two ways: financial assistance was given to 12 delegates from the Far East who otherwise may not have been able to attend and share their knowledge and experience with us and FADINAP's assistance enabled us to expand the technical program to give broader coverage to the subject of NPK production through the use of compaction/granulation technology. This granulation technique is currently receiving considerable attention as an alternative to conventional NPK technology.

Finally, I would like to introduce my IFDC colleagues: Dr. D. H. Parish, Mr. R. S. Giroti, Mr. N. D. Le, and Mr. V. E. Leon. The IFDC staff, in addition to contributing to the technical program, will be on constant alert to ensure that the workshop flows smoothly and that your needs are attended to.

We have a full agenda before us. Please let me remind you that this is a "workshop." Therefore, we urge each of you to be informal and fully participate by asking questions, making comments, and generally sharing your experience. The technical papers that will be presented have been selected to give a broad coverage to the topic of NPK production and use. The invited papers are intended to stimulate thought and discussion. Ample time has been allowed for such discussion and questions.

Again on behalf of our cosponsors, FAI and FADINAP, and of IFDC, let me thank you for your participation; we look forward to your enthusiastic participation in this workshop experience.

Dr. D. H. Parish, Director of Outreach Division, IFDC; Mr. A. G. Vaes, Team Leader, FADINAP; and Mr. S. Seetharaman, Regional Director, FAI, then welcomed the participants on behalf of their respective organizations.

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Keynote Address
Role of NPK Fertilizers in Optimizing Agricultural Production

T. S. Manickam, Dean, Agricultural College and Research Institute, Madurai, India

Abstract

Agricultural production will have to be increased by 60% within the next 20 years in order to sustain the increased world population. Part of this increased production will come from the intensive use of new agro-technologies, including the more efficient use of fertilizers. In the past, many crops have removed more nutrients from the soil than have been replaced by use of applied fertilizers. This has inevitably led to nutrient-deficient soils.

The current use of modern high-yielding, fertilizer-responsive crop varieties has greatly increased the need for more fertilizer. However, the production of more fertilizer will soon exhaust the cheap sources of raw materials and thereby increase costs and limit fertilizer use. These conditions will necessitate the judicious use of all available resources, including the allocation of fertilizers among the various users.

Optimum agricultural production depends on many things including soil characteristics, crops planted, climate (especially rainfall), farming methods, availability of fertilizer materials, and development of new technologies. The new fertilizer component of these technologies must be based on information gathered from on-site testing. Blanket recommendations can be used for estimating the needs of large areas, but recommendations based on specific soil tests will be needed for fertilizer applications on individual farms.

Introduction

As the world's population increases, our appreciation of the limits of our finite resources becomes ever clearer. Thus, it becomes increasingly important that our research efforts provide not just information that can lead to maximum production but also information that can lead to production optimization in terms of the most efficient use of our available resources. Though the high-yielding crop varieties of the Green Revolution have provided us with the mechanism for obtaining higher production, judicious resource management by way of choosing the right mix of agro-inputs becomes the key for achieving production optimization. Increased fertilizer use has played a dominant role in increasing agricultural production. This is the reason for the intensive research that is being carried out to determine the need for fertilizers and the optimal application rates.

The present estimates reveal that agricultural production will have to be increased by 60% in the next 20 years to sustain the increased world population. Agricultural production can be increased through improved agro-technologies, with fertilizer input as the key factor along with water.

It is considered that more than 40% of the increase in agricultural production can be attributed to the use of inorganic fertilizers in almost all the countries. When intensified agriculture is practiced, the soil resources in terms of nutrient supply are subjected to rapid depletion, hence, the need for inorganic fertilizers to supplement the soil's native resources. This has resulted in a rapid expansion of the capacity of inorganic fertilizer production.

Crop Nutrient Requirements

The higher yields now sought and obtained with modern crop varieties require a greater quantity of plant nutrients than the conventional and traditional crop varieties used earlier. When conventional or traditional agricultural methods are used, the nutrients removed by the crops are normally replenished through many natural processes. But in modern agriculture the nutrients needed by high-yielding crop varieties cannot be met by the soil alone, so there is an absolute need for the use of outside sources of plant nutrients. For example, a popular conventional rice variety grown in Tamil Nadu during the 1950s and early 1960s, namely rice GEB 24, was found to remove about 75 kg of N/ha, whereas a recently introduced high-yielding rice variety like IR 50 was found to remove 180 to 210 kg of N/ha. This simple example itself illustrates the situation clearly. A few summarized results presented in Tables 1-6 will further indicate the conditions

existing now under different situations. These data clearly indicate the need for rationalizing our approach to fertilizer use in optimizing agricultural production.

Table 1. **Nutrients Removed From Soil by Rice**

Yield Level	Nutrients Removed (kg/ha) N	P_2O_5	K_2O
4 mt/ha	75	40	95
10 mt/ha	200	75	215

Source: Tamil Nadu Agricultural University (TNAU). 1982. *Annual Report*, Coimbatore, India (2).

Table 2. **Nitrogen Balance Under Different Cropping Systems**

Crop Rotation	N Balance (kg/ha/year) Addition	N Removal by Crop	Balance
Rice-wheat-pearl millet	310	323	-13
Rice-wheat-greengram	337	401	-64
Rice-rapeseed-wheat	320	335	-15
Rice-rapeseed-soybean	314	489	-175
Rice-potato-wheat	360	383	-23

Source: AICARP Project. 1981. *Annual Report*, ICAR, Delhi, India (1).

Table 3. **Nutrient Uptake in a Sorghum-Based Cropping System**

Cropping System	Nutrient Uptake (kg/ha) N	P_2O_5	K_2O
Sorghum (alone)	177	18.4	273
Sorghum + soybean	155	19.3	203
Sorghum + greengram	179	17.5	217
Sorghum + cowpea	179	20.2	198
Sorghum + sunflower	248	29.5	300

Source: Selvaraj, S. 1978. Master of Science (Agriculture) Dissertation. Tamil Nadu Agricultural University, Coimbatore, India (8).

Table 4. **Nutrient Removal Under Different Cropping Systems**

Crop Rotation	Nutrients Removed (kg/ha) N	P_2O_5	K_2O
Castor-sorghum-blackgram	293	45.7	303
Castor-pearl millet-cowpea	211	37.8	254
Castor-redgram-greengram	143	22.2	128
Castor-cowpea-coriander	82	7.5	103

Source: Chinnappan, R. 1978. Master of Science (Agriculture) Dissertation. Tamil Nadu Agricultural University, Coimbatore, India (4).

Table 5. **Nitrogen Balance in Cotton-Based Multiple Cropping System Over a 30-Month Period at Coimbatore**

Cropping System	N Balance (kg/ha) Quantity Added	Quantity Removed	Balance
Cotton + sorghum + ragi	540	938	(-)398
Cotton + sunflower + ragi	560	654	(-) 94
Cotton + maize + ragi	630	743	(-)113
Cotton + cotton + greengram	320	446	(-)126
Setaria + greengram	320	557	(-)237

Source: Venugopal, S. 1978. Master of Science (Agriculture) Dissertation. Tamil Nadu Agricultural University, Coimbatore, India (10).

Table 6. **Total Nutrient Uptake by 30 Crops (10 Each of Ragi, Maize, and Cowpea)**

Treatment	Total Uptake (kg/ha)			Added as Fertilizer (kg/ha)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
50% optimum NPK	2,070	370	2,140	1,250	360	220
100% optimum NPK	2,340	450	2,580	2,500	720	440
150% optimum NPK	2,660	510	2,810	3,750	1,080	660
100% NP	2,390	430	2,290	2,500	720	440
100% N	1,080	170	960	2,500	0	0
100% NPK + FYM[a]	2,940	570	3,200	2,750	720	440
Control	770	130	620	0	0	0

a. Farm yard manure.

Source: Tamil Nadu Agricultural University. 1985. *Annual Report*, LTFE Project, Coimbatore, India (3).

Fertilizer Crisis

The constantly increasing demand for fertilizers resulting from agricultural development in many countries and the exhaustion of cheap sources of raw materials for fertilizer manufacture have caused a worldwide awareness of the adverse affects of a fertilizer shortage. For example, India's fertilizer consumption in absolute terms has increased from 785,000 mt nutrients (N, P_2O_5, and K_2O) in 1965/66 to 8,721,000 mt nutrients in 1985/86. In these two decades the fertilizer production only increased from 356,000 to 5,753,000 mt nutrients. Thus the gap between fertilizer consumption and production has increased from 429,000 mt nutrient tons in 1965/66 to 2,968,000 mt nutrients in 1985/86. This increasing trend in consumption and the widening gap between consumption and production have necessitated massive imports of fertilizers (3,315,000 mt nutrients) which amount to an import bill of about Rs 18 billion (US $1.4 billion). This situation warrants the proportioning of the limited supplies any country can obtain or afford. Because fertilizer needs vary widely with type of crop, soil, and location, these sources of variation should logically provide the basis for such distribution of fertilizers at all levels of consideration, for example, among the fields in individual farms, soils within regions, regions within countries, and idealistically, the countries of the world, all for the greatest general good with appropriate allowances for current economic and supply situations.

Such an apportioning procedure must be based on the answers to some common questions:

What are the economic fertilizer requirements indicated by the data from a fertilizer experiment?

Are these fertilizer requirements related to locality or type of soil and if so, what should be the general recommendations for these localities or soils?

What is the basis for evolving location-specific recommendations for a soil-crop-climate combination scenario?

On the basis of simple fertilizer experiments, is it possible to correlate nutrient availability with crop response? If so, how can we extrapolate from these statistical relationships to obtain the best estimates of economic fertilizer rates?

What is the economic importance of soil testing apart from its statistical significance?

These and similar questions all require lengthy computations for proper answers, and in the past they have gone largely unanswered or have been answered only after inordinate delays. Thanks to modern developments in communication and computing facilities, data can now be easily processed to provide soil scientists with the information needed to answer such questions.

The recently introduced concept of "Soil Based Agrotechnology Transfer" is used by the Bench Mark Soils Project of Hawaii Institute of Tropical Agriculture and Human Resources. In this concept, the soil taxonomy (which is more nearly a quantitative representation of our knowledge of soils since most soil properties can now be characterized in terms that have quantitative meaning at some level of precision) is the basis for transferring agrotechnologies developed for one site to another. Development of a soil family network will help solve the problems encountered in defining the boundary conditions for optimizing fertilizer use. Parenthetically it may be noted that the kind of reasoning on which this concept is based conforms to the theories of realism, originally postulated by Plato and later moderated by Aristotle, according to which universal truths exist and are implicit in particular instances.

This concept enables researchers to develop yield response equations for a soil family at all sites where it occurs so that appropriate fertilizer inputs can be made to give economically optimum yields. It is also realized, however, that the soil and climatic conditions existing at each site, even for the same soil family, can have measurable effects on the productivity of the soil. Therefore, it is imperative that this concept include the appropriate soil and climatic parameters in the yield equations to allow adjustment for local variation.

Choice of the Yield Response Function

The basic difficulty in selecting the response model, which is immediately apparent, is the form of the response equations used to optimize yields. Unfortunately there is no general fundamental model describing the effects of nutrient application rate on yield, and any choice of a model must be based on observation and experience (must be empirical). There are, of course, many models like the various polynomial expressions, orthogonal polynomial functions, linear plateau model, two straight line equation exponential expression of the type proposed by Mitscherlich, Cape function, and so forth to choose from; each has its adherents, and it seems possible to collect data to support any of them. Moreover, there are endless opportunities for debate on the merits of the alternative models since experimental data usually contain error aberrations and the nature of the relationship varies with crop and growing conditions. In the words of Heady and Dillon, "A skeleton of theory is lifeless without empirical flesh; to be more than play-things in an ivory tower, response models must be specific in terms of real-world situations."

Thus, the development of a model to predict yield is essential. However, it should be based upon the logic, economics, or physical and biological conditions that describe the production process being examined. There is a scientific principle known as the "Law of Parsimony" that seems to have some appropriateness for mention here. This law, which has relevance to the choice of production functions, emerged sometime in the 14th century. It says that you should not explain a behavioral phenomenon by a higher, more complex process if a lower or simpler one will do. Translated to research terms, this means that we should select the simplest, least complex, and easiest way to calculate an equation that provides a tolerable approximation of the biological response to fertilizers and that also contains attributes that are meaningful and desirable for economic interpretation.

General Recommendation

Fertilizer requirements vary with location and year in most regions because of more or less unpredictable effects of variations in soil features, seasonal weather conditions, farming methods, pest and disease damage, and so on. Given such variability, the usual sequence of scientific research is to seek explanations by carrying out fertilizer experiments and studying the correlation between the crop response to fertilizers and the identifiable features of the soils, climate, and other factors and ultimately trying to devise methods for predicting the variations. The amount of work required for this type of research is, however, enormous; the time required is at least several years, and the final results may well prove disappointing, as has been the case, for example, with so many projects aimed at devising fertilizer recommendations for various crops. In the meantime, decisions have to be made on fertilizer use, and scientists can help by providing an unbiased general estimate for a specific unit of land, based on the available information. Such an estimate for a variable unit of land is termed the "general fertilizer requirement or recommendation," and it is general in the sense that the estimate applies to the optimum use of fertilizers on the unit as a whole over a long period of many years in production. Because the land unit is variable, it is inevitable that any general estimate of requirements will be accurate for only a small proportion of crops being grown at any particular time. For the remainder, the general rate will be either too high or too low. The general estimate is simply the best estimate possible for the present with existing information. However, this may introduce another problem, namely, a general acceptance of the recommendation as being good enough, or worse, as being accurate for the whole of the land unit, which possibly covers many thousands of farmers' fields. Apart from noticing gross deviations from expected results, there is always a danger that the fundamental variability of fertilizer requirements between fields and farms will be forgotten. Hence it is important that estimates of the general optimum rates always be accompanied by information on variability, both to indicate the proportion of disappointing results that can be expected and the need for local, more specific studies on fertilizer requirements.

Fertilizer Recommendations

On the basis of the results from a few field experiments, blanket or general recommendations were proposed and used (see Tables 7 and 8). The recommendations in Table 7 did not consider soil types, crop varieties, and seasons. Hence, they were then followed by a slightly improved recommendation based on a soil test, which gave some emphasis to the native soil fertility. This was found to be better, at least in most areas. Because of the shortcomings in the two recommendations in Table 7, different models have been tried and Mitscherlich Bray's concept has been found to be workable.

Table 7. **Blanket Fertilizer Recommendations for Important Crops in Tamil Nadu**

	Nutrients (kg/ha)		
	N	P_2O_5	K_2O
Rice			
Short duration varieties (100-110 days)			
Basal	50	50	50
Topdress (day 21)	50	-	-
Medium duration varieties (120-135 days)			
Basal	60	60	60
Topdress (day 21)	35	-	-
Topdress (day 70)	25	-	-

Table 8. **Soil Test Fertilizer Recommendations for Rice (in Heavy Soils)**

Soil Test Value (kg/ha)	Recommended Nitrogen Application, kg/ha, to Achieve Indicated Yields (% of Maximum Yield)		
	75% Yield	87.5% Yield	94% Yield
89	106	173	242
104	101	168	235
121	96	163	230
138	89	158	225
155	84	151	215
172	79	146	212
190	72	141	207
207	67	133	203
225	62	128	195
242	54	124	190
259	49	116	185

Other approaches followed also indicate the possibility of rationalized recommendations.

Site- and Situation-Specific Recommendations

Attention must be drawn to the fact that experimentation with plant nutrients is fundamentally different from experimentation with other yield-controlling factors, such as distance between plants and time of planting. The soil is able to provide the crop with a certain amount of each of the nutrients, and the response of the crop to the application of a certain nutrient is due to the change in level of that particular nutrient in the soil. The crop response to the application of a nutrient thus depends on how well the unfertilized soil may be able, by itself, to provide the crop with the given nutrient. There is, therefore, the need to measure or estimate by some procedure how much of each nutrient the corresponding soils can provide to the crop in order to be able to work out fertilizer rates for optimum yields.

Soil chemists have dedicated a great deal of effort and time to evaluating the quantities of available nutrients in soils by analyzing soil samples. To date, however, such analyses, though not proven entirely accurate, have served as a basis for arriving at site-specific fertilizer rates. A family of response models for arriving at fertilizer rates corresponding to optimum yields exists, and these models embrace the soil fertility variables (see Tables 9-14). Again the one that deserves mention is the Mitscherlich-Bray response function, which has gained much use in this part of India.

The recent experience of the soil scientists in the state of Tamil Nadu, India, should be mentioned at this juncture. A case study was made for rice using the results of soil testing and fertilizer experiments in Papanasam Taluk of Thanjavur delta, the rice bowl of Tamil Nadu.

The soils studied came from Papanasam Taluk of the Thanjavur district and belong to the Kalallur and Adanur soil series. The soil test data relating to 30 villages were processed to work out the village fertility indices as well as master equations for each nutrient on the basis of the Mitscherlich-Bray approach (see Table 14). By substituting the village soil fertility indices in the master nutrient equation, it was found that the native soil fertility itself is sufficient to produce 50% to 70% of the maximum possible yield in rice. The results clearly indicated the highly varied nature of soil fertility, and thus the general blanket prescription proved to be either an underestimate or an overestimate of the actual requirements of fertilizer nutrients. The results also revealed how misleading a fertilizer recommendation would be that does not take into account the native soil fertility level. The results clearly indicated that for nitrogen the presently recommended level of 100 kg/ha for rice is insufficient in almost all villages. For obtaining a yield of 5 mt/ha, the fertilizer nitrogen requirement was 150 kg/ha, an increase of 50 kg from the presently recommended level of 100 kg/ha. With respect to phosphorus and potassium, there were indications of the need for further grouping the soils as low or high with respect to their availability because some of those soils that record high soil fertility indices do not require phosphorus and potassium dressings for obtaining economic yields. When this revised schedule, based on village soil fertility indices, was compared with general blanket recommendations, the results indicated that the revised schedule was superior for obtaining optimum yields. Moreover, in terms of even the quantity required for the study area, the recommendations on village fertility indices indicated a realistic approach.

Table 9. **Relation Between Fertilizer Levels, Grain Yields, Value/Cost Ratio, and Achievement Level (Data from 16 Experiments)**

Treatment	Fertilizer Rates N	P_2O_5	K_2O	Grain Yield Range	Mean	Achievement Level	Value:Cost Ratio
	(kg/ha)			(mt/ha)		(%)	
Control	0	0	0	2.0-4.0	2.6	-	-
Blanket	100-120	50-60	50-60	4.0-5.6	4.7	-	3.9
Target Yield (mt/ha)							
4.5	45-65	0-18	0	3.7-5.0	4.4	98	9.4
5.0	65-88	5-22	0	3.9-5.3	4.7	94	8.2
5.5	88-110	12-33	0	4.0-5.4	4.7	85	6.6

Table 10. **Soil Fertility Indices of Five Selected Villages in Papanasam Taluk, Thanjavur District**

Name of Village	Number of Samples Studied	Village Level Fertility Indices N	P_2O_5	K_2O
		(kg/ha)		
Papanasam	41	251	3	145
Koonancherry	105	130	93	293
Saliamangalam	92	193	65	278
Ayyampettai	50	135	40	40
Alangudi	50	242	286	1,149

Table 11. **Percent Sufficiency of Nutrients Due to Soil Fertility in Five Selected Villages in Papanasam Taluk for Rice**[a]

Name of Village	Percentage Sufficiency N	P_2O_5	K_2O
Papanasam	64	14.0	79.0
Koonancherry	41	99.9	96.0
Saliamangalam	55	96.0	95.0
Ayyampettai	43	87.0	35.0
Alangudi	63	99.9	99.9

a. The amounts of nutrients furnished by the soil were determined from the soil fertility indices.

Table 12. **Fertilizer Recommendations for Rice at Different Sufficiency Levels as Measured by Soil Fertility Indices for Five Selected Villages in Papanasam Taluk**

Name of Village	Fertilizer Requirement (kg/ha) N for 87.5% Sufficiency	N for 94% Sufficiency	P for 98% Sufficiency	K for 98% Sufficiency
Papanasam	135	230	105	170
Koonancherry	205	300	-	55
Saliamangalam	170	263	-	65
Ayyampettai	200	293	50	250
Alangudi	140	235	-	-

Table 13. **Comparison of Fertilizer Recommendations Based on Soil Fertility Indices With General Blanket Recommendations for Rice for Two Villages in Papanasam Taluk**

Parameter Compared	Village	
	Koonancherry	Papanasam
	(%)	
1. Combined percentage sufficiency due to native soil fertility	39	7
2. Combined percentage sufficiency due to application of fertilizers stipulated in the general blanket recommendation	72	44
3. Increase in percentage sufficiency due to blanket recommendation minus native soil fertility	33	37
4. Combined percentage sufficiency due to application of Mitscherlich-Bray response function recommendations:		
84%	45	77
90%	51	83
5. Increase in percentage sufficiency due to Mitscherlich-Bray response function over native soil fertility indices:		
84%	6	70
90%	12	76

Table 14. **Total Fertilizer Requirement for Rice for 30 Case Study Villages in Papanasam Taluk**

Estimated Fertilizer Application	Requirement of		
	N	P_2O_5	K_2O
	(mt)		
1. By general blanket recommendation of 100 kg N, 20 kg P_2O_5, and 40 kg K_2O/ha	805	160	320
2. By recommendations based on soil fertility indices for a combined sufficiency of 84% (N for 87.5% and P_2O_5 and K_2O for 98%)	1,210[a]	150[b]	845[c]
3. By recommendations based on soil fertility indices for a combined sufficiency of 90% (N for 90% and P_2O_5 and K_2O for 98%)	1,430[a]	150[b]	845[c]

a. Required for all 30 villages.
b. Required for only 5 villages.
c. Required for only 15 villages.

Future Thrust

Past experience indicates that agronomists and the soil fertility specialists should concentrate their attention on the following areas.

1. More concentrated efforts should be made to attain balanced fertilization and synergistic nutrient interactions. Instead of a single-nutrient approach, a multinutrient approach must be taken to ensure balanced fertilization.

2. Integrated nutrient management must be established for a well-identified agro-ecosystem involving soil, climate, and plants.

3. The optimization of agricultural production must aim not only at achieving the desired yield targets of crops

but also at eliminating nutrient deficiency and increasing the efficiency of the applied nutrients.

4. Use of organic materials such as grain legumes, green manures, bio-fertilizers, and organic manures must be properly integrated with other nutrient resources.

5. To optimize agricultural production, the synergistic interactions between fertilizers, seeds, water, agrochemicals, and management skill ought to be properly exploited, and the effective role of fertilizers should be properly defined and allowances made for these interactions.

6. Fertilizer use research in rainfed agriculture has to be properly evaluated for specific soil-climatic complexes.

7. In the past three decades, fertilizer recommendations have been made only on the basis of individual crops; it is essential, however, to develop fertilizer recommendations for a cropping system as a unit.

Achievement of the agricultural production goals is closely linked with fertilizer use, and it seems impossible to think of optimizing agricultural production without use of fertilizers. The current fertilizer consumption pattern indicates that a major share is used by a few crops: rice (40%), wheat (24%), sugarcane (9%), cotton (7%), and others (20%). Dryland crops occupy around 60% of the arable land but account for less than 15% of the fertilizers used. Furthermore, assuming a present level of 18 million mt of nutrient removal per year in India, the consumption level of 8 million mt leaves a wide gap which will lead to rapid depletion of the soil nutrients. This will become intensified with the intensification of cropping and farming systems. Further, the new potential areas of fertilizer use must be in (a) rainfed agriculture, (b) new cropping and farming systems involving pulses and oilseeds, and (c) reclaimed lands.

Although a tremendous increase has been made in fertilizer consumption, much more remains to be done in terms of increasing the use efficiency of the applied nutrients. Probably a major part of the agronomists' attention should be directed toward increasing the use efficiency with the currently available quantities of plant nutrients as opposed to increasing the production further and further. To highlight this, if it is possible to increase the use efficiency of applied nutrients in rice farming alone from the current average level of 25% to around 50%, a substantial quantity of fertilizer nitrogen can be saved which can be diverted to other crops. This situation will hold good for other nutrients also. Soil scientists and agronomists should concentrate their efforts in this major area, and they should be given proper support from industries in taking up large-scale research to find ways and means of increasing the use efficiency of the applied nutrients.

The increased agricultural production witnessed the world over during the past three or four decades was made possible by the introduction of high-yielding, fertilizer-responsive varieties of plants, especially grains such as rice, maize, and wheat during the late 1960s. But this trend did not continue. Nor did it attain the full level of expectation, and at present agricultural production is once again static at another plateau. If agricultural production is to increase and to move beyond this plateau, it must be realized that the production of crops cannot be increased significantly by introducing modern crop varieties alone. Other factors have to be taken into account such as climate, soil fertility, and crop production techniques. The general blanket fertilizer recommendation technique has to be replaced with a suitable location-specific technology. Appropriate knowledge about soil fertility and fertilizer use for location-specific situations may be the answer for achieving the expected goals in crop yields. It may be necessary to reorient the current production technology by changing from "seed-based technology" to a "soil-based technology" in which equal emphasis is given to the nutrients, water, and seeds. Fertilizer use should be properly integrated with an effective soil fertility evaluation program. Soil testing should be the foundation of the nutrient management system designed to optimize agricultural production. Optimization should involve not only quantity but also source of nutrients and efficiency of use, including proper timing and method of application. Thus, the prescription models that are aimed at higher crop yields should also increase use efficiency and sustain soil fertility. These prescription models have to be evolved in a systematic manner for the major cropping systems and also the farming systems involving crops, animals, trees, aqua-culture, bio-fertilizers, and other factors.

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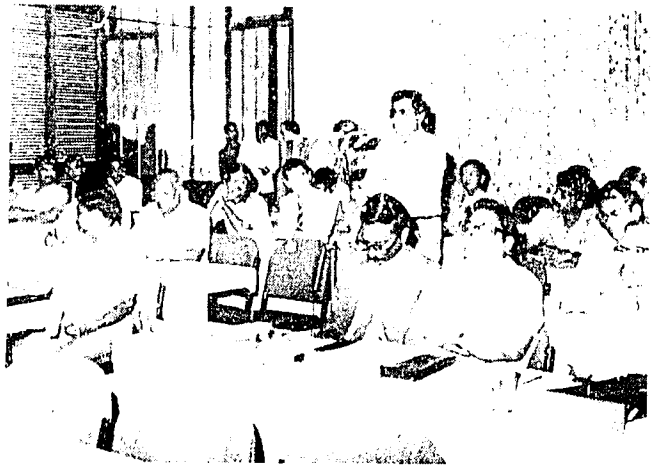


Foreword – NPKs in Perspective – Fertilizer Products and Farmer Needs

D. H. Parish, Director, Outreach Division, International Fertilizer Development Center

Introduction

Chemical manures, or artificial fertilizers as they were invariably called, have revolutionized agricultural production on a global scale only since the 1960s. They had, however, already proven to be indispensable to many farm production systems of the industrialized nations for almost a century before their global role developed. Now, without their use, mass starvation would follow in many nations.

The economics of fertilizer use are governed by production, distribution and storage costs, the costs of application in the field, and the value of the crop response per unit of nutrient provided by the fertilizer. Government intervention at all levels in the fertilizer sector – supply, distribution, and use distorts the use of fertilizers in terms of the products made available to the farmer and the level of use based on the fertilizer price and the value of the crops the farmer sells; nevertheless, the objective of most developing country governments is to increase crop production and therefore also fertilizer use.

The farmer is uninterested in national goals and will use fertilizer only to make a profit. To maximize this profit, the farmer must integrate optimal soil preparation, seeding, time of planting, weed, insect, and disease control, and nutrient supply, with known crop needs; it is in the latter area that fertilizer product selection, including NPKs, has a role to play.

The Development of the Demand for Fertilizers

The fertilizer industry began essentially in northern Europe during the industrial revolution – a revolution which saw the beginning of massive movements of a burgeoning population from the countryside to the cities and a consequent rapid growth in the market demand for food.

The history of fertilizer use is therefore closely linked to the production of cereal crops and to this date, wheat, rice, and maize account for most of the fertilizer consumed annually.

Developments in the production technologies of these three crops have impacted not only on the quantities of fertilizer used but also on the products used.

Before the advent of the high-yielding wheat and rice varieties and of hybrid maize, the major sources of plant nutrients were legume crops and farm and domestic manures. With these farming systems, the major constraint on cereal production was the low levels of soil phosphate which, in turn, led to the early development of the commercial phosphatic fertilizer industry (1842) based on cheap phosphate rock.

The exploitation of potash deposits in Germany (1860) followed, and potassium chloride became an important fertilizer. Nitrogen thereafter became the key constraint to cereal production, particularly in northern Europe where the legume crops, although essential, represented a lost opportunity to grow a cereal crop. The advent of synthetic nitrogen fertilizers in the early twentieth century led to only a slow replacement of the traditional sources of nitrogen with nitrogenous fertilizers. This slow growth in demand was due to economic factors (high cost of nitrogenous fertilizers and low cereal prices) and to the genetically unimproved nature of the cereal varieties used. At this stage of agricultural development, crop varieties available to farmers were not high-yielding; and the bane of farmers around the world trying to grow higher yields of cereals was crop lodging, an affliction particularly associated with high fertility soils. For this reason, the emphasis in fertilizer use was on phosphate and potash with nitrogen being used only sparingly compared with today's practices. Under these conditions, as shown in Figures 1 and 2, the use of a 1:1:1 ($N:P_2O_5:K_2O$) mixture at cereal planting time was, and still is, a widely accepted practice.

As the key crops (wheat and rice) were self-pollinating, a wide range of distinct varieties existed. The challenge, therefore, was to use the various characteristics of the different varieties to produce crops which did not lodge and which therefore could respond in terms of higher yields to higher levels of soil fertility. Breakthroughs occurred over a very short period and rice yields in Japan and wheat yields in the United Kingdom soared.

In the United States, the major crop with the potential for rapid intensification was maize, an open pollinated crop; it was not until the introduction of hybrid maize that yields, and consequently the demand for fertilizer, exploded.

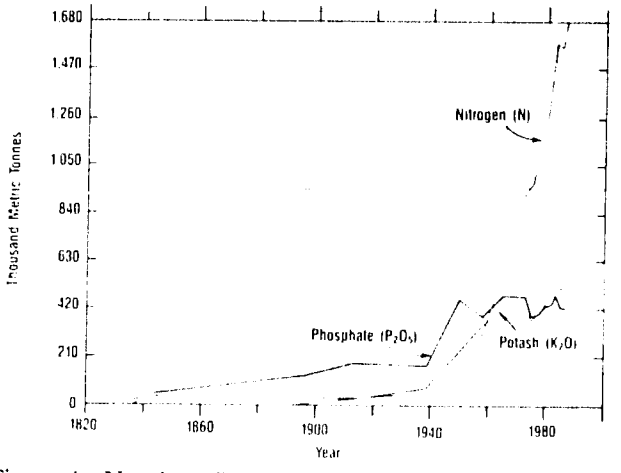


Figure 1. **Nutrient Consumption in United Kingdom, 1837-1987.**

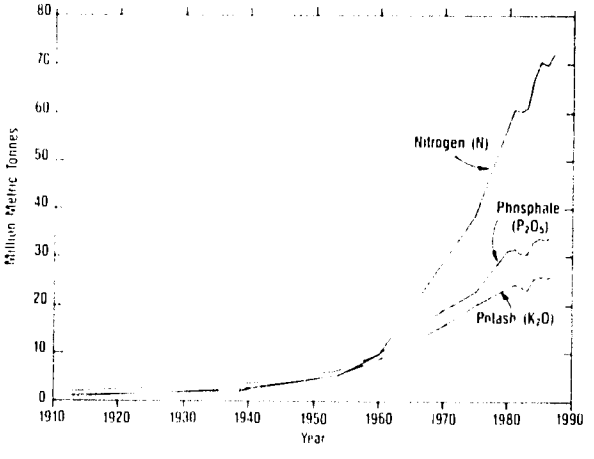
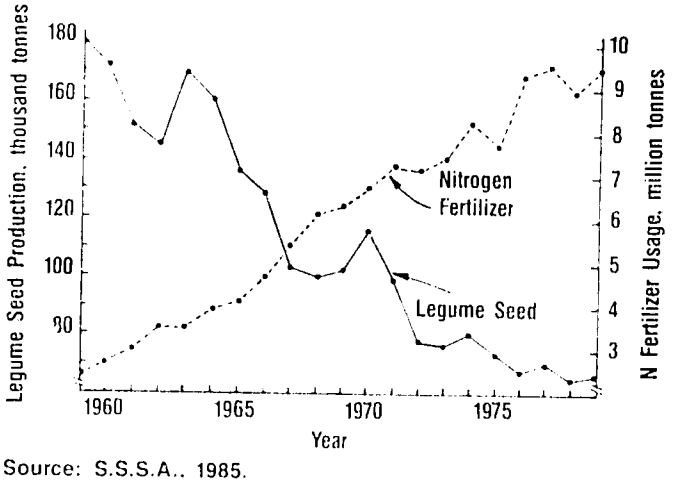


Figure 2. **Nutrient Consumption in World, 1913-1987.**



Source: S.S.S.A., 1985.

Figure 3. **Legume Seed Production and Nitrogen Fertilizer Use in the United States, 1959-1979.**

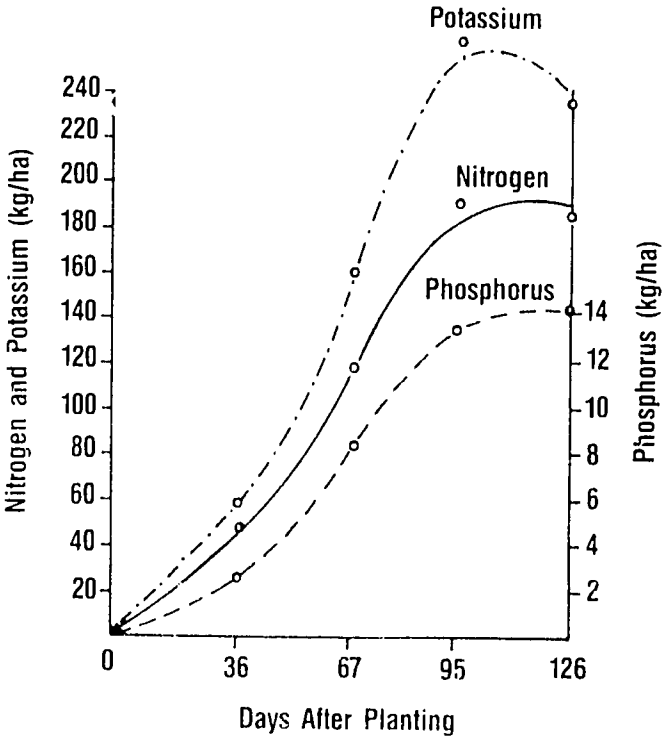
The plant breeder in the developing world also radically changed the agronomic efficiency of fertilizers by doubling and tripling the grain production per unit of nitrogen applied to wheat and rice.

With the advent of cheap synthetic nitrogenous fertilizers and cereal varieties which could convert high levels of nitrogenous fertilizer into greatly increased yields, the requirements of the farmer changed rapidly. In many areas, legumes were abandoned as were animal and domestic manures. The rapidity of this change is shown in Figure 3 which shows clearly the relationship between the decreasing use of legumes as a source of nitrogen and the increased reliance on synthetic nitrogen.

The Agronomics of Fertilizer Use

Without an adequate supply of 13 mineral elements, plant growth is stunted. Fortunately, the major agricultural soils have adequate supplies of most nutrients, the exceptions being nitrogen, phosphorus, and potassium, which are the major mineral constituents of the plant and the basic nutrients of commercial fertilizers.

After the initial lag phase of seedling development, cereals grow essentially in a logarithmic fashion in terms of both dry matter production and in terms of nutrient uptake as illustrated in Figure 4. The increasing demand for nutrients as the plant grows is met by a root system which has also grown vigorously.



Source: I.P.I., 1983.

Figure 4. **Nutrients Accumulated by the Aerial Parts of Wheat Plants From Emergence to Maturity, Average of the 2 Varieties Inia and Ciano at 400 kg/ha N (Mexico).**

As both the soil and the plants act as buffer systems in terms of nutrient supply, with a typical arable crop the effect of a nutrient stress caused by a low soil supply of the nutrient shows first by only marginal decreases in growth. However, there are periods when the intensity of nutrient supply to the plant is critical and a shortage of nutrients at these stages can severely effect grain yield.

With seedlings, the soil near the seed must be high in phosphate and potash and in nitrogen also. As the root system develops, a much lower level of phosphate and potash throughout the rooting zone can continue to sustain growth.

In the case of the modern varieties of wheat and rice, there are very critical periods when nitrogen supplies must be at a high level. This has led to the well-known splitting of nitrogen fertilizer treatments on the semi-dwarf rice and wheat varieties. With maize, the occurrence of critical nitrogen supply periods is less marked, nevertheless, side-dressing after the spring growth is well underway is a common practice.

Fertilizer Products and Farm Practices

With the low-yielding agriculture of the 1930s and 1940s, the widespread use of manures and legume crops, and the lack of detailed knowledge of crop response compounded with farmer caution meant that fertilizer use developed only slowly and quite differently in different countries. Essentially, only the higher value cash crops were fertilized and fertilizer recommendations were of the simplest order – one bag of this or two bags of that.

In France and Germany, particularly, the use of multinutrient general purpose fertilizers containing N, P_2O_5, and K_2C was highly developed and materials such as 15:15:15 became established not only in the home market but also overseas where they were used on plantation and small farm cash crops.

Given a good soil supply of phosphate and potash, nitrogen is the key yield maker; and its management is becoming increasingly critical.

As a general rule, all the P_2O_5 and K_2O needed by a crop should be applied at or before planting, while applications of nitrogen should be made at times and rates defined by the climate, the soil, and the crop. Given this statement the scope for the fertilizer industry to manufacture multinutrient fertilizers exactly matched to soil and crop needs is limited, a fact which led to the popularity of prescription applied bulk blends. Nevertheless one or two carefully selected grades of good quality multinutrient fertilizers can play an important role over large areas where simple fertilizer practices can be helpful or in fact may be all that is needed.

Agronomists have often became involved in the problems of fertilizer product selection based on marginally different crop yield results; while the economics of scale of modern fertilizer production units and major reductions in distribution and storage costs achievable through the use of a minimum number of high-analysis fertilizer products have, in fact, pre-empted such refinement in product selection.

When based on cost per unit of nutrient applied in the field, high-analysis fertilizers are increasingly competitive at the farm level. This fact has benefited many NPKs as they are already relatively high-analysis materials. However, the main advantage of the traditional NPKs has been their high uniformity, low hygroscopicity, and good physical quality. This means that they fit better into the developing country situation involving movement in bags and long-term storage under humid conditions than do the more hygroscopic urea-based NPKs or bulk blends.

A situation which will possibly lead to an increase in the demand for homogeneous NPKs in developing countries is the increasing need for a source of nitrogen, phosphorus, and potassium with additions of magnesium, sulfur, and the trace elements for use at time of planting. Such complex nutrient needs mean that granular NPKs that uniformly incorporate these supplementary elements should be able to compete with bulk-blended products which attempt to supply such nutrients. The competitive edge of such fortified homogeneous NPKs will, however, only apply if fertilizer quality controls are strictly applied and provided also that the agronomists do not over-tailor their fertilizer recommendations.

NPK Market Share

Worldwide production of homogeneous multinutrient (NPK) fertilizers continues to show moderate growth but is lagging behind the growth in total nutrient consumption – about 55 million tonnes of homogeneous NPK products was produced in 1980 – compared with about 60 million tonnes today. This amounts to about 15% of the world's total product tonnage. This annual tonnage is complemented by about 25 million tonnes of binary (NP) products; about 280 million tonnes of single nutrient materials, some of which are blended prior to application; and about 30 million tonnes of fluids (Figure 5). Thus, the world's total annual production of fertilizer products amounts to about 400 million tonnes. Of this amount, an estimated 20% (about 80 million tonnes) is actually applied in the form of NPK products including those

straight materials and fluids that are blended prior to application.

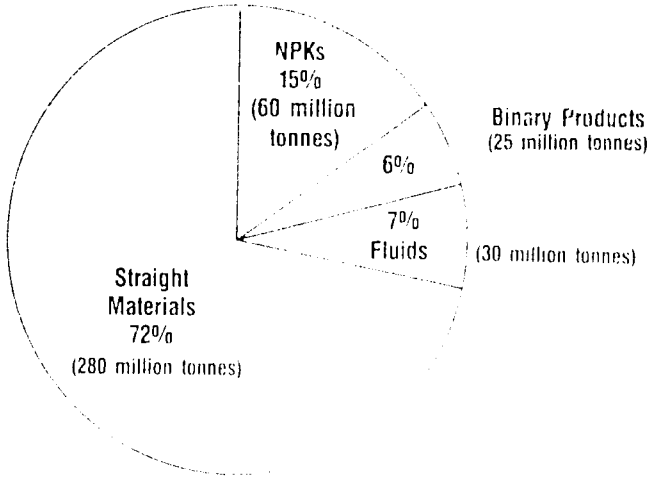
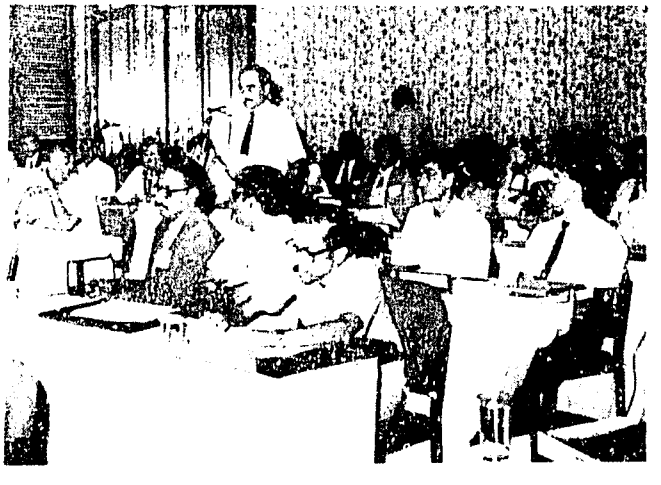


Figure 5. **Estimated Current Annual World Fertilizer Use by Type (Product Basis).**



Review of the Fertilizer Situation in Asia and the Pacific With Reference to Multinutrient (NP and NPK) Fertilizers

Alain G. Vaes, Team Leader, ESCAP/FAO/UNIDO Fertilizer Advisory, Development, and Information Network for Asia and the Pacific (FADINAP)

Abstract

In the late 1960s the use of modern high-yielding varieties of rice and wheat that are responsive to nitrogen fertilizers became widespread throughout Asia and the Pacific area. At the same time there was an ample supply of nitrogen resulting from new and improved technology in the production of ammonia and urea. Together, these facts spurred the use of fertilizers in all the region. For the first time in history, grain production outstripped the population growth in most of Asia. This paper gives the production and consumption figures for most of the countries in Asia and the Pacific region.

Introduction

With the exception of Japan, the Republic of Korea, and Taiwan, large-scale fertilizer use in Asia and the Pacific started only after 1965. Up to that year, the use of fertilizer was largely restricted to industrial plantation crops such as tobacco, coffee, tea, sugarcane, and oil palm. Since the total acreage under such crops was relatively small, the total amount of fertilizer used in the Asian region was also rather small.

Nitrogen, phosphate, and potash were used almost in the same ratio as that used by the rest of the world or about 1:1:1. The turnaround for most of Asia came in the late 1960s. It was triggered by the spread of modern, high-yielding varieties of rice and wheat that are responsive to nitrogen fertilizers. This development coincided with the ample availability of cheap nitrogen resulting from the new, large-scale compressor ammonia technology.

Nitrogen consumption started a meteoric rise about 1970 (Figure 1). Ever since, grain output has outstripped population growth in most of Asia. Both fertilizer consumption and food production in Asia increased at a much faster rate than in the rest of the world.

Since the seed and the fertilizer-based "Green Revolution" started to have an impact (after 1965), the development of fertilizer consumption in Asia has followed a pattern distinctly different from that of the rest of the world. The dominance of rice in Asian agriculture and its food economy is the major factor that differentiates Asia from the rest of the world (1).

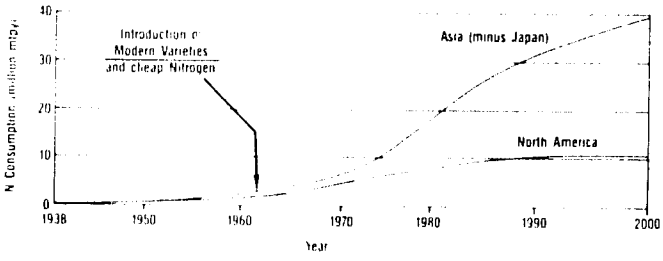


Figure 1. **Trends in Nitrogen Consumption in Asia and North America, 1938-2000.**

Regional Overview of Fertilizer Production in Asia and the Pacific

In Asia in 1985/86 there was a marginal increase in the production of N while P_2O_5 production declined by 4.67% and K_2O production increased by more than 25% compared with the preceding year (1984/85). The overall production of all the three nutrients increased by 0.6%. Among China and India, the two major fertilizer-producing countries of Asia, China recorded a decline in the production of all the nutrients in 1985/86. Against 12.42 million mt of N, 2.42 million mt P_2O_5, and 32,000 mt of K_2O produced in 1984/85, the production in 1985/86 totaled 11.15 million mt of N, 1.83 million mt of P_2O_5, and 24,000 mt of K_2O. Thus the annual growth rate of N, P_2O_5, and K_2O registered a decline of 6.2%, 24.4%, and 25.0%, respectively. India, however, recorded a positive growth in 1985/86 fertilizer production. N and P_2O_5 production in 1985/86 increased to 4.32 million mt and 1.46 million mt from 3.92 and 1.34 million mt, respectively, in 1984/85 registering an annual growth rate for N of 10.2% and P_2O_5 of 8.9%. India does not produce potash fertilizers (Figure 2).

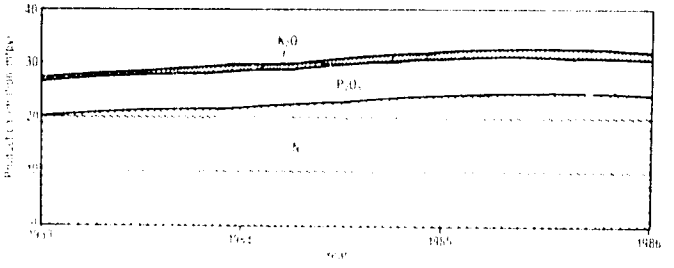


Figure 2. **Asian Fertilizer Production.**

There has been a major shift in the nitrogen fertilizer industry during the 1980s. Prior to that time about 50% of the total nitrogen requirement was produced in the developed countries, but from 1980 onwards almost 70% of the requirement was being produced in centrally-planned and developing market economy countries. The average plant capacity also increased from 700 to 1,500 mt of ammonia per day.

Nitrogen Fertilizer

The nitrogen fertilizer requirements are estimated at 71 million mtpy for 1986/87 and 82 million mtpy for 1991/92. A global surplus situation in nitrogen supply is likely to persist until the end of the present decade. In 1990 the nitrogen supply and demand balance is estimated to be 0.08 million mt. A small deficit is anticipated at the beginning of the next decade, and by 1995/96 an extra 10 million mt of nitrogen would be needed as compared with that required in 1990/91. This would result in a new growth of the nitrogen industry in the future. Table 1 shows the nitrogen fertilizer supply, demand, and balance in the Asian region for 1987 through 1991.

Table 1. **Nitrogen Fertilizer Supply, Demand, and Balance in the Asian Region**

	1987	1988	1989	1990	1991
	(million mt)				
Supply	22.42	23.67	24.32	24.64	25.08
Demand	27.01	28.12	29.12	30.16	31.20
Balance	-4.59	-4.45	-4.80	-5.52	-6.12
World total balance	2.43	2.40	1.40	0.08	-0.97

The Phosphate Industry

At present this sector of the fertilizer industry is faced with an over-capacity situation, owing to the stagnation in demand in the early 1980s. At the same time there was a capacity increase in many countries as a result of an anticipated 4% annual growth in consumption. Since demand did not increase to the same level as the capacity, the operating rate was greatly reduced.

After 3 years of stagnation, there was a marked increase in the world phosphate demand in 1984/85 and this pace was maintained in 1985/86. It is hoped that demand in the coming 3 years will equal 90% of the production capacity, considered to be optimum provided no new capacity comes on stream. It is anticipated that the surplus phosphate supply situation at the global level, estimated at about 2.5 million mt in 1986/87, will increase further to 3.7 million mt in 1988/89, after which it will decline to about 2.5 million mt in 1991/92 (Table 2).

Table 2. **Phosphate Fertilizer Supply, Demand, and Balance in the Asian Region**

	1987	1988	1989	1990	1991
	(million mt)				
Supply	4.40	4.62	4.82	5.00	5.25
Demand	7.98	8.36	8.75	9.15	9.55
Balance	-3.58	-3.74	-3.93	-4.15	-4.30
World total balance	2.53	3.74	3.57	3.13	2.55

The Potash Industry

Worldwide, the supply and demand balance for potash is likely to show a surplus of some 3.2 million mt of K_2O in 1986/87. It is anticipated that this surplus will increase to 3.7 million mt in 1989/90 and then decline to about 3.4 million mt by 1991 (Table 3).

Table 3. **Potash Fertilizer Supply, Demand, and Balance in the Asian Region**

	1987	1988	1989	1990	1991
	(million mt)				
Supply	0.03	0.05	0.07	0.07	0.07
Demand	2.92	3.18	3.36	3.51	3.64
Balance	-2.89	-3.13	-3.29	-3.44	-3.57
World total balance	3.19	3.11	3.74	3.72	3.38

Fertilizer Market Study in Developing Countries in Asia and the Pacific With Particular Reference to Multinutrient (NP and NPK) Fertilizers

After 3 years of stagnating growth rates from 1982/83 through 1984/85, the fertilizer use in developing countries of Asia and the Pacific actually declined in 1985/86 for the first time since 1974/75. The reduction in volume in 1985/86 amounted to 2.2 million mt (minus 6.0% compared with the apparent demand in 1984/85) to reach a total volume of 34.2 million mt of nutrients.

The demand in 1985/86 consisted of 24.9 million mt of nitrogen, 6.9 million mt of phosphates, and 2.4 million mt of potassium.

The influence of developments in the fertilizer sector within the People's Republic of China has a significant effect on the trends indicated for the region. This was underlined by a decline in fertilizer use in China by 2.9 million mt in 1985/86.

In general, urea is the preferred product in Asia and the Pacific region. In Bangladesh, India, and Indonesia, urea alone accounts for more than 50% of the fertilizer consumption. Ammonium sulfate is relatively important in Thailand and Fiji. Both in Iran and Pakistan, DAP is the most popular fertilizer product, whereas in the Republic of Korea multinutrient (NP and NPK) fertilizers occupy the largest market share with 67% in 1985/86. India is a major DAP user, while Indonesia and Bangladesh prefer TSP as a source of phosphate (Tables 4 and 5). Straight fertilizers are predominantly used in Bangladesh, Burma, Indonesia, Iran, Fiji, Vietnam, and to a lesser extent also in Sri Lanka.

Table 4. **Fertilizer Consumption in Asia, 1985/86**

	Bangladesh	India	Indonesia	Iran	Nepal
	('000 mt)				
Urea	795	10,015	2,607	552	45
AS	-	506	475	18	2
DAP	-	2,178	-	927	-
TSP	297	3	1,048	-	1
MOP	60	1,412	290	-	1
NP/NPK	-	2,629	-	-	54
Others	4	2,598	-	19	-
Total	1,156	19,341	4,420	1,516	103

Source: FADINAP Database.

Table 5. **Fertilizer Consumption in Asia, 1985/86**

	Pakistan	Philippines	Korea	Sri Lanka	Thailand
	('000 mt)				
Urea	173	413	468	184	210
AS	93	140	24	76	257
DAP	495	9	-	-	-
TSP	15	1	-	49	-
MOP	-	39	53	86	30
NP/NPK	426	229	1,126	24	495
Others	214	14	67	2	9
Total	1,416	845	1,738	421	1,001

Source: FADINAP Database.

Single superphosphate (SSP) is still used in large quantities in India, although it is facing more and more strong competition from DAP. As a source of phosphate, DAP has overtaken SSP. DAP use increased rapidly after 1980/81 from around 800,000 mtpy up to 2.7 million mtpy in 1986/87, according to latest FAI information.

With regard to the multinutrient (NP and NPK) fertilizers, these are popular in India, the Republic of Korea, Thailand, Pakistan, the Philippines, and Nepal.

Table 6 shows the consumption trends of multinutrient (NP and NPK) fertilizers in those selected countries in Asia over the last 5 years from 1982/83 through 1986/87.

Table 6. **Consumption of (NP/NPK) Fertilizers in Asia, 1982-87**

	1982/83	1983/84	1984/85	1985/86	1986/87
	('000 mt)				
India	-	2,314	4,673	2,629	2,848
Nepal	36	33	50	54	45
Pakistan	428	403	379	426	400
Philippines	305	247	236	229	315
Korea	780	1,046	1,118	1,160	1,160
Sri Lanka	33	25	28	24	29
Thailand	-	-	616	584	524

Source: FADINAP Database.

Table 7 shows the consumption of multinutrient fertilizer in Asia as compared with the total fertilizer consumption in 1985/86. In the Republic of Korea, Thailand, and

Nepal, more than 50% of all fertilizers consumed are multinutrient (NP and NPK) fertilizers. In the case of Pakistan and the Philippines the share of multinutrient fertilizer as compared with the total fertilizer consumption amounts to 30% and 27%, respectively.

Table 7. **Consumption of (NP/NPK) Fertilizers in Asia as Compared With Total, 1985/86**

	NP/NPK	Total	NP/NPK
	('000 mt)		(%)
India	2,629	19,340	14
Nepal	54	103	53
Pakistan	426	1,416	30
Philippines	229	847	27
Korea	1,160	1,738	67
Sri Lanka	24	468	5
Thailand	584	1,090	54

Source: FADINAP Database.

Imports by Selected Countries

To supply the required volume of fertilizers in 1985/86, the developing countries of Asia and the Pacific contributed 25.5 million mt of nutrients in local production. In addition, 10.8 million mt of fertilizer nutrients was imported of which 17.8% originated from intraregional sources. Half of the imports consisted of nitrogen, whereas phosphate accounted for 27% and potash 23%. Estimates indicate that the imports were valued at US $3.4 billion (c.i.f.) and represent over 20 million mt of products.

Tables 8, 9, and 10 show the magnitude of the fertilizer imports in the region.

Table 8. **Fertilizer Imports in Asia, 1985/86**

	Bangladesh	China	India	Indonesia	Iran
	('000 mt)				
Urea	196	3,586	2,828	-	508
AS	-	-	-	-	9
DAP	-	1,220	1,750	-	927
TSP	346	-	-	-	-
MOP	89	680	1,490	300	-
NP/NPK	-	930	-	-	-
Total	631	6,416	6,068	300	1,444

Source: FADINAP Database.

Table 9. **Fertilizer Imports in Asia, 1985/86**

	Korea	Malaysia	Nepal	Pakistan
	('000 mt)			
Urea	-	270	62	-
AS	-	170	5	-
DAP	-	20	-	336
TSP	-	10	-	-
MOP	406	505	-	57
NP/NPK	-	115	63	58
Total	406	1,090	130	451

Source: FADINAP Database.

Table 10. **Fertilizer Imports in Asia, 1985/86**

	Philippines	Sri Lanka	Thailand	Vietnam
	('000 mt)			
Urea	684	182	210	504
AS	175	111	429	151
DAP	-	-	21	5
TSP	-	38	-	-
MOP	71	111	29	55
NP/NPK	59	21	480	72
Total	989	463	1,169	787

Source: FADINAP Database.

Most of the countries in the region prefer to import urea, DAP, and MOP. The latter is not available in the region. A large part of the urea and to a much lesser extent DAP can be imported from other countries in the region.

Ammonium sulfate is imported by a few countries, namely Fiji, Malaysia, Thailand, the Philippines, and Sri Lanka. Substantial volumes of TSP are procured as phosphate material by Bangladesh. Burma and Sri Lanka are also importers of TSP. Pakistan imports small tonnages of SOP. China imports sizable volumes of compound fertilizers.

China and India imported, respectively, 3.4 and 3.3 million mt of nutrients in 1985/86. Together they represented 62% of the region's fertilizer imports. Compared with a year ago their purchases were greatly reduced.

Other major importers were the Islamic Republic of Iran (852,100 mt) and Malaysia (633,800 mt). More than

half of Malaysia's imports consisted of potash, which is in high demand for use on the tree and plantation crops. With the exception of the large importers such as China and India, all the other small-to-medium large importers imported at least one-third of their requirements from intraregional sources.

With specific reference to imports of multinutrient fertilizers, an overview of the situation by selected countries is given below.

Malaysia - Imports of multinutrient (NP and NPK) fertilizers in 1985/86 amounted to 115,000 mt: 60,000 mt of 16-20-0, 35,000 mt of 12-12-17, and 20,000 mt of 15-15-6.

Nepal - Imports of NP multinutrient fertilizers in 1985/86 amounted to 63,000 mt, which was exclusively grade 20-20-0.

Pakistan - Imports of NPK multinutrient fertilizers in 1985/86 amounted to 58,000 mt: 30,000 mt of 13-13-21 and 28,000 mt of 10-20-20.

The Philippines - Imports of multinutrient (NP and NPK) fertilizer in 1985/86 amounted to 59,000 mt, of which 30,000 mt was 14-14-14 and 29,000 mt was 16-20-0.

Sri Lanka - Imports of multinutrient (NPK) fertilizers in 1985/86 amounted to 21,000 mt of 15-15-15 only.

Thailand - Imports of multinutrient (NP and NPK) fertilizers in 1985/86 amounted to 480,000 mt, which included 231,000 mt of 16-20-0, 108,000 mt of 15-15-15, 46,000 mt of 20-20-0, 30,000 mt of 13-13-21, and 65,000 mt of 16-16-8.

Vietnam - Imports of multinutrient (NP and NPK) fertilizers in 1985/86 amounted to 72,000 mt; 42,000 mt was 16-16-8 and 30,000 mt was a binary (NP) product of grade 20-20-0.

Exports by Selected Countries

The developing countries of Asia and the Pacific have not fully emerged as large-scale exporters of chemical fertilizers. In 1985/86 their share in the world trade amounted to 3.3%. It should, however, be mentioned that the regional export has been expanding at annual compounded growth rate of 31% since 1981/82.

As shown in Table 11, the major exporters are Indonesia, the Republic of Korea, and the Philippines. Smaller tonnages were exported in 1985/86 by Malaysia (122,000 mt), Burma (91,000 mt), and Bangladesh (5,000 mt). Bangladesh entered the export market fully in 1987 and 1988 with a possible export volume of up to 500,000 mt scheduled for 1988/89. Malaysia is well established as a main granular urea exporter while the Philippines is concentrating its exports on DAP and NP and NPK grades such as 16-20-0 and 15-15-15. The quantities exported by the Philippines were 12,000 and 70,000 mt, respectively.

Table 11. **Export of Fertilizers in Asia, 1985/86**

	Urea	DAP	NP/NPK	AS	Total
	('000 mt)				
Indonesia	735	-	-	-	735
Philippines	-	506	82	-	588
Korea	65	433	622	108	1,228
Malaysia	122	-	-	-	122
Japan	115	26	76	565	782
Burma	91	-	-	-	91
Pakistan	371	-	-	-	371
Bangladesh	5	-	-	-	5

Source: FADINAP Database.

The Republic of Korea - Korea had the largest export of multinutrient (NP and NPK) fertilizers in Asia in 1985/86 amounting to a total of 622,000 mt of different grades which included 314,000 mt of 16-20-0, 83,000 mt of 15-15-15, and 225,000 mt of other grades.

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The Role of Agglomeration in the Fertilizer Industry

James J. Schultz, Fertilizer Production Specialist, and
Jorge R. Polo, Engineering Coordinator, International Fertilizer Development Center

Abstract

Worldwide production of fertilizer amounted to about 400 million tonnes in 1986 (including about 40 million tonnes in the United States). Although a significant amount of this fertilizer was produced in nongranular and fluid forms, much (at least 200-250 million tonnes) was produced in some form of granule.

The term "granular," derived from the Latin "granus," suggests a particle size comparable to cereal grains. Thus, for the purpose of this paper, granular fertilizers will refer to solid fertilizers produced by a variety of process mechanisms including agglomeration, accretion, prilling, or a combination of these. The particle size of granular fertilizers in the Americas is usually in the range of about 1-4 mm, whereas a size range of about 2-5 mm is more common in much of Europe and many other locations.

Agglomeration is the principal mechanism used to produce multinutrient granular fertilizers - those fertilizers that usually contain all three of the primary nutrients (nitrogen, phosphorus, and potassium) and, if needed, a number of secondary and micronutrients. In most fertilizer agglomeration processes other mechanisms are also involved; therefore, most processes are described in terms of the principal mechanism, recognizing that supporting or competing influences are usually present.

This paper describes the technology of agglomeration as it pertains to the fertilizer industry and includes a discussion of the most important granulation technologies. The comparative production economics of various fertilizer agglomeration schemes and the expected future trends in the role of fertilizer agglomeration are also described.

Introduction

Granulation of fertilizers is one of the most important applications of agglomeration in the agriculture industry. Annual world production of granular fertilizers probably amounts to at least 200-250 million tonnes (1). In this context the term "granulation" refers to all methods for producing solid fertilizers of the desired size range and with the desired physical properties whether starting with solids, solutions, melts, chemical reactants, or combinations of these forms.

There is no generally agreed-upon definition of the particle size of "granular" fertilizer. However, the U.S. Agency for International Development has published specifications for fertilizers that may be exported under its programs; if claimed to be granular, they must be at least 90% within the size range of 6-16 mesh (3.3-1.0 mm), 100% minus 4 mesh (4.7 mm), 98% plus 28 mesh (0.6 mm), and "free flowing" (2). In practice most products are more closely sized, at least when initially produced and loaded for shipment from the factory. In many countries, a somewhat larger particle size is preferred, about 2-5 mm. For special purposes, such as aerial application, still larger granules are preferred.

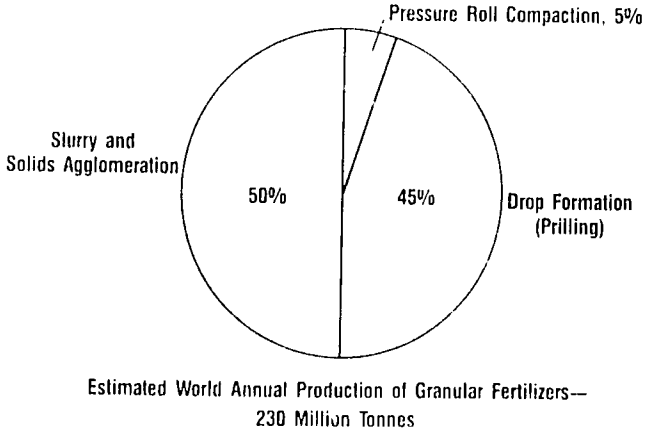


Figure 1. **Principal Methods Used to Produce Granular Fertilizers.**

Sherrington divides granulation processes and technology into four subdivisions - (1) compaction (pressure), (2) drop formation (prilling), (3) agglomeration, and (4) heat bonding (sintering/nodulization) (3). Except for heat bonding, all techniques are used quite widely to produce granular fertilizers (Figure 1). Drop formation (prilling) is among the most widely used granulation processes in the fertilizer industry. About 90% of the world's urea (about 40 million annual tonnes of product) is produced by prilling. Likewise, most ammonium

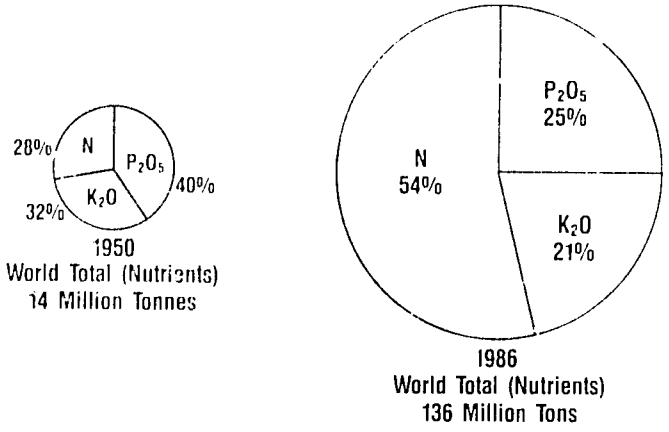
nitrate/calcium ammonium nitrate products, the other major source of nitrogen fertilizer (about 50 million annual tonnes of product), are produced by prilling. About the same amount of granular fertilizer (approximately 80-100 million tonnes) is produced annually by a number of agglomeration processes that will be discussed.

A Look at the Fertilizer Industry

To appreciate the application of agglomeration in the fertilizer industry, a brief look at the industry may be helpful. The fertilizer industry is extremely dynamic, constantly responding to changes in demand, product types, technical innovations, government policy initiatives, and the farmer's reaction to adverse economic, weather, and market conditions.

Production and Consumption

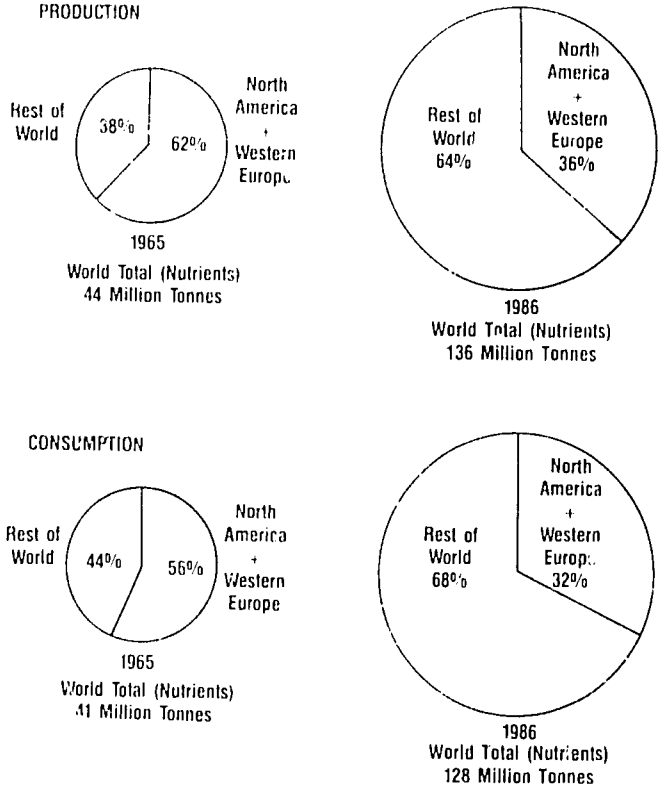
Worldwide production of chemical fertilizers (commonly called commercial fertilizers) has grown from about 14 million tonnes of the primary nutrients, identified as N (nitrogen), P_2O_5 (phosphate), and K_2O (potash), in 1950 to 136 million tonnes today (Figure 2) (4). About 54% of the current production is nitrogen, followed by phosphate at about 25% and potash at about 21%. When expressed in terms of fertilizer product, 136 million tonnes of nutrients amounts to about 400 million tonnes of product containing an average nutrient concentration of about 34%. Annual production and consumption usually remain fairly well balanced.



Source: FAO.

Figure 2. **World Fertilizer Production (Nitrogen, Phosphate, and Potash).**

In 1965, about 62% of all chemical fertilizers (expressed in terms of nutrients) were produced in North America (excluding Mexico) and Western Europe. Today North America and Western Europe account for only about 36% of the total world production. Fertilizer consumption has followed a similar pattern; North America and Western Europe have declined from about 56% of world consumption in 1965 to about 32% today (Figure 3).



Source: FAO.

Figure 3. **Fertilizer Production and Consumption Patterns.**

Who Owns the Industry?

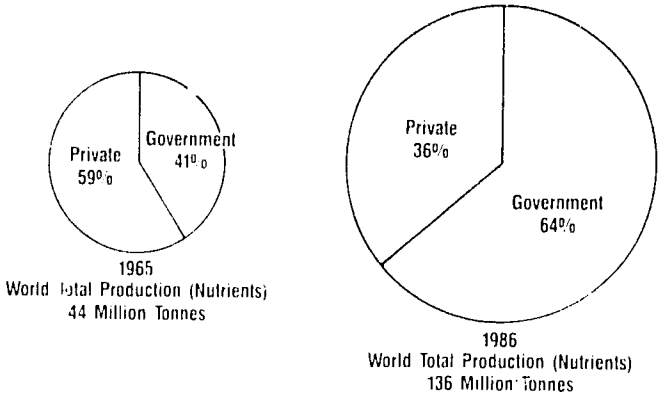
Today, as shown in Figure 4, more than 60% of the fertilizer industry is owned by governments (state-owned enterprises). Twenty-five years ago government ownership amounted to only about 40% of the total industry (5).

Sulfur, an important ingredient for processing phosphate rock into the soluble form required for most fertilizers, is also produced largely in government-owned facilities. Approximately 1 tonne of sulfur in the form of sulfuric acid is required to produce 1 tonne of water-soluble P_2O_5. Today, the greatest growth in sulfur production is occurring in the sour natural gas and oil industries; these facilities, too, are largely government owned.

Commercial Value of Fertilizer

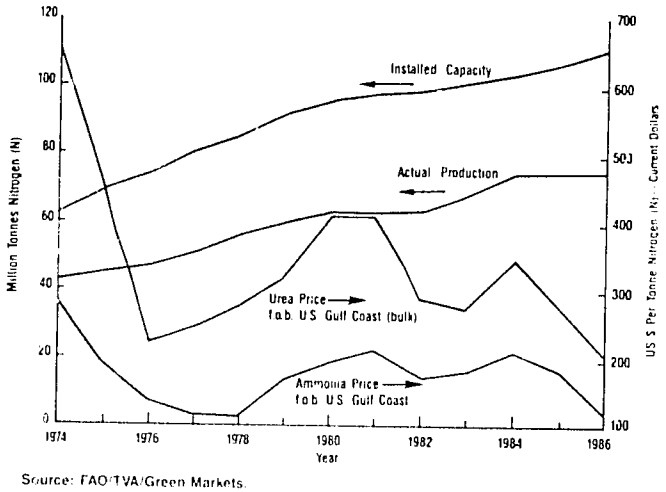
The international selling price of various fertilizers compared with other commodities is shown in Table 1 (6). The commercial value of fertilizer in the domestic and international marketplace varies quite widely with product type, location, government policy initiatives, and the over-

all world economics. For example, as shown in Figure 5, the nitrogen supply/demand balance remained quite stable during the period 1974-86, but the price of nitrogen, in the form of ammonia and urea, declined dramatically.



Source: International Fertilizer Industry Association (Industry Ownership Data). FAO (Production Data)

Figure 4. **Approximate Distribution of Fertilizer Industry Ownership (Nitrogen, Phosphate, and Potash).**



Source: FAO/TVA/Green Markets.

Figure 5. **Trends in World Nitrogen Supply and Price.**

The high prices for fertilizer (especially nitrogen products) brought about by the energy hysteria of the mid-1970s quickly declined with increased supplies of energy and abundant supplies of fertilizer contributed in part by a new generation of government-owned enterprises. For the most part, these government-owned enterprises have deeply penetrated the international marketplace with the assistance of a number of subsidy schemes. Today, therefore we see a generally depressed international price structure, not only for nitrogen, but for phosphate and potash fertilizers as well. The future pricing structure, however, is quite uncertain.

Table 1. **Approximate Prices of Selected Fertilizers Compared With Other Internationally Traded Commodities**

Commodity	US $/tonne[a]
Bauxite (Jamaica)	32
Bituminous coal (U.S. port)	56
Coffee (U.S. Gulf port)	3,200
Cotton (U.S. product, Liverpool port)	1,400
Fertilizer	
Diammonium phosphate, DAP (U.S. Gulf port)	169 (185)[b]
Potash, KCl (Vancouver port)	85 (65)[b]
Triple superphosphate, TSP (U.S. Gulf port)	119 (150)[b]
Urea (West Europe port)	142 (95)[b]
Iron ore (North Sea port)	23
Maize (U.S. Gulf port)	113
Natural rubber (New York spot)	930
Rice (Bangkok port)	217
Tea (London auction)	2,200
Wheat (U.S. Atlantic port)	128

a. Approximate mid-1985 price (current dollars) at indicated location.
b. Approximate mid-1987 price at U.S. Gulf port (current dollars).
Source: *Commodity Trade and Price Trends*, 1986 Edition, The World Bank.

Fertilizer Agglomeration Technology

Why Granular Fertilizers?

The original purpose of granulation of fertilizers was to prevent caking in bags during storage and shipment so that the product reached the farmer in suitable condition for use in field application equipment. Today, over 80% of the dry fertilizers are shipped in bulk, and therefore granulation is needed to ensure that the product is free flowing for ease in loading and unloading; that it does not cake severely during bulk shipment or storage; and that the individual granules are strong enough to withstand mechanical handling without significant breakage. There is also a growing need to ensure that the loading and unloading operations produce a minimum of dust, especially at ports and in warehouses and workplaces. As a result of this environmental requirement, powdered elemental sulfur, an essential fertilizer raw material, also is often granulated to decrease dustiness.

From the farmers' point of view, granular fertilizers also serve an important agronomic purpose. Easily handled and applied granular fertilizers decrease labor requirements and facilitate uniform placement on the field or crop. Moreover, the availability of a combination of various essential nutrients in homogeneous particles permits application in one operation. Although not proven, fertilizers containing all nutrients in homogeneous granules are perceived by some farmers to be agronomically more desirable than physical mixtures (bulk blends) of granular materials such as urea, diammonium phosphate (DAP), and potash.

A Brief History of Granulation

The beginning of fertilizer granulation technology is easily traced to about the mid-1920s. In 1926 a German firm (I.G. Farbenindustrie) introduced a line of compound NPK fertilizers called "Nitrophoska," a trade name still used today by BASF. These products were reported to be produced by a "graining process," in a pug mill. Beginning in 1929 the Oberphos Company of Baltimore (United States) produced a form of semigranular superphosphate in a batch-type process by using a rotary drum-type vessel that served as a reactor (for digestion of phosphate rock with sulfuric acid) and a granulator. In about 1935 the Davison Chemical Company of Baltimore began producing granular superphosphate and some NPK products in a continuous rotary drum process. At about the same time (1930s), Imperial Chemical Industries of Great Britain began producing a number of granular compound fertilizers based on the continuous agglomeration of solid ammonium sulfate and potash with an ammonium phosphate slurry.

Development of fertilizer granulation technology moved quite slowly until the end of World War II. The post-war civilian population swelled and, along with the reconstruction effort, the need for food and fiber production grew rapidly, increasing the need for fertilizers with reasonably good chemical and physical qualities. These events resulted in rapid growth in the fertilizer industry, especially in North America and Western Europe. The number of NP and NPK fertilizer granulation plants in the United States reached a peak of over 200 in the early 1960s and thereafter slowly declined to about 40 today. Of these remaining plants, only about 25 produce granular fertilizers containing all three of the primary nutrients – N, P_2O_5, and K_2O. The current plants are quite large compared with their 1960 counterparts. Today, however, primarily for economic reasons, homogeneous granular compound fertilizers in the United States have been largely replaced by granular straight materials (urea, ammonium nitrate, diammonium phosphate, and potash) and fluid mixtures. The straight materials are often bulk blended prior to application to obtain the desired nutrient mix.

During this post-war boom, the Tennessee Valley Authority, working mostly with the United States industry, provided a number of innovations that substantially advanced the technology of granulation and improved the chemical and physical quality of the products produced worldwide (7).

Types of Agglomeration Used in the Fertilizer Industry

Solids Agglomeration – In the fertilizer industry, the term "agglomeration", and more specifically "solids agglomeration," usually refers to a specific mechanism for bringing about particle size enlargement (granule formation). It refers to those granulation methods in which a relatively large amount of solid raw materials, for example, superphosphate, ammonium sulfate, and potassium chloride, are cemented together into a granule (usually 1-5 mm in diameter) with the aid of a binding agent and mechanical forces. In practice, the binding agent is a solution of partially dissolved fertilizer salts (raw materials); the most common are ammonium nitrate/sulfate/phosphate, urea, and potassium chloride. The ratio of salt solution (liquid phase) to "dry" solids is controlled by the addition of water and/or heat to the process and by regulating the amount of dry solids fed to the agglomerating device (granulator). This type of solids agglomeration of compound fertilizers, including single-nutrient products such as superphosphate, occurs with a relatively low liquid phase – about 2%-5% of the total granulating mass when measured in terms of free water and about 5%-15% when measured in terms of the total dissolved salt solution. Thus, we see that solids agglomeration in the fertilizer industry usually refers to the cementing together of mostly solid raw materials to produce a relatively homogeneous granule containing the desired nutrients.

Melt or Slurry Agglomeration – Another common method for granulating fertilizer included in the category of agglomeration by Sherrington and some others is based on accretion or layering (3,7). In the fertilizer industry, the application of accretion-type granulation (agglomeration) processes, often referred to as "melt or slurry granulation" is quite different from the previously described solids agglomeration processes. Accretion-type granulation is used widely to produce granular urea, ammonium phosphate, some forms of triple superphosphate, and some compound NPK fertilizers. With the accretion-type processes, the raw materials are almost always fed to the granulator as a slurry, melt, or solution. Except for recycled solids, solid raw materials are rarely fed to the granulator.

One of the most common processes used in the United States for accretion-type granulation of urea is the Spherodizer® process (8). A Spherodizer® is a horizontal rotary drum unit in which molten urea is sprayed onto a

continuous curtain of falling solids (granules). A stream of air passes through the unit to facilitate cooling and solidification of the molten urea on the surface of the recycled solids. On the average, a particle of urea passes (recycles) through the unit about two times before it reaches the desired product size. This would be described as a recycle-to-product ratio of 2. Many of the newer urea plants are using fluidized beds to achieve the same result (9). About 6%-8% of the world's supply of urea is produced by using either the Spherodizer® or a fluidized-bed process. Variations of the Spherodizer® process are also used quite widely to produce granular ammonium nitrate and a number of NPK products.

Accretion (slurry agglomeration) is also the primary mechanism used to produce granular DAP (18-46-0). In a typical DAP granulation process, a partially reacted (ammoniated) ammonium phosphate slurry is sprayed onto a rolling bed of solids (recycle material) in a rotary drum-type granulator. The slurry is caused to solidify, layer upon layer, on the surface of the recycled solids by the addition of ammonia, which decreases the solubility of the slurry, and by evaporation of some of the free water. The remaining moisture is removed in a separate drying step. Worldwide, about 20 million tonnes of granular ammonium phosphate is produced annually by variations of this process.

In all accretion-type granulation processes, using either a melt or a slurry, some agglomeration of solids also occurs simultaneously with accretion. Granular fertilizers produced primarily by accretion have a very smooth and spherical appearance, whereas granules formed primarily by solids agglomeration are usually less spherical in shape and more rough in texture.

Pressure Roll Compaction/Granulation – Pressure roll compaction/granulation of solid fertilizer materials represents still another method often included in a discussion of fertilizer agglomeration. Pressure roll compaction/granulation is widely used to produce granular potash – about 10 million tonnes annually, or approximately 20% of the world's potash production. However, only limited use has been made of this method for granulating NPK fertilizers. Some NPK granulation plants based on pressure roll compaction are operating in France, Guatemala, Portugal, Switzerland, the United States, and West Germany. The United States plants are used primarily for producing specialty (horticultural) fertilizers, whereas the other plants produce a number of agricultural-type fertilizers. An evaluation by IFDC indicates that in some instances compaction/granulation may be a practical alternative to other methods of solids granulation (10). Compaction techniques are also useful for preparing large particles (supergranules weighing 1-3 g each) of fertilizers for precise placement in plant root/soil zones (for example, in flooded rice cropping) to optimize the agronomic efficiency of the fertilizer (11).

Characteristics of Fertilizer Produced by Solids Agglomeration

Although the smooth and spherical products prepared by accretion-type granulation processes are often preferred by most farmers, the family of products produced by solids agglomeration also serve an important purpose in the fertilizer industry. Solids agglomeration methods are most often used to produce compound fertilizers containing the three primary nutrients – N, P_2O_5, and K_2O – and sometimes a number of secondary and micronutrients. Today, such agglomerated compound fertilizers account for only about 5% of the fertilizers produced in the United States and about 10% on a world basis. Fertilizer granulation processes based primarily upon solids agglomeration are characterized as follows:

1. High flexiblity with regard to raw material inputs.
2. Maximum utilization of solid raw materials.
3. Relatively low dependence upon chemical reactions (process chemistry) and external energy for raw material preparation/processing.
4. Relatively simple process and modest investment requirements.
5. Relatively small annual capacity, typically 50,000-200,000 tonnes per year.
6. High dependence upon operator's skill.

A brief discussion of the importance of these characteristics follows.

Raw Materials – Fertilizer granulation processes based on solids agglomeration are especially useful because they can accommodate a wide range of raw materials (solids and liquids) that are quite variable in composition, particle size, texture, and related chemical/physical properties. Often, fertilizer granulation plants based on solids agglomeration are referred to as "garbage dumps." They have the unique characteristic of being able to convert low-grade, off-specification, or byproduct raw materials into premium fertilizers. Most successful NPK granulation plants based on solids agglomeration routinely use low-value byproducts for raw materials; some examples are (1) crystalline or caked ammonium sulfate, (2) water-damaged or off-specification ammonium phosphate, (3) potash fines, and (4) waste nitrogen liquors or dilute/spent acids. This flexibility in raw material use together with skilled procurement, management, and plant operating practices, usually makes solids agglomeration quite economic.

Moreover, because of this flexibility the plant can rapidly respond to changes in product demand, especially with respect to nutrient content and source. This feature

makes such plants especially appropriate in regions undergoing rapid development and change in agricultural practices—for example, many developing countries.

Process Chemistry/Energy/and Capacity—In most NPK granulation processes based on solids agglomeration more than 70% of the raw materials are fed as "dry" solids. The fluid feeds (usually ammonia, salt solutions, acids, and steam) required to achieve the appropriate level of liquid phase and heat to optimize agglomeration are small. As a result, facilities for storing and handling raw materials are conventional, and the low level of process reactions (chemistry) simplifies the plant equipment/technical requirements. The input of energy for raw material processing and pollution control is also minimized. The simplicity of process and the relatively low capital investment requirements make it possible to construct modest-size units designed to serve specific market regions without adversely affecting the overall production economics.

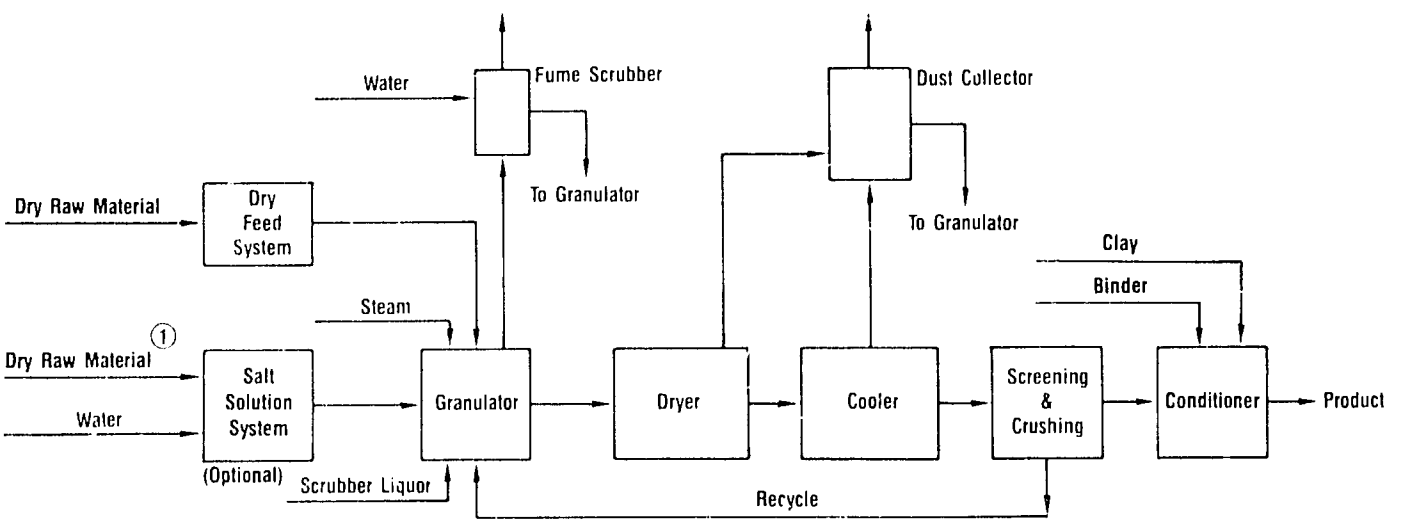
Process Simplicity and Operator Skill—Although a typical NPK granulation plant using solids agglomeration appears to be relatively simple compared with the more complex DAP or nitrophosphate-based NPK plants using slurry agglomeration (accretion) techniques, the design and operation of such units requires a unique element of skill. From the engineering/design point of view, the equipment systems must be generous in capacity and "forgiving." This is necessary to enable the plant to accept a wide range of raw materials and process conditions and thus fully benefit from the previously described advantages of such technology.

Current Solids Agglomeration Technology

A diagram of a typical fertilizer granulation process, using solids agglomeration as the principal particle growth mechanism, is shown in Figure 6. The process, operated on a continuous basis, is usually based on the use of a horizontal rotary drum-type granulator in which all raw materials are brought together for final reaction and initial agglomerate formation. In some cases, a mixer of some type (usually a double-shaft pug mill) may be used to premix the dry raw materials, recycled solids, and liquid phase materials before they are fed to the drum granulator. In other cases, only a pug mill is used and the drum granulator is eliminated. In all cases, the dry and fluid raw materials are carefully metered to the process to ensure that the correct grade specification (nutrient content) is achieved.

Optimum temperature and solids-to-liquid conditions are maintained in the granulator to obtain a relatively steady state of agglomeration and controlled particle growth. This is done by adjusting the flow of water, steam, and recycled solids to the granulator. These adjustments are the key to efficient operation. Because the operator's skill and intuition are needed to maintain optimum granulation conditions, it has been observed that fertilizer granulation, especially by solids agglomeration, is often more an art than a science.

The moist and plastic material continuously discharges from the granulator and enters a rotary dryer. In addition to drying, a considerable amount of consolidation of the agglomerates and final granule formation occur in this unit. The evaporation of water, of course, results in the strengthening of the bonds (salt bridges) between the individual particles of each granule. In practice, the fertilizer plant operator usually views the granulator and the dryer as a single unit operation since the process duty performed in the dryer, in most cases, is an extension of what is initiated in the granulator.



1 Typically Urea, Ammonium Sulfate, or Potash.

Figure 6. Typical NPK Granulation Process Based on Solids Agglomeration.

In most NPK plants it is preferred to partially cool the material discharged from the dryer to improve the performance of the sizing (screening and crushing) equipment. In many cases, if the material is not partially cooled, it may be quite plastic and tend to plug the screens and crushers. A significant amount of drying (up to about 30% of total in some cases) also occurs during the cooling process.

After screening, the material that is less than product size (fines) is returned to the granulator. The oversize material is crushed and usually rescreened before it is returned to the granulator. Rescreening is preferred because it yields some additional product and ensures that only fines are actually returned to the granulator. If more dry material is needed to maintain proper conditions in the granulator than can be supplied by the fine material fraction, then some product-size material is also returned to the granulator. Most solids agglomeration processes operate at a recycle-to-product ratio in the range of 1 or 2, whereas some melt and most slurry agglomeration processes usually require a higher ratio (often as much as 5 or more). The high ratio, of course, translates to larger process equipment and usually a higher overall energy cost per tonne of product.

The product-size fraction is usually further cooled in either a rotary drum-type cooler or in some type of fluidized bed or cascade-type unit. After final cooling, the product is often treated with a conditioning agent, usually kaolin clay, to improve its storage properties.

Recent Technical Innovations

The basic solids agglomeration-type granulation process described above has changed little since the 1950s. However, certain improvements in process know-how, energy optimization, materials of construction, and equipment systems have resulted in improved capacity utilization, lower production costs, and improved product quality. Some of the most notable innovations are:

1. Pipe reactor technology has been developed; in some cases this technology decreases the consumption of fuel required for drying because the heat of chemical reactions is more effectively utilized.

2. Fabric bag-type dust collectors are sometimes used in place of wet scrubbing systems to clean process gases. This decreases the overall energy requirements and problems associated with utilization/disposal of unwanted scrubber liquor.

3. Process air required for product cooling is sometimes reused for drying. This technique decreases the required capacity for the dust collection and process air cleaning systems. The consumption of fuel for drying is also decreased because of the recycled heat that is recovered from the cooling step.

4. Improvements in materials of construction and equipment design have greatly improved plant operation reliability, thereby improving capacity utilization and decreasing operating costs. Some of the most notable advances have been in the development of (a) corrosion/erosion-resistant metal alloys and nonmetal construction materials, (b) heat-and acid-resistant conveyor belting and dust collector fabric filter bags, (c) improved strength of bucket elevator chains, (d) durable pump packing and shaft seal systems, (e) reliable process instrumentation, especially the modular replacement/repair concept, and (f) industrial-quality equipment/instrumentation for monitoring the environment.

5. Process know-how and technical competence have also evolved at a relatively rapid pace in recent years largely because of increased economic, environmental, and product quality (competitive) pressures in the industry.

Economic Considerations

Granulation by solids agglomeration as described in this paper is based on the use of a relatively large proportion of solid raw materials and a minimum amount of chemical reaction. In many instances, this results in more favorable (lower) capital investment and production costs than can be achieved with fertilizer granulation processes involving a higher level of chemical reactions and technology characterized by many accretion-type (slurry-agglomeration) granulation methods. Compared with most slurry-type granulation units, the fixed capital investment requirements for solids agglomeration-type granulation units are lower because (1) storage facilities for solid raw materials are less costly than similar facilities for ammonia and acids, (2) the process equipment systems are less complex and therefore less costly, and (3) for a given production rate the plant is smaller and therefore less costly because the recycle-to-product ratio is smaller with the solids-based units.

Likewise, it usually costs less to produce a comparable granular fertilizer by solids agglomeration than by slurry agglomeration because (1) raw and intermediate materials are less costly, particularly if byproduct and off-specification materials are used, (2) energy input is usually lower, and (3) process simplicity results in lower overall costs for technical skills (labor), maintenance, and capital recovery.

Table 2. **Capital Investment Estimate for Two Methods of Fertilizer Granulation**[a]

	Granulation Method[b]	
	Solids Agglomeration	Slurry Agglomeration
	(US $ x 1 million)	
Granulation (agglomeration) unit, 700 tonne/day battery limits units	7.5	12.0
Bulk storage (solid raw materials and product)[c]	2.4	1.
Ammonia storage (3,000 tonnes)	-	1.2
Sulfuric acid storage (5,000 tonnes)	-	0.4
Phosphoric acid storage (5,000 tonnes)	-	0.6
Auxiliary and support facilities	1.5	2.5
Total installed cost	11.4	18.4
Project management and startup[d]	0.6	0.9
Interest during construction[e]	0.9	1.5
Total fixed capital investment	12.9	20.8
Working capital[f]	3.7	3.8
Total capital investment	16.6	24.6

a. Mid-1987 cost basis, U.S. Gulf Coast plant location.
b. Typical for NPK granular fertilizer such as 15-15-15.
c. Based on 34,000 tonnes for solids agglomeration and 24,000 tonnes for slurry agglomeration.
d. Equivalent to 5% of total installed cost.
e. Equivalent to 8% of total installed cost.
f. equivalent to 1 month inventory of raw materials and 1 month inventory of finished product.

A comparison of the estimated capital investment and production cost for a typical granular compound NPK fertilizer (15-15-15) made by two methods of granulation (solids agglomeration and slurry agglomeration) is shown in Tables 2 and 3. These estimates are based on a new (grass roots) factory at an assumed water port location. The annual capacity is 200,000 tonnes of NPK fertilizer. All raw materials are assumed to be delivered to the plant site by water transport in 2,000 tonne minimum lots.

These data show that the capital investment (Table 2) required for a solids agglomeration-type unit is about 67% of that needed for the larger and more complex slurry-type unit. The major difference between the two plants is the cost of the battery limits process unit. The slurry unit is significantly larger in size and therefore more costly. The larger size is due to the higher recycle-to-product ratio, and therefore material throughput rate, required for slurry-type processing. The need for relatively large and costly liquid storage facilities required for the slurry unit also increases the cost quite significantly (US $3.9 million compared with US $2.4 million).

The production cost estimate (Table 3) indicates that the cost of solids agglomeration is about 94% of that required for slurry agglomeration. The greatest savings in solids agglomeration is attributed to the fixed capital recovery charge (US $9.7/tonne for solids process compared with US $15.6/tonne for slurry process). The raw material cost component is about equal for the two processes described in this example. However, as previously indicated, the solids agglomeration process is more flexible with respect to using off-specification materials that can often be obtained at a cost substantially lower than indicated in this example.

Future of Fertilizer Granulation Based on Solids Agglomeration

Today, as previously indicated, the use of solids agglomeration to prepare granular compound NPK fertilizers is quite low. This is caused by a combination of factors that are primarily economic in nature.

Current fertilizer needs (on a worldwide basis) are met mostly through the application of straight materials such as urea, ammonium nitrate, superphosphate, ammonium phosphate, and potash. Except for superphosphate and potash, these granular products are granulated primarily by using prilling and slurry-agglomeration methods. In some cases, especially in Canada, Ireland, Japan, Korea, and the United States, these granular materials are bulk blended to produce a large number of NP and NPK grades. In the United States in particular, fluid fertilizers such as anhydrous ammonia, nitrogen solutions, and NPK suspensions also supply a major portion of the market.

Table 3. **Production Cost Estimate for Granular NPK (15-15-15) Fertilizer Produced by Two Methods of Granulation**[a]

	Granulation Method[b]	
	Solids Agglomeration	Slurry Agglomeration
	(US $/tonne 15-15-15)	
Raw Material Cost		
Prilled urea - 46-0-0 (US $100/tonne)	13.3	10.5
Standard ammonium sulfate - 21-0-0 (US $55/tonne)	15.8	-
Nongranular monoammonium phosphate - 10-50-0 (US $175/tonne)	53.2	-
Standard muriate of potash - 0-0-60 (US $70/tonne)	17.9	17.9
Ammonia - 82-0-0 (US $115/tonne)	-	14.6
Sulfuric acid - 96% H_2SO_4 (US $45/tonne)	-	11.7
Phosphoric acid - 52% P_2O_5 (US $145/tonne)	-	43.9
Conditioner (US $40/tonne)	0.6	0.6
Subtotal	100.8	99.2
Variable Conversion Cost		
Electricity (US $0.04/kWh)	1.0	2.0
Steam (US $10/tonne)	0.6	0.3
Water (US $0.50/tonne)	0.5	1.0
Fuel (US $8.0/million kcal)	1.0	0.6
Miscellaneous chemicals and supplies	0.3	0.5
Subtotal	3.4	4.4
Fixed Conversion Cost		
Operating labor	2.0	2.5
Overhead and general expenses	2.0	2.5
Maintenance (labor and materials)	2.3	3.7
Insurance and taxes	1.1	1.8
Interest on working capital	2.8	2.9
Fixed capital recovery	9.7	15.6
Subtotal	19.9	29.0
Total Production Cost	124.1	132.6

a. Refer to Table 2 for capital investment estimate.
b. Assumed annual production of 200,000 tonnes of NPK 15-15-15.

In the longer term, however, interest in solids agglomeration is expected to increase and lead to renewed growth. This expectation is based on several trends, including the following:

1. The need to decrease the amount of fertilizer used in order to decrease the cost of crop production and minimize nutrient losses to the environment and particularly to decrease contamination of surface and ground water.

2. The need to use fertilizers closely tailored to the requirements of the crop relative to nutrients and nutrient uptake/timing characteristics. Much of this can be accomplished by the preparation of prescription-type fertilizer compounds that can be carefully applied (placed), taking into consideration the plant root and soil moisture profile.

3. Continued improvements in fertilizer application equipment are underway to facilitate precision placement of fertilizer to achieve optimum plant uptake and agronomic response. Optimum operation of such machinery is expected to be heavily dependent upon the physical properties of the fertilizer products.

To meet the above objectives of increased agronomic efficiency and decreased environmental impact, it is expected that a new generation, or family, of homogeneous granular fertilizer products will be required. These fertilizers, in addition to being very uniform in particle size to facilitate precision application and containing the necessary nutrients, may also contain biological additives designed to regulate nutrient release patterns and plant growth. Because of the organic biological additives, it is quite likely that low-temperature, chemically neutral agglomeration techniques will be required for the

preparation of such fertilizers. Most solids agglomeration methods, including pressure roll compaction, appear to be appropriate for this purpose. This new family of products is also expected to be relatively high in value compared with the commodity fertilizers of today.

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Nitrophosphates Versus Ammonium Phosphates

Erik Aasum, Manager, Process Section, Licensing and Product Development Department, Norsk Hydro a.s.

Abstract

The growth of fertilizer use during the last 15 years has been remarkable all over the world but more so in Asia than elsewhere. This trend is expected to continue because of the increase in population and the decline in new arable lands that may be brought into cultivation. In countries like India which have limited supplies of raw materials and need a diversity of fertilizers for small farms, it is believed that high-quality, homogeneous complex fertilizers will have many advantages over bulk-blended products. Two different major routes appear to be feasible for producing the complex fertilizers:

1. Production of nitrophosphate-based NP/NPKs by the nitric acid route.

2. Production of ammonium phosphate-based NP/NPKs by the sulfuric/phosphoric acid route.

Advantages of the nitrophosphate process are: its complete independence of sulfur supply; its high energy efficiency; its freedom from byproduct deposition problems; and its capacity to meet today's strict environmental requirements.

Advantages of the ammonium phosphate route are: higher analysis product grades are possible; greater flexibility exists in locating the plant; and, if such is desirable, the product can be made with a lower nitrogen content than is possible with the nitrophosphate process.

Cost estimates for the two processes vary widely, depending upon the location, the supply and cost of raw materials, energy, infrastructure, and other site-specific factors. Estimates are given in this paper for two cases. A comparison based on producing equivalent amounts of N and P_2O_5 by the two routes clearly show that the ammonium phosphate route (when based on imported sulfur) is more expensive. The nitrophosphate process with an N:P_2O_5 ratio of 2:1 will avoid the need for processing the byproduct calcium ammonium nitrate and thereby reduces the cost of production compared with that of a 1:1 ratio.

Introduction

The annual growth rates in grain production and fertilizer use over the period 1973-83 have been remarkable all over the world. However, when comparing the growth rates in Asia with those of the rest of the world, it is striking to see the dominance of this first region.

In the future Asia must maintain rapid growth of fertilizer consumption because of the population growth rate, low potential for opening up new land for food production, and a food demand that is growing at a faster rate. These general considerations for Asia particularly apply to India. Considering the limited availability of raw materials in India, the need for diversification in the supply of fertilizer, the gaining importance of multinutrient fertilizer, and the small farm size, what form should this increase in fertilizer production take? Should it be as bulk-blend or homogeneous multinutrient (complex) fertilizers?

In our opinion the use of high-quality homogeneous complex fertilizers will have many significant advantages over a bulk-blend product.

The homogeneous quality product can be made by two different major routes:

1. Production of nitrophosphate-based NP/NPK by the nitric acid route.

2. Production of ammonium phosphate-based NP/NPK by the sulfuric/phosphoric acid route.

This paper compares the production cost and farm-gate cost of fertilizers made by these two routes.

A simplified but very interesting version of this last route is based on importing phosphoric acid instead of importing sulfur. There seems to be considerable interest in expanding India's P_2O_5 fertilizer production in this way.

In cost comparisons, assumptions have to be made and it must be appreciated that some of the cost factors

involved are of a highly dynamic nature. Thus the comparative results might well change over the lifetime of a project.

An important factor in production economics is the size of an operation. In most cases production costs are reduced with increasing scale. In this respect, the size of the complexes does not produce any major difference in investment cost for the two routes.

Since this is a general paper, it is essential that the economic results of the different routes be viewed as illustrations of relative significance and not as absolute values.

The absolute production cost will vary widely depending on raw material costs, financial charges, and site location. It is difficult to present the results of variations in all parameters in a simple form. A selection as to the major cost-influencing factors therefore has to be made.

The influence from varying these factors leads to a better understanding of the flexibility and constraints that determine the relative cost for the different routes.

Ammonium Phosphate-Based NP/NPK

Figure 1 shows a block diagram for the production of granular ammonium phosphate-based NP/NPK. The raw materials are phosphate rock, sulfur, and ammonia. This route is often referred to as the wet-process phosphoric acid route.

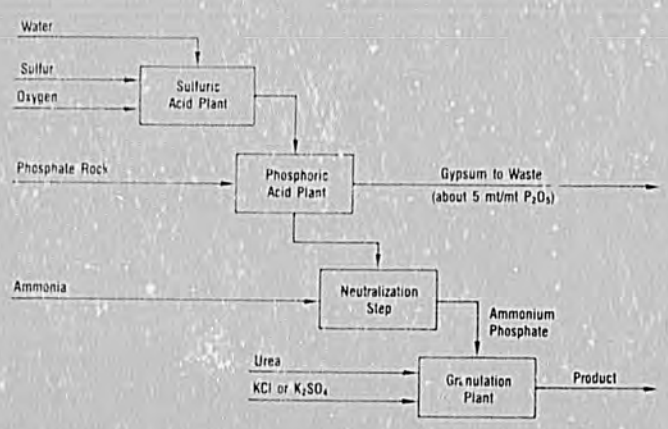

Figure 1. **Diagram for Ammonium Phosphate Production.**

Sulfuric acid is reacted with phosphate rock to produce phosphoric acid and gypsum. Subsequently, the phosphoric acid is neutralized with anhydrous ammonia to form monoammonium or diammonium phosphate (MAP or DAP). This product can either be granulated as such, that is as an NP product, or granulated together with potash to form an NPK material. Urea, or alternatively ammonium nitrate (AN), can also be introduced for the production of UAP(K) or ANP(K) grades. For this paper the production of UAP has been selected.

The advantages of the ammonium phosphate process over the nitrophosphate route are:

1. Higher product nutrient content.
2. Higher flexibility in plant location, since the nitrophosphate route should have an ammonia plant as an integral part of the facility.
3. If desirable, the ammonium phosphate product can have a lower nitrogen content than can the nitrophosphate product.

Nitrophosphate-Based NP/NPK

Figure 2 shows a block diagram for the production of nitrophosphate and ammonium nitrate or alternative byproducts.

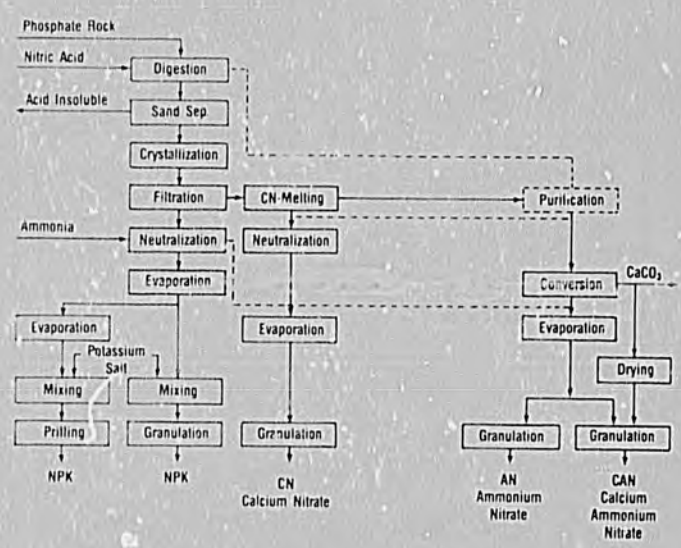

Figure 2. **Norsk Hydro Nitrophosphate Process With Alternative Byproducts.**

Nitric acid is reacted with phosphate rock to form phosphoric acid and soluble calcium nitrate. The latter is separated from the former and then converted to ammonium nitrate or to calcium ammonium nitrate by utilizing part of the byproduct calcium carbonate. The remaining solution, mother liquor, is ammoniated to form an NP-liquor. After removal of the water by evaporation, the resulting NP-melt is processed into solid NP granules or NPKs by adding potassium chloride or potassium sulfate. If necessary elemental sulfur, magnesium salts, and trace elements can be added and evenly distributed in the homogeneous granules.

A feature of the nitrophosphate process is that the overall N-to-P_2O_5 nutrient ratio in the product is about 2:1. This means that the product may either be one grade like 27-13.5-0 or two products like 22-22-0 plus ammonium nitrate or calcium ammonium nitrate. Both of these last alternatives will be dealt with in this paper.

The main reasons for adapting this technology instead of the ammonium phosphate route are:

1. The nitrophosphate process is completely independent of sulfur.

2. It has high energy efficiency which means low production costs.

3. The process is without byproduct disposal problems.

4. The process is well suited to meet today's strict environmental restrictions.

Nitrophosphate Versus Urea Ammonium Phosphate (UAP) Production Economy

General

The purpose of this discussion is to assess the economics of nitrophosphate-based production and compare this with the alternative cost of producing equivalent quantities of N and P_2O_5 as UAP through the addition of urea.

Such a comparison will be influenced by the conditions of production, plant capacities, and other factors, but a general and relative guideline is presented for a selected set of conditions.

The comparison will be based on a 1:1 ratio of N:P_2O_5 in a nitrophosphate product with pan-granulated calcium ammonium nitrate as a coproduct. Since a feature of the nitrophosphate process is an overall product in which the N:P_2O_5 ratio is 2:1, that ratio will also be assumed and then there is no calcium ammonium nitrate byproduct.

The alternative route produces the same amount of N and P_2O_5 as 1:1 UAP plus urea or only as UAP with an N:P_2O_5 ratio of 2:1.

A 300-mtpd ammonia plant has been assumed as basis for both alternatives. This amount of ammonia can come from a separate unit which, in spite of its size, could prove economic or it could be an "over-the-fence" supply.

Urea is foreseen as being produced in a new unit at the site. Thus, carbon dioxide would be required for this unit as well as the alternative nitrophosphate plant.

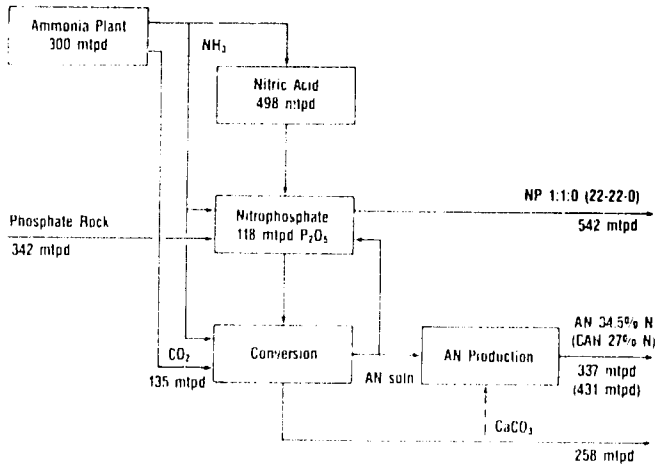

Figure 3. **Production of Nitrophosphate and Ammonium Nitrate or Calcium Ammonium Nitrate.**

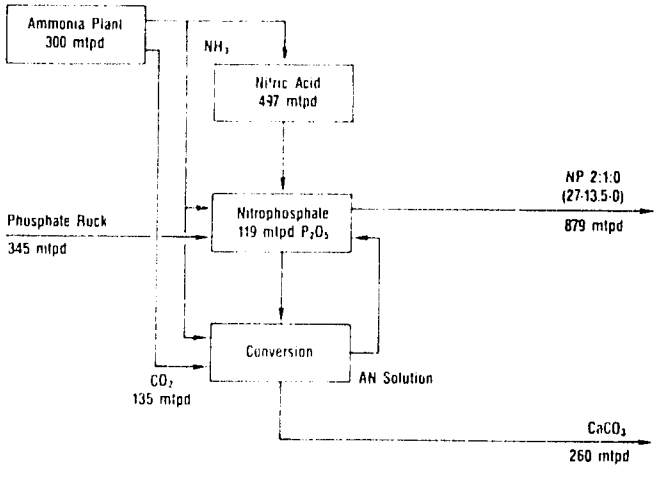

Figure 4. **Production of Nitrophosphate With a 2:1 Ratio of N:P_2O_5 With No Byproduct Ammonium Nitrate or Calcium Ammonium Nitrate.**

Case 1 – Nitrophosphate Process (See Figures 3 and 4)

The nitric acid unit is a single pressure plant of conventional design. A simple, very economical alternative would be to utilize an already existing nitric acid unit (and, of course, also an existing ammonium nitrate/calcium ammonium nitrate plant).

The nitrophosphate plant produces an NP product with a water solubility in excess of 80%, and this will ensure equivalence in agronomic feasibility and response for the phosphorous compared with phosphorous in products based on phosphoric acid.

Case 2 – Sulfur Route to NPK (See Figures 5, 6, and 7)

The ammonia supply situation is the same in this case as in case 1. A urea granulation plant will deliver a minor portion of its product to the UAP plant (see Figures 5 and 6). The main amount of urea, 266 mtpd, will be delivered

as such. Thus the total output of N will be the same as in case 1.

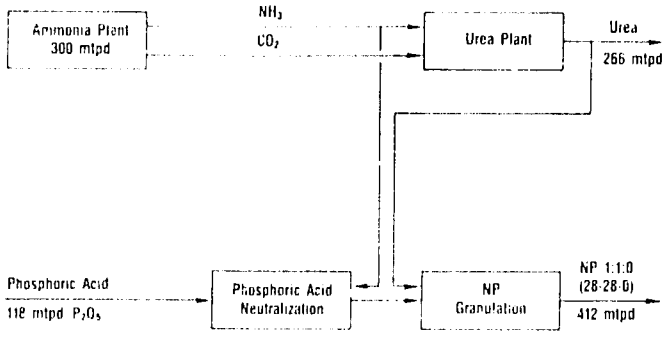

Figure 5. **Production of UAP and Urea (Based on Imported Phosphoric Acid.**

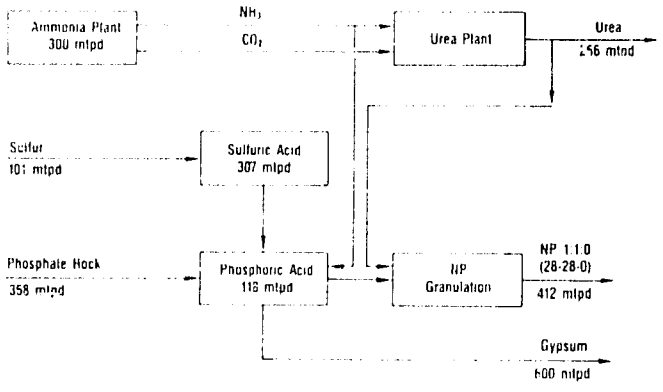

Figure 6. **Production of UAP-Urea (Based on Sulfur).**

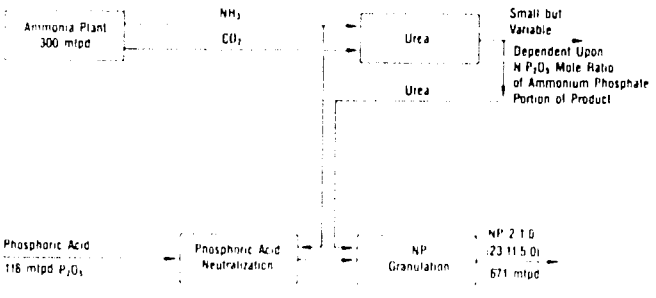

Figure 7. **Production of UAP With N:P_2O_5 – Ratio 2:1 Based on Imported Phosphoric Acid.**

An alternative with only one product, a UAP with an N:P_2O_5 ratio of 2:1, is also illustrated (Figure 7).

For the production of sulfuric acid, elemental sulfur has been chosen as feedstock. A standard double-absorption system will be used. The latest developments have been incorporated for recovering low-grade heat, including the so-called HRS (Heat Recovery System).

The phosphoric acid process chosen is a standard dihydrate version that typically produces 54% P_2O_5 acid. Of course, other processes in the form of hemi- or hemi-dihydrate can be seen as alternatives, depending upon technical/economic evaluations. Grinding of phosphate rock is included in the investment figure. Disposal of the calcium sulfate will entail a sizable amount of investment. However, this is not included in the total investment presented here.

Production of the homogeneous complex NP fertilizer is based on feeding solid urea to minimize the recycle ratio. A pressure neutralizer process is used for neutralization of phosphoric acid followed by the prilling of MAP which is subsequently fed to the rotary drum granulation process.

The other alternative would be to base the P_2O_5 product on imported phosphoric acid. Investment in storage facilities would be necessary for the acid, but the overall investment cost would be greatly reduced.

Table 1. **Investment Costs for Ammonium Phosphate and Nitrophosphate Plants**

	Ammonium Phosphate Plant Based on				
	Imported Phosphoric Acid		Imported Sulfur	Nitrophosphate	
	1:1:0	2:1:0	1:1:0	1:1:0	2:1:0
	(million US $)				
Ammonia	46.3	46.3	46.3	46.3	46.3
Sulfuric acid			16.5		
Phosphoric acid			6.8		
Nitric acid				10.0	10.0
Nitrophosphate				31.0	34.0
Calcium ammonium nitrate				7.7	
UAP-granulation	7.2	9.8	7.2		
Urea	26.7	26.7	26.7		
Process plants	80.2	82.8	103.3	95.0	90.3
Product storage	0.7	0.7	0.7	1.0	0.9
Raw material storage	5.4	5.4	5.9	4.6	4.6
Utilities	6.8	7.0	8.7	8.0	7.6
Interconnections	2.8	2.9	3.6	3.3	3.2
Project management, startup, and commissioning	7.8	8.0	10.0	9.2	8.8
Total capital investment	104.0	107.0	132.0	121.0	115.0

NOTE: Totals may vary due to rounding.

Cost Estimates

Comments on Cost Assumptions

For the battery limit process units, European conditions have been assumed for developing the cost (Table 1).

A construction time of 2 years has been assumed in the case using imported phosphoric acid. For the nitrophosphate case and for the sulfur-based route, a 3 year construction period has been assumed.

For utilities, interconnections, start-up, and commissioning, including project management, the actual investment figures would depend heavily on the conditions at each site and could favor any one of the routes over the others. Thus the figures given are the best available at this stage for comparing these auxiliary investment costs relative to the battery limit cost for a process plant.

In addition to the investment costs for a battery limit process plant, evaluations have also been made of the budget figures estimated for storage facilities to accommodate the raw materials, intermediate products, and final products (Table 2). The basic cost data used most certainly need some adjustments to be valid for Indian conditions.

Table 2. **Investment Cost for Storage Facilities**

				Costs, US $	
Type of Storage	Plant Capacity (mtpd)	Storage Days	Storage Capacity (mt)	Unit Investment (US $/mt)	Total Storage Investment (US $ x 1 million)
Ammonia	300	20	6,000	600	3.60
Sulfur	102	20	2,040	20	0.04
Sulfuric acid	310	3	930	300	0.28
Phosphoric acid	220	20	4,400	400	1.76
Nitric acid (as 60%)	830	3	2,490	300	0.75
Phosphate rock	360	20	7,200	30	0.22
MAP	215	1	215	50	0.01
NP (22-22-0)	542	20	10,840	50	0.54
NP (27-13.5-0)	885	20	17,700	50	0.89
NP (28-28-0)	420	20	8,400	50	0.42
NP (35-17.5-0)	675	20	13,500	50	0.68
CAN (22.7-0-0)	436	20	8,720	50	0.44
Urea	266	20	5,320	50	0.27

Sulfur stock has been assumed for 20 days and the same is assumed for phosphoric acid and phosphate rock.

Working Capital

The working capital is determined from the value of a specific inventory of raw materials and final products (Table 3). For final products the accounts receivable after 30 days of gross sale have been used. The cash portion refers to 30 days of fixed cost.

Table 3. **Working Capital**

		Ammonium Phosphate Plant Based on				
		Imported Sulfur	Imported Phosphoric Acid		Nitrophosphate	
	mt	1:1:0	1:1:0	2:1:0	1:1:0	2:1:0
		(million US $)				
1. Inventory						
Ammonia	6,000	2.100	2.100	2.100	2.100	2.100
Sulfur	2,040	0.298				
Sulfuric acid	930	0.048				
Phosphoric acid	4,400		1.364	1.364		
Nitric acid (60%)	2,490				0.259	0.259
Phosphate rock	7,200	0.468			0.447	0.447
MAP	215	0.069	0.069			
Urea	266					
2. Finished product (Value at variable cost)		0.427	0.427	0.386	0.510	0.461
3. Accounts receivable (30 days of gross sales)						
NP (1:1:0)		3.843	3.843		4.439	
NP (2:1:0)				7.461		6.638
Calcium ammonium nitrate					2.936	
Urea		3.120	3.120			
4. Cash (30 days of fixed cost)		0.190	0.148	0.151	0.175	0.168
Total working capital		10.563	11.070	11.462	10.867	10.073

Note: Totals may vary due to rounding.

Capital Expenses

Capital expenses are shown in Table 4. General annual interest rate is 17.5% for all loans. Loan repayment is an annuity over 15 years in line with the evaluated lifetime of the project. The project is assumed to be 100% owned by an Indian company.

Cost of Raw Materials, Utilities, and Other Items

Table 5 lists the assumed unit costs for raw materials, utilities, salaries, freight, and miscellaneous items. As far as possible, data from "Fertilizer Statistics 1985-1986" have been used. In addition, other information from India has been incorporated.

In order to calculate working capital, we have assumed certain retention prices for NP, urea, and CAN in India. These prices do not represent the actual price levels.

Phosphate Rock – The quality of phosphate varies significantly from source to source and these differences can have a major impact on production cost and investment requirements particularly in the sulfur-based route.

Table 4. **Capital Investment**

	Ammonium Phosphate Plant Based on				
	Imported Sulfur	Imported Phosphoric Acid		Nitrophosphate	
	1:1:0	1:1:0	2:1:0	1:1:0	2:1:0
	(million US $)				
Fixed capital investment	132	104	107	121	115
Working capital	10.6	11.1	11.5	10.9	10.1
Interest during construction, 17.5% annual rate	52.0[a]	28.8[b]	29.7[b]	47.5[a]	45.3[a]
Total Capital Requirement	195	143	148	180	171

a. 3-year construction period.
b. 2-year construction period.
NOTE: Totals may vary due to rounding.

Table 5. **Assumed Prices for Raw Materials, Utilities, Freight, and Products**

Natural gas consumption	29.00 million Btu/mt NH_3	
Natural gas price	4.50 US $/million Btu	
Catalyst for ammonia	2.50 US $/mt NH_3	
Phosphate rock, domestic, c.i.f.	65.00 US $/mt	832 Rs
Sulfur, f.o.b.	110.00 US $/mt	
Phosphoric acid, 54% P_2O_5, f.o.b.	265.00 US $/mt ($P_2O_5$)	
Carbon dioxide	2.20 US $/mt	
Ammonia (over the fence)	350.00 US $/mt	
Nitric acid (over the fence)	104.00 US $/mt	
MAP (over the fence)	320.00 US $/mt	
Sulfuric acid (over the fence)	52.00 US $/mt	
Steam	5.90 US $/mt	75 Rs
Electricity	56.25 US $/1,000 kWh	720 Rs
Cooling oil	391.00 US $/mt	5,000 Rs
Cooling water	0.022 US $/$m^3$	
Formaldehyde	500.00 US $/mt	
Platinum	20.00 US $/gram	
Salaries including social welfare	234.00 US $/work month	3,000 Rs
Freight:		
Sea freight:		
Sulfur (including jetty costs)	36.00 US $/mt	
Phosphoric acid (including jetty costs)	45.00 US $/mt ($P_2O_5$)	
Inland freight:		
Liquid sulfur (800 km), assumed	38.00 US $/mt	
Phosphoric acid (800 km), assumed	58.00 US $/mt	
Product transportation cost:		
Bagging	12.00 US $/mt	180 Rs
Freight, 500 km	11.00 US $/mt	141 Rs
Commercial expenses	2.30 US $/mt	30 Rs
Assumed product prices (used as basis for calculation of working capital)		
NP 22-22-0	202.80 US $/mt	2,600 Rs
NP 28-28-0	281.50 US $/mt	3,600 Rs
NP 27-13-0	257.80 US $/mt	3,300 Rs
NP 35-17-0	265.30 US $/mt	3,400 Rs
Urea	183.00 US $/mt	2,350 Rs
CAN	145.00 US $/mt	1,860 Rs

These variations can be due to the chemical composition in which case the sulfuric acid consumption is directly influenced or, to the physical condition such as hardness and porosity of the rock.

The nitrophosphate process has a much lower sensitivity to rock quality variations both in operating costs and in the investment level. The acceptability of rocks of significantly lower quality will be a very important parameter for utilizing new rock sources with a minimum of beneficiation.

A beneficiated Jhamarkotra rock from Udaipur has been chosen as a basis for these estimates. This phosphate has been successfully tested at Norsk Hydro's nitrophosphate pilot plant unit. According to the domestic rock analysis in "Fertilizer Statistics," several other domestic rocks also seem suitable for use in the nitrophosphate process. Examples are Maton and Jhambua (Table 6).

Imported rock can be the alternative, and Norsk Hydro has commercial experience with Florida, different grades of Jordan, Morocco, Senegal, and many others.

The c.i.f. prices of domestic rock and imported rock (from Jordan) are nearly identical.

The P_2O_5 efficiency of the nitrophosphate plant is 99% while 95% has been used for the sulfur-based route. If phosphoric acid is imported, 99% P_2O_5 efficiency is used.

Sulfur and Phosphoric Acid – The quality of sulfur is constant and it is fed as dry sulfur to the sulfuric acid plant. The price indicated in Green Markets in February 1988 was around US $110/mt f.o.b. and this has been used as an example.

The phosphoric acid has been assumed to be a 54% P_2O_5 acid of standard grade. The indicated price is US $265/mt P_2O_5 with another US $45/mt P_2O_5 added to obtain the price on the jetty in India.

The sulfur price and the phosphoric acid price will be specifically dealt with during the discussion where the influence of different price levels will be illustrated.

Energy – The ammonia plant is essential for optimum utilization of energy among the different units in such complexes.

For the nitrophosphate process, several recent developments have significantly reduced the energy consumption of the process to today's rather low level.

Integrating the ammonia plant, the nitric acid plant, and the nitrophosphate unit makes the complex virtually self-supplied in electric power (see Figure 8).

The sulfur-based scheme of UAP plus urea has an overall natural gas consumption similar to the nitrophos-

Table 6. **Analysis of Indian Phosphate Rocks**[a]

	Beneficiated RSMM-Rock (Norsk Hydro Analysis)	Jhamarkotra (RSMM, Udaipur)[b]	Maton (HZL, Udaipur)[b]	Jhambua (MPSMC)[b]
P_2O_5	35.6	35.5	31.7 - 35.5	31.55 - 37.61
CO_2	2.60	0.71 - 2.3	0.5 - 0.9	0.39 - 0.91
SiO_3	-	8.02 - 10.05	7.5 - 16.5	8.88 - 17.71
Insoluble in HNO_3	6.82			
CaO	51.1	47.83 - 48.84	43.0 - 49.0	40.68 - 48.54
SO_2	0.1	0.06	0.15 - 0.20	0.08 - 0.20
Fe_2O_3	0.95	0.8 - 1.3	1.7 - 2.5	0.57 - 1.42
Al_2O_3	1.02	0.48 - 0.64	0.8 - 1.5	0.47 - 1.63
MgO	0.74	0.50 - 0.76	0.16 - 0.40	Nil
F	3.24	3.29 - 4.06	1.6 - 3.8	1.93 - 3.28
Cl	0.008	0.008	0.1	0.005 - 0.01
Loss on ignition	2.7	0.87	1.5 - 1.8	-
Org + combined water	0.1	0.27	0.6 - 1.3	0.40 - 2.54

a. Dry basis, weight percent.
b. Analysis from Fertilizer Statistics.

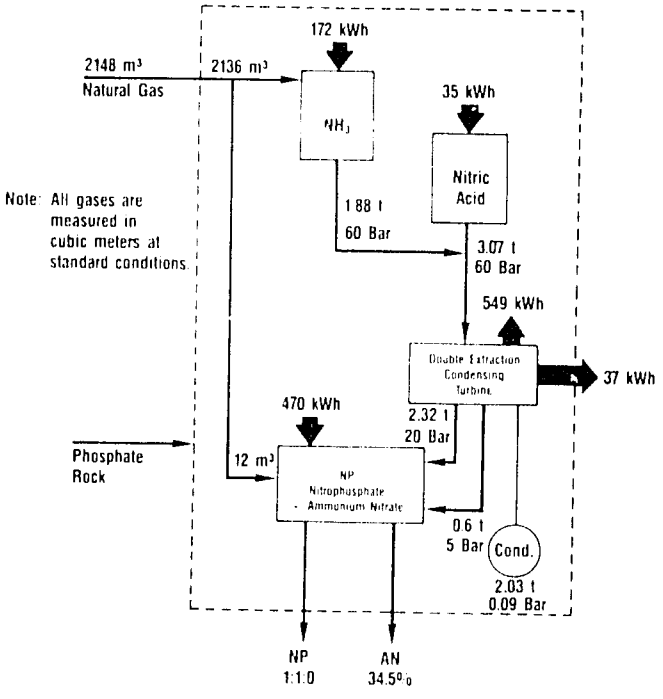

Figure 8. **Overall Energy Balance for Nitrophosphate Process. (Values are per mt P_2O_5).**

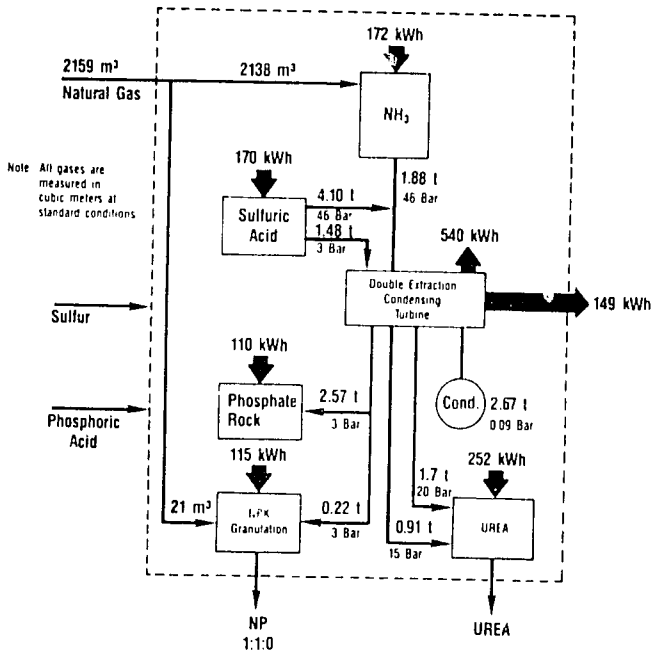

Figure 9. **Overall Energy Balance for Sulfur-Based Complex Producing UAP and Urea. (Values are per mt P_2O_5).**

phate case. The complex can, however, have a regular electric power export (Figure 9). For the phosphoric acid-based alternative, there is a need for regular electric power import (Figure 10).

The illustration of possible integration of the units with respect to available energy was done to emphasize this similarity between the different routes as to energy consumption. The impact of energy is thus small in the overall production cost.

Plant Location and Freight–The infrastructure could play an an important role in the selection of the process.

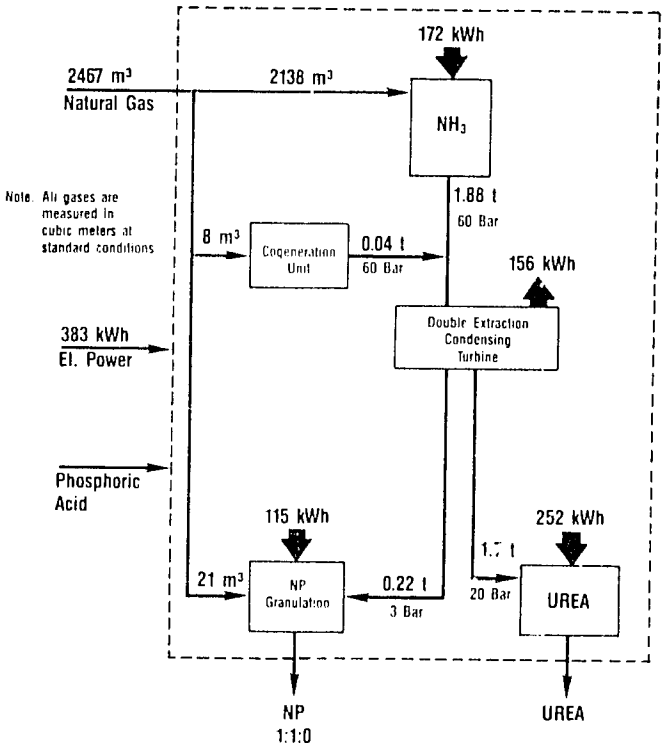

Figure 10. **Overall Energy Balance for Phosphoric Acid-Based Complex Producing UAP and Urea. (Values are per mt P_2O_5).**

A complete logistic analysis has to be undertaken to minimize the total freight cost for raw materials entering the plant and products leaving for each process and for each site, and these findings must be incorporated in the final cost analysis.

In this paper which deals with the comparison of farm-gate costs of the products made by the principal routes, specific microcriteria can be selected and the differences between the two cases can then be evaluated. Thus, in the following situations it has been assumed that sulfur, or alternatively phosphoric acid, needs to be imported. Phosphate rock, on the other hand, is domestically supplied and so is the hydrocarbon for ammonia production. For phosphate rock the price also includes an assumed cost for transportation.

For scenario A a plant location has been chosen where the hydrocarbon is available at the same location as the port used to import sulfur (or phosphoric acid). The available hydrocarbon could be natural gas or coal.

It has further been assumed that the fertilizer products would be completely consumed within a transport distance of 500 km from the production site. The products would be sent in the bagged form. A cost of US $12/mt has been assumed for bagging and US $11/mt for the 500-km train transport.

Scenario B assumes that all raw materials, except the hydrocarbon will have to be transported to the production site. This is only foreseen when phosphoric acid is used as the P_2O_5 source. We have little information on the freight rate for phosphoric acid in India, but a rate of US $40/mt has been assumed.

Tables 7 and 8 present the production costs and the farm-gate costs for these two scenarios. The cost figures are for NP plus calcium ammonium nitrate or a 2:1 grade in the nitrophosphate case and for UAP plus urea or a 2:1 UAP product in the cases of production based on phosphoric acid.

Table 7. **Operational and Production Cost, Scenario A** (Plant Site, Including Ammonia Production, at Port Location)

	Ammonium Phosphate Plant Based on				
	Imported Sulfur	Imported Phosphoric Acid		Nitrophosphate	
	1:1:0	1:1:0	2:1:0	1:1:0	2:1:0
	(million US $/year)				
NH_3	12.92	12.92	12.92	12.92	12.92
Catalyst for NH_3	0.25	0.25	0.25	0.25	0.25
Phosphate rock, c.i.f.	7.72	0.00	0.00	7.34	7.34
Phosphoric acid, f.o.b.	0.00	10.39	10.39	0.00	0.00
Steam net	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	0.24	0.24	0.24	0.10	0.10
Sulfur, f.o.b.	3.70	0.00	0.00	0.00	0.00
Catalyst for HNO_3	0.00	0.00	0.00	0.39	0.39
Formaldehyde	0.28	0.28	0.28	0.00	0.00
Coating oil	0.27	0.27	0.44	0.35	0.57
Electric power	(-)0.16	0.40	0.40	(-)0.04	(-)0.04
Cooling water	0.50	0.42	0.42	0.93	0.83
Raw material transport for sulfur and phosphoric acid	1.21	3.27	3.27	0.00	0.00
Bagging	2.72	2.72	2.67	3.87	3.50
Subtotal variable operating cost	29.65	31.15	31.28	26.11	25.86
Salaries including social welfare	0.39	0.30	0.30	0.37	0.37
Maintenance, 3% of equipment cost	1.04	0.80	0.83	0.95	0.90
Insurance and taxes, 0.50% of capital investment	0.66	0.52	0.53	0.61	0.58
Subtotal fixed production cost	2.09	1.62	1.67	1.93	1.85
Total operational cost	31.74	32.77	32.94	28.03	27.71
Transfer cost	31.74	32.77	32.94	28.03	27.71
Interest on working capital, 17.5%	1.85	1.94	2.01	1.91	1.77
Capital costs, 17.5%, 15 years	35.44	25.43	26.21	32.40	30.84
Plant gate cost (bagged product)	69.04	60.15	61.16	62.34	60.32
Commercial expenses	0.52	0.52	0.51	0.74	0.67
Freight	2.49	2.49	2.45	3.56	3.22
Total Farm-Gate Cost	72.05	63.16	64.13	66.64	64.21

NOTE: Totals may vary due to rounding.

Results of Economic Comparison

Table 7 illustrates the yearly plant-gate production cost for scenario A at a sulfur cost of US $110/mt f.o.b. or phosphoric acid at a price of US $265/mt f.o.b. A correspondingly evaluation for scenario B is given in Table 8. Again it must be emphasized that this analysis is basically an illustration of the relative costs incurred in production by the two routes.

Discussion

When examining the different factors of the total farm-gate cost, some have relatively small influence, for example, utilities, bagging, and fixed production costs.

The main contributing factors to the variations in total costs are the raw materials and capital costs including interest on working capital.

To improve the accuracy of the capital cost estimates would necessitate a thorough investigation of local conditions which is impractical at this time. Thus a sensitivity analysis of capital cost variations seems irrelevant.

The cost of producing nitrophosphate was compared with different phosphoric acid prices. The results shown in Figures 11 through 15 indicate the sensitivity in the UAP alternative.

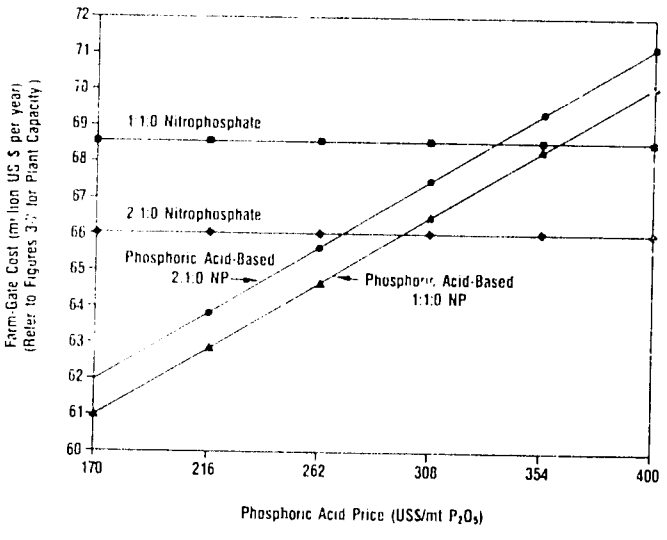

Figure 11. **Impact of Phosphoric Acid Price on Farm-Gate Cost (Scenario A).**

Because the two routes do give different amounts of product, a sensitivity analysis was done with variable freight distances and rates. Figures 15 and 16 show the result of this analysis for scenario A in absolute figures and in relative ratios. The final farm-gate cost is on more or less the same level for the nitrophosphate alternative and the phosphoric acid-based process.

Table 8. **Operational and Production Cost, Scenario B (Plant Site at Ammonia Production Facility Remote From Port Facility)**

	Ammonium Phosphate Plant Based on				
	Imported Sulfur	Imported Phosphoric Acid		Nitrophosphate	
	1:1:0	1:1:0	2:1:0	1:1:0	2:1:0
	(million US $/year)				
NH_3	12.92	12.92	12.92	12.92	12.92
Catalyst for NH_3	0.25	0.25	0.25	0.25	0.25
Phosphate rock, c.i.f.	7.72	0.00	0.00	7.34	7.34
Phosphoric acid, f.o.b.	0.00	10.29	10.29	0.00	0.00
Steam net	0.00	0.00	0.00	0.00	0.00
Carbon dioxide	0.24	0.24	0.24	0.10	0.10
Sulfur, f.o.b.	3.70	0.00	0.00	0.00	0.00
Catalyst for HNO_3	0.00	0.00	0.00	0.39	0.39
Formaldehyde	0.28	0.28	0.28	0.00	0.00
Coating oil	0.27	0.27	0.44	0.35	0.57
Electric power	(-)0.16	0.40	0.40	(-)0.04	(-)0.04
Cooling water	0.50	0.42	0.42	0.93	0.83
Raw material transport for sulfur and phosphoric acid	2.49	7.41	7.41	0.00	0.00
Bagging	2.72	2.72	2.67	3.87	3.50
Subtotal variable operating cost	30.93	35.20	35.32	26.11	25.86
Salaries including social welfare	0.39	0.30	0.30	0.37	0.37
Maintenance, 3% of equipment cost	1.04	0.80	0.83	0.95	0.90
Insurance and taxes, 0.50% of capital investment	0.66	0.52	0.53	0.61	0.58
Subtotal fixed production cost	2.09	1.62	1.67	1.93	1.85
Total operational cost	33.02	36.82	36.99	28.03	27.71
Transfer cost	33.02	36.82	36.99	28.03	27.71
Interest on working capital, 17.5%	1.85	1.94	2.02	1.91	1.77
Capital costs, 17.5%, 15 years	35.44	25.43	26.20	32.40	30.84
Plant gate cost (bagged product)	70.31	64.19	65.22	62.34	60.32
Commercial expenses	0.52	0.52	0.51	0.74	0.67
Freight	2.49	2.49	2.45	3.56	3.22
Total Farm-Gate Cost	73.33	67.21	68.18	66.64	64.21

NOTE: Totals may vary due to rounding.

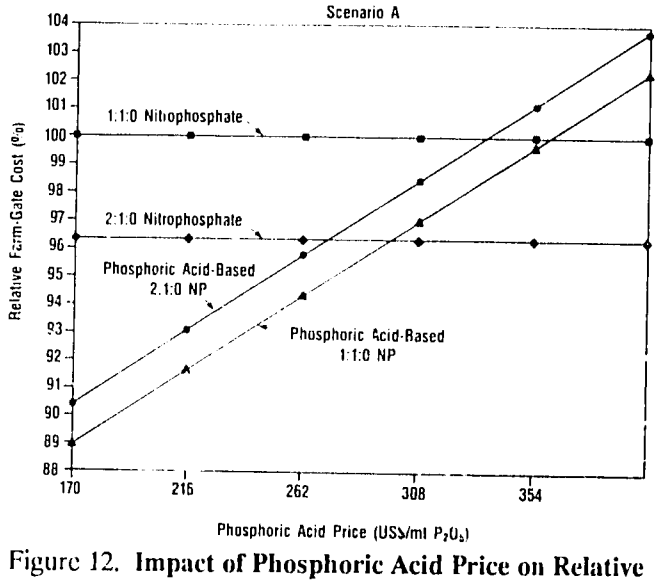

Figure 12. **Impact of Phosphoric Acid Price on Relative Farm-Gate Cost (Scenario A).**

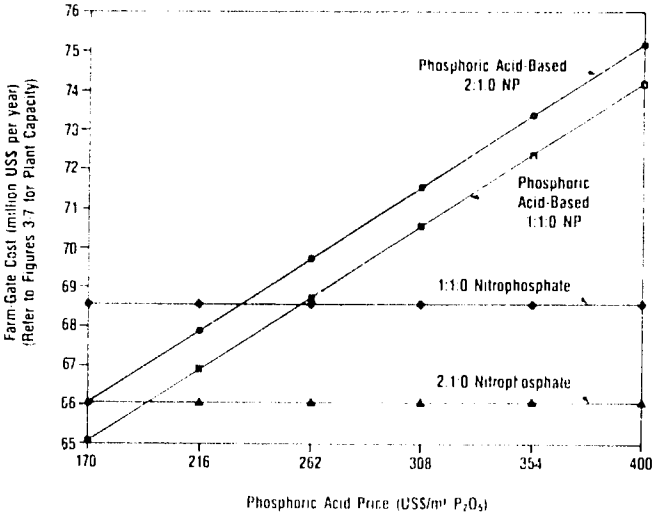

Figure 13. **Impact of Phosphoric Acid Price on Farm-Gate Cost (Scenario B).**

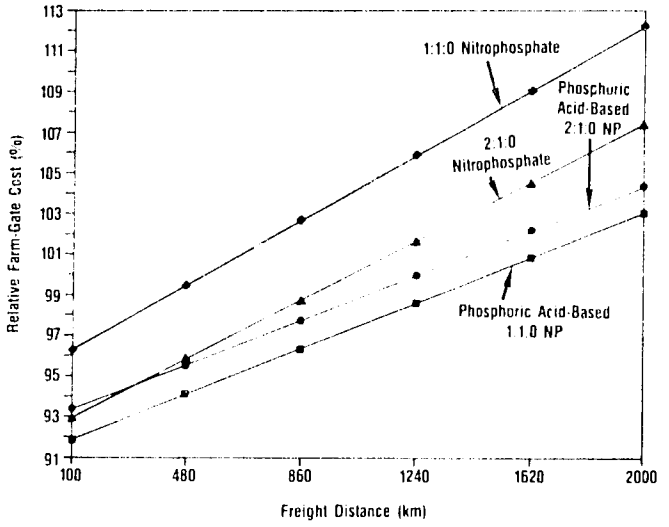

Figure 16. **Impact of Freight Distance on Farm-Gate Cost (Scenario A).**

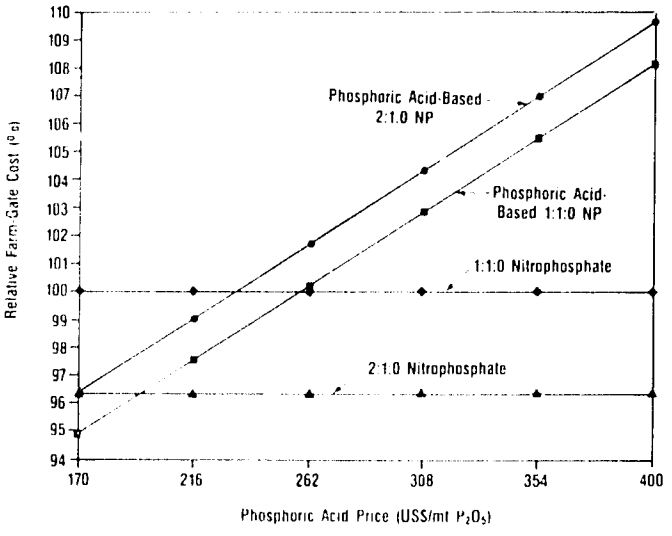

Figure 14. **Impact of Phosphoric Acid Price on Farm-Gate Cost (Scenario B).**

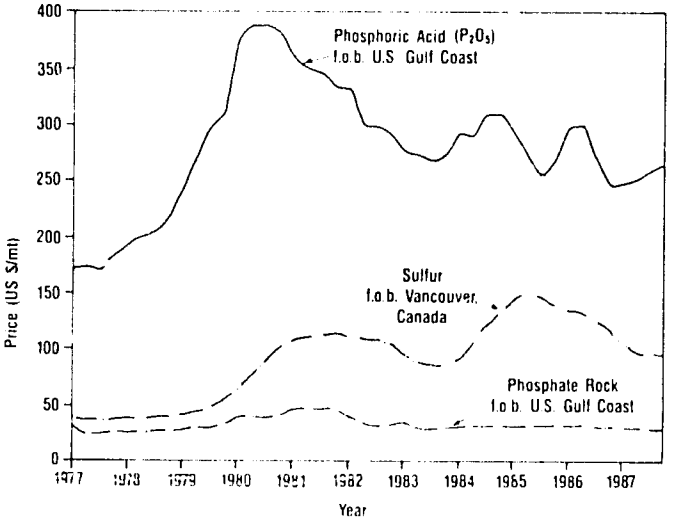

Figure 17. **Historical Export Price Trends.**

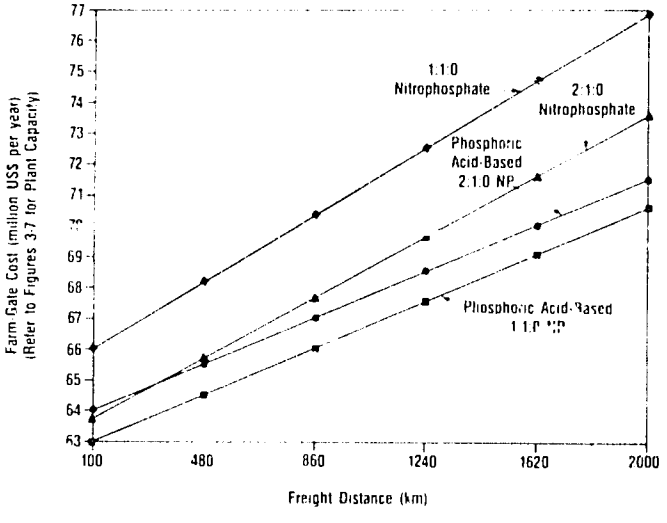

Figure 15. **Impact of Freight Distance on Farm-Gate Cost (Scenario A).**

Phosphate Rock – One of the main contributions to the farm-gate cost in the nitrophosphate route comes from phosphate rock. As mentioned above, the price for domestic rock, if available, is about the same as that for imported rock of equal quality. The historical trend curve for phosphate rock (Figure 18) also shows a relatively stable price level at a period when there were big fluctuations in sulfur and phosphoric acid prices. Thus, it is natural to compare the nitrophosphate route against different phosphoric acid prices.

Sulfur Price Trend – A discussion of the future price of phosphoric acid is best started by examining the future availability and price of sulfur.

Over the last 15 years the sulfur price has actually increased more than sevenfold, from around US $15/mt in 1970 to today's level of US $110/mt (British Sulphur Corporation, Ltd.). The historical data up to 1987 show

periods of dramatic increase with fallbacks in between. However, the overall price level has increased significantly (See Figure 17).

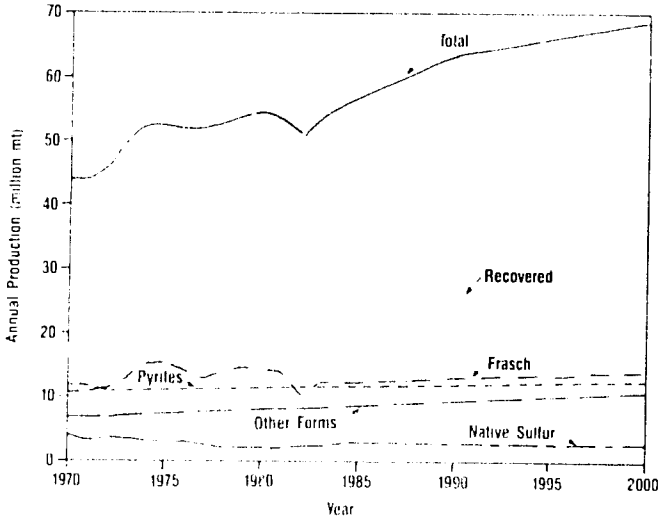

Figure 18. **World Sulfur Production – Actual and Projected (Figures Refer to Elemental Sulfur Equivalent).**

In 1985 the prediction was for an even steeper price increase (British Sulphur Corporation, Ltd.) in the years ahead. The figures for 1985 and 1986 did instead show a significant drop from the peak value of more than US $150/mt.

The dramatic increase in the price since 1970 has been caused by the following:

Even though the sulfur production rose from about 43 million mt in 1970 to more than 57 million mt in 1984/85 (Figure 18), this was more than outweighed by the increased demand for fertilizer production. The result was a quite dramatic reduction in stocks as illustrated in Figure 19.

The future situation is very difficult to predict. The significant drop in P_2O_5 production during 1985 and 1986 will undoubtedly continue to have its strong impact on the sulfur prices. On the other hand, the Frasch sulfur production is being reduced at the moment, and there is no significant increase in pyrites or other native sulfur sources.

Thus at the moment, recovered sulfur seems to be the only possibility for coping with the fertilizer demand on the one hand and the seemingly further reductions in stocks on the other hand.

There are strong individual supplies entering the market in the coming years, like the huge Astrakhan (Russia) sour gas fields with their expected production of 3 million mtpy of sulfur by 1990.

New Frasch mines could be economically viable and add another 1.5-2 million mtpy. Other minor supplies by current technology could come from pyrites and smelters.

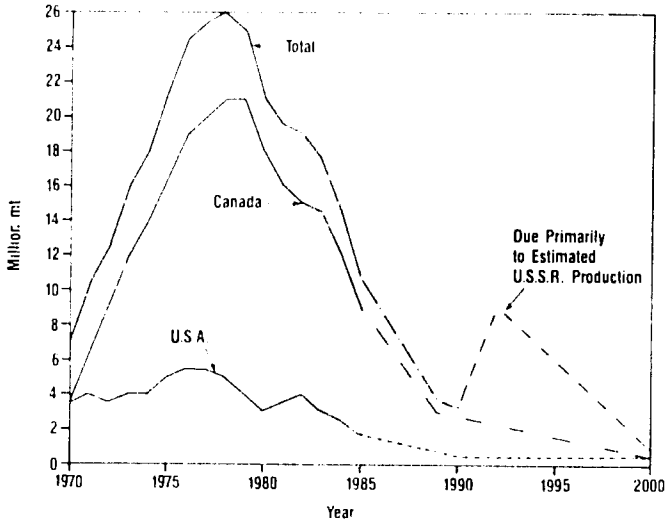

Figure 19. **Year-End Stocks of Sulfur by Major Producers – Actual and Projected (Figures Refer to Elemental Sulfur Equivalent).**

Future technologies will likely focus on the economic viability of processes to utilize gypsum either by the circular-grate process or by a fluid-bed process. Other technology may include recovery of sulfur from ultra-high hydrogen sulfide gas or from hydrogen sulfide gas of lower sulfur content. The present sulfur price level seems, however, to be too low to support these new developments.

Phosphoric Acid as a P_2O_5 Source – Several factors seem to favor the present Indian policy of importing phosphoric acid such as its possible positive impact on countertrade and the low required investment cost for downstream P_2O_5 units.

It also seems evident that India wishes to enjoy a strong bargaining leverage with their overseas suppliers. This is signaled by India's participation in joint ventures.

In the long run the price of phosphoric acid will be dictated by the price of sulfur even though a time delay, influenced by many factors, may make the historical price seem to have different trends over short time intervals as illustrated in Figure 19.

Savings in Foreign Exchange – With India's present supply of domestic phosphate rock, the rock used in a nitrophosphate plant would probably have to be imported. Thus, a gain of about US $3 million/year would be the resulting difference for raw materials in favor of the nitrophosphate process. If the phosphate rock can be

supplied, the savings would be more than three times (US $10 million per year).

The division of the total capital requirement between domestic and foreign sources is more difficult to predict. However, it seems reasonable to assume about 75% domestic and 25% foreign for both processes. This would mean a total extra foreign capital burden of about US $10 million for the nitrophosphate process compared with the phosphoric acid route. This could amount to about US $1 million in extra foreign costs each year.

Conclusions

Three different routes for producing fertilizers with equivalent amounts of N and P_2O_5 were compared:

1. Sulfur-based P_2O_5 production plus urea.
2. Imported phosphoric acid plus locally produced urea.
3. Nitrophosphate-based production.

The first route was clearly the most expensive. The difference between the two last routes for a seaside-located plant showed only marginal differences in total farm-gate costs.

For an inland location the economics favor the nitrophosphate alternative.

The cost for the second route, using imported phosphoric acid, showed a great dependence on the phosphoric acid price. The break-even point compared with the nitrophosphate alternative for the farm-gate cost occurs at today's phosphoric acid price of about US $260/mt f.o.b.

With the delivery of an $N:P_2O_5$ product of 2:1 ratio (for example, 27.0-13.5-0 grade), the nitrophosphate process avoids the byproduct calcium ammonium nitrate and reduces the production cost to compete with the phosphoric acid-based alternative.

The 2:1 product will enable the nitrophosphate process to handle the more difficult domestic phosphate rocks and greatly improve the foreign exchange savings as compared with the phosphoric acid-based production.

Kemira's Mixed-Acid NPK Process

S. Swanström, Assistant Director, Kemira Engineering

Abstract

Kemira, a state-owned Finnish fertilizer and chemical company with activities in 19 countries, produces about 6 million mt of fertilizers per year. About two-thirds of this production is in the form of NPKs. The company also produces some MAP, DAP, SSP, and KCl. Kemira's process for making NPKs is a mixed-acid nitrophosphate slurry process. Details of the process are described in this paper. Among the advantages of this technology are computer control of the various systems to improve the operating efficiency and decrease the effluents, thereby maintaining good control of pollution.

Introduction

Kemira is a state-owned Finnish company established in 1920. Originally Kemira's only task was securing the domestic fertilizer supply. Later on the company diversified into many fields of the chemical industry such as pigments, paints, herbicides, and textile fibers. In addition, Kemira has strengthened its position as a leading manufacturer of NPK fertilizers in Western Europe, now ranking No. 2, as a result of acquisitions in Holland, United Kingdom, Belgium, and Denmark (Table 1).

Table 1. **Kemira's Acquisitions of Fertilizer Businesses**

Year	Operations Acquired	Current Name
1982	I.&K. Fertilisers Ltd, UK	Kemira Ltd
1985	Esso Chemie BV, Netherlands	Kemira BV
1986	N.I.S. Fertilisers Ltd	
1986	Gechem, Belgium	Kemira SA
1987	Superfos, Denmark (65%)	Superfos Goedning

The Kemira group has activities in 19 countries. About 40% of its 14,000 employees are working abroad. The annual turnover in 1987 was over US $2 billion at the current exchange rate.

The NPK fertilizer production in Finland alone has reached 1.5 million mtpy. The total capacity for fertilizers in the Kemira Group is around 6 million tpy, and two-thirds of this is NPK. A thorough article covering Kemira appeared recently in *Fertilizer International* (1).

Different Routes to NPK Fertilizers

There are numerous routes to NPK fertilizers or compound fertilizers. But the primary raw materials are the same for the main nutrients.

Nitrogen: Ammonia
Phosphorous: Phosphate rock (igneous or sedimentary)
Potassium: Potassium chloride (KCl), mined as such or recovered from brine

A good overview of different possibilities as well as other valuable information can be found in the IFDC publication *Fertilizer Manual* (2). There are two kinds of NPK's – compounds and bulk blends. Bulk blends consist of mechanically mixed intermediates with one or two nutrients per intermediate, for example, DAP, SSP, and KCl. Chemical compounds have a uniform composition of nutrient salts, usually manufactured through a slurry stage.

The Kemira NPK Process

To respond to market demands and to have possibilities of using a wide variety of raw materials, the patented Kemira NPK-process was first utilized in 1972 at the Siilinjärvi NPK plant in Finland.

The process is a mixed acid nitrophosphate slurry-based process, producing chemically uniform product as granules. The granulation method and the raw materials can be changed and combined in many ways, as will be described later.

The process is divided into the following steps:

1. Reaction of raw materials to produce a slurry.
2. Granulation and drying.

3. Screening, crushing and recycle handling.
4. Cooling of product.
5. Coating (anticaking).
6. Recovery of nutrients and heat from the gas streams.

A typical process flow diagram with spherodizer granulation is shown in Figure 1.

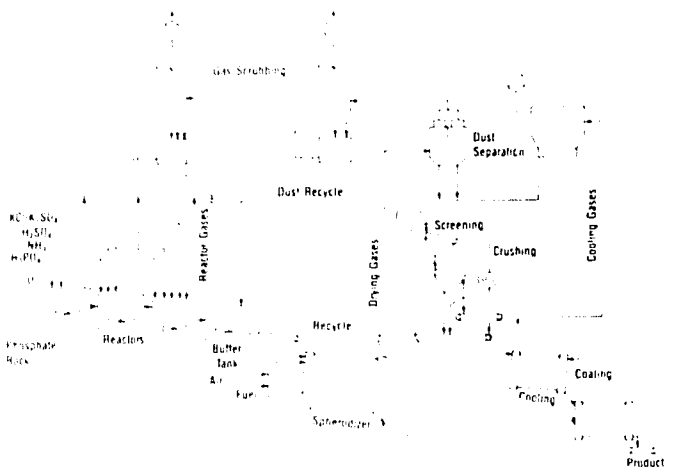

Figure 1. **Kemira's Process Flow Diagram for Production of NPK Fertilizers.**

The Reaction Section

A mixed-acid (or phosphonitric) NPK process involving three reactors is used. The raw materials are: ammonia and nitric acid for nitrogen, rock phosphate and phosphoric acid for phosphorus, and potassium chloride or potassium sulfate for potassium. Sulfuric acid and micronutrients are also used in some formulations.

In addition to this, the process can also accept without modification MAP, DAP, and ion exchange solution (H_3PO_4 + KNO_3) from the Superfos ion exchange process.

In the first reactor nitric acid attacks the rock phosphate. In the second reactor the overflow from the first reactor is ammoniated and scrubbing liquid (underflow from settler) is added. The third reactor provides for final ammoniation of overflow from the second reactor. Here phosphoric and sulfuric acids are added and the KCl is dissolved. Any micronutrients to be incorporated in the formulation are added at this point. A buffer tank is used as a liquor feed tank for the spherodizer and as a receptacle for recovering fertilizer dust from the bag filters and cyclones.

Naturally, the ratio of different raw material feeds varies according to the grade to be produced. An important feature is that the water solubility of the P_2O_5 in the product can be adjusted by adjusting the phosphoric acid/phosphate rock ratio. In practice this means also altering the AN/AS ratio by simultaneously adjusting the H_2SO_4 and HNO_3 amounts to balance the formulation. Less rock phosphate means more sulfuric acid and less nitric acid. In general, the lowest raw material cost for a given grade is for the formulation with lowest attainable water-soluble P_2O_5. That in turn occurs when the H_2SO_4 is zero and the filler properties of rock phosphate are maximized. Of course, the higher the nutrient sum (N + P_2O_5 + K_2O), the less rock phosphate can be used in place of phosphoric acid.

A wide range of grades with wide variations in the water-soluble P_2O_5 have been produced with the Kemira process. It should be noted that almost all of the total P_2O_5 is citrate-soluble, even if the water-solubility is low. Citrate-soluble P_2O_5 is often also called "available P_2O_5." Examples of grades produced with the Kemira process are shown in Table 2.

Table 2. **Examples of Grades Produced With the Kemira Process**

8-24-14	15-15-15	17-17-17	23-23-0
10-20-20	15-20-15	20-10-10	20-20-0
12-24-12	16-16-16	30-10-0	18-22-0

Granulation and Drying

The slurry in the buffer tank typically contains about 10% water. The temperature is around 135°C. Granulation and drying take place simultaneously in a combined granulator-dryer called a spherodizer. Slurry is pumped through nozzles with air dispersion, and sprayed on the recycle material in the spherodizer. The recycle material forms a curtain in the spherodizer as a result of the lifter flights in the rotating drum. The granulation is a layering process, or an "onion skin mechanism," resulting when the slurry drops hit the recycle particles repetitively. The drying mechanism is predominantly flash drying at the slurry nozzle outlet, but normal diffusion also occurs further on in the spherodizer.

The maximum output for one granulator-dryer depends on several small details in design and operation. The obvious variables are slurry water content and physical dimensions of the spherodizer. A standard 4.25 m diameter granulator-dryer can now be operated at 1,200 mtpd, whereas 600 mtpd was used as a design figure around the world 15 years ago.

To improve fuel economy, the hot cooling gas is returned to the dryer inlet via a bag filter.

Screening, Crushing and Recycle Handling

Product-size material, 2-4 mm, is separated from the total throughput by screening the material leaving the spherodizer. Part of the product-size material is diverted to the recycle conveyor to keep the recycle amount constant. The diverter is automatically controlled by a beliweigher on the recycle conveyor. Constant recycle is essential for stable granulation. Movement of the product-size diverter is an early indicator of changes in granulation.

Over-size material is crushed, undersize is recycled. That part of the product-size material which is not recycled goes to the cooler

Cooling

Cooling air can be ambient air or precooled and dehumidified air. Precooling is achieved by ammonia evaporation in a finned-tube heat exchanger. After the air has been precooled, water droplets are usually separated by slightly elevating the temperature with a small steam tube heat exchanger arrangement. In a hot humid climate, the recycle of cooling air to the dryer in combination with precooling of the cooling air improves the product quality and increases the capacity of the dryer.

Nowadays the product cooler is often a fluidized-bed cooler instead of a rotary-type cooling drum. The fluidized-bed cooler has higher operating costs than the drum, but lower investment costs and lay-out advantages for the fluidized bed cooler sometimes offset the operating costs.

Coating

Anticaking treatment or coating is carried out in a small rotating drum.

Nutrient and Heat Recovery From Gas Streams

In an NPK process with a typical water balance, the water enters with the raw materials and leaves the plant through the stack. With no liquid effluent, there are only two ways for water to leave the system: through the stack and with the product as moisture content.

A water balance reveals that the efficiency depends on reducing the water feed to the reactors and minimizing the slurry water content. The water balance for the whole plant is almost the same as for the reactors (Figures 2 and 3).

The scrubbing system is designed to obtain a maximum efficiency in emission control with a modest consumption of fresh water. The fresh water is introduced in the last stage of the reactor gas scrubbers. The pH of the scrubbing liquid is automatically controlled by addition of acid.

The nutrient content of the scrubber liquor increases as it moves countercurrently through the reactor gas scrubbing system to the dryer gas scrubbers. In the dryer gas scrubbers additional water is evaporated, which further concentrates the liquid. In this phase the nutrient salts are separated in, for example, a Lamella separator or a centrifuge from where the "thick phase" is returned to the reactor and the clearer liquid is recirculated to the scrubber system. The excellent results of Kemira's developments in the gas cleaning field were presented at the Nitrogen 86 conference (3).

Improvement of Control Systems

Computer-control systems (DDC) have been developed and utilized in Kemira's NPK plants. One of the most beneficial features is the stepless simultaneous regulation of all raw material feeds, which means stepless regulation of the production rate without disturbances. Other features are computer-controlled change of grade and correction of raw material feed rates to achieve proper product analysis, based on results from the automatic NPK analyzer.

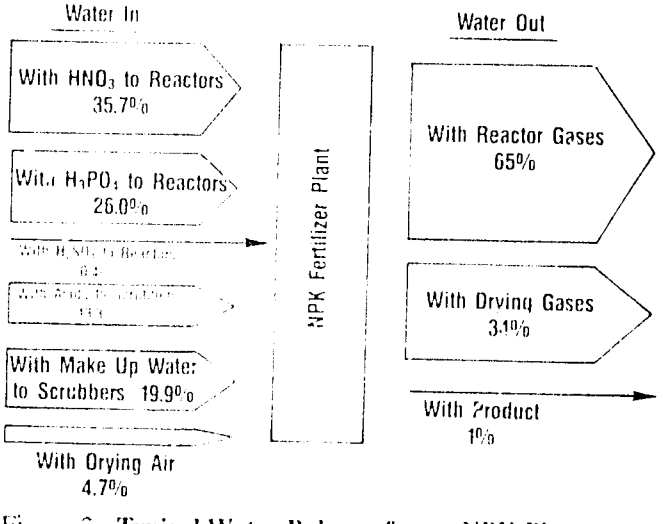

Figure 2. Typical Water Balance for an NPK Plant.

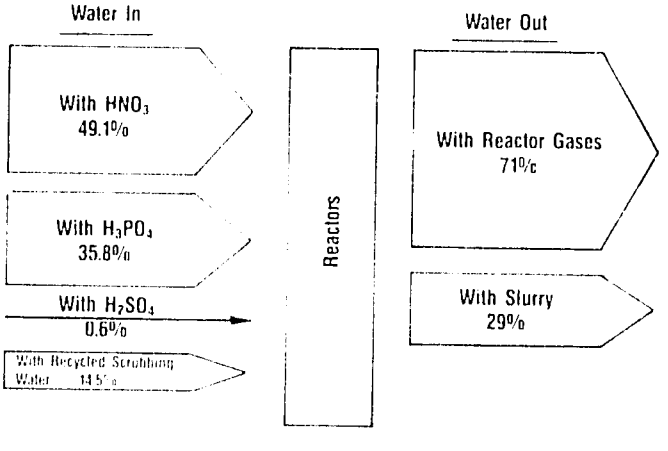

Figure 3. Typical Water Balance for the Reactors.

Economical Analysis

Investment profitability is not solely dependent on the product selling price and investment cost. The annual costs in a typical case may be broken down as shown in Table 3.

Table 3. **Typical Breakdown of Fertilizer Costs Calculated on the Basis of Price of the End Product**

Item	% of Total Cost
Fixed cost	2.0
Operating cost	6.0
Return on investment	6.4
Depreciation and interest	8.8
Raw material costs	76.8
	100.0

The importance of the raw material costs can hardly be overemphasized. World market prices for raw materials do not always follow the end product prices, or vice versa. There are two important ways to safeguard competitiveness:

1. Maximizing the share of domestic raw materials.
2. Retaining the flexibility to produce grades with variable levels of water-soluble P_2O_5.

An analysis of this subject was presented at the UNIDO Round Table discussion in Tunisia 1985 (4). An example that shows how water-soluble P_2O_5 affects the raw material costs is shown in Figure 4. The citrate-soluble P_2O_5 remains over 95% of the total P_2O_5, while the water-soluble P_2O_5 is lowered by using less phosphoric acid and correspondingly more phosphate rock.

Raw material prices used in the example are shown below.

	US $/mt
NH_3	110
HNO_3	40
Rock phosphate (32% P_2O_5)	30
H_3PO_4 (as P_2O_5)	300
KCl	75
H_2SO_4	50
Filler (inert)	20

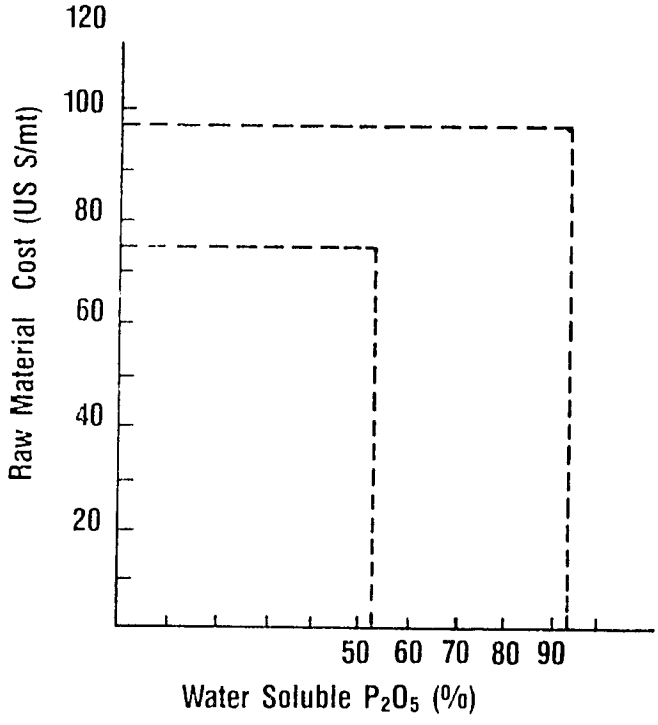

Figure 4. **Water Solubility Versus Raw Material Costs.**

Rehabilitation of RCF's Plant in Bombay

Introduction

Rashtriya Chemicals and Fertilizers Ltd. (RCF) is a major producer of fertilizers and chemicals in India. The company has two production sites in the Bombay region—the older Trombay site in Chembur, a suburb of Bombay and a newer ammonia/urea site in Thal, also close to Bombay. The Trombay unit is within a heavily populated region. Among other units at the Trombay site is the NPK plant called Suphala. The Suphala plant was started up in 1965 and enlarged in 1975. After enlargement the plant has a capacity of 1,100 mtpd of 15-15-15 NPK, using two reactor lines of the PEC type and six spherodizer granulation lines.

Objectives of Modernization

In the Bombay region great attention has been paid to air pollution control. A modification of existing effluent control systems at the Suphala plant was called for. RCF contacted Kemira for the first time in 1978.

The following targets for the modification were set:

1. Improvement of pollution control.
2. Decrease of raw material consumption by improvement of nutrient efficiency.
3. Increase of production capacity to 1,500 mtpd.
4. Reduction of energy consumption.

In late 1983 RCF signed an agreement with Kemira for consulting services on the rehabilitation of the Suphala NPK plant based on Kemira process technology.

Scope of Services Supplied by Kemira

1. Process License.
2. Basic and detailed engineering for reaction section and gas cleaning facilities.
3. Basic engineering for the salt (granulation and solids handling) section.
4. Reactor agitators and Lamella separator for scrubber liquor solids separation.
5. Training of RCF personnel in Finland at Kemira's NPK plants.
6. Supervision services and startup of the plant.

Modifications Made

Reactor Section–The original two PEC reactor lines with 34 U-tube type reactors were replaced with one reactor line having three reactors that use the Kemira process.

Salt Section–The six spherodizer lines were to be modified to four lines. So far two lines have been modified and the other two lines will be modified later. The product cooling was improved by installing air precoolers in the cooling drum air inlet for the modified lines. Fuel economy was improved by recirculating cooler air to the gas burner for the spherodizer air heating.

Gas Scrubbing–A closed-circuit water circulation system was established together with installation of a Lamella separator. The reactor gas scrubbers were modified by using the existing equipment with rearrangement of the flows and other modifications. The drying gas scrubbers were renewed and one scrubbing stage was added.

Instrumentation–A major revamping of the instrumentation system was also made including installation of a computer-controlled system (DDC).

Project Procedure

A thorough fact-finding study in the beginning of 1984 started off the project. Drawings, specifications, and an extensive photographing program completed the collection of basic data for the engineering phase. RCF had selected an Indian engineering office for the detailed engineering work outside Kemira's scope. All parties formed project organizations and established good communication links.

Kemira delivered the design manual in July 1984 and the operation manual two months later. The equipment from Finland was shipped in January 1985. Detailed engineering work in India was continued during 1985 along with equipment procurement. The erection work started in spring 1986 and in March 1987 the plant was ready for partial start-up. Heavy production demands were met. The fiscal year ending 31st of March saw the modified plant running and the production target of the fiscal year achieved.

Results of the Suphala Rehabilitation–Rehabilitation of the Suphala plant accomplished the following:

1. Improved air pollution control.
2. Reduced amount of liquid effluents.
3. Improved raw material efficiency.
4. Increased plant capacity (35%).
5. Reduced energy consumption.
6. Reduced maintenance costs.

A few more benefits are to be expected like a higher time onstream factor and improved product quality.

Conclusion

Some of the features that make a fertilizer process competitive are:

1. Flexibility in the use of different raw materials.
2. Ability to produce a wide range of grades with variable levels of water-soluble P_2O_5.
3. Plants that are thermodynamically efficient.
4. Environmentally clean plants with no liquid effluents, no solid effluents, and a very low level of gaseous emissions.
5. Easy and stable operation due to advanced computer control.

In view of these advantages the Kemira NPK process appears to be an interesting alternative for the production of compound fertilizers.

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Compaction/Granulation of Fertilizers

R. Zisselmar, Head of Department - Briquetting, Compaction, and Size Reduction, Maschinenfabrik KÖPPERN GMBH & CO. KG

Abstract

In compaction granulation a fertilizer is subjected to enough pressure to remove most of the voids in the bulk material and thereby bring the individual particles close enough together to permit molecular attraction to occur. This is accomplished by passing the material through a roller press where the material is forced between two counter-rotating rollers that are pressed together by a hydraulic pressure system. The result is typically a flat sheet of material that is 5-20 mm thick and has an apparent density that is one and a half to three times as great as that of the feed material. The compacted sheet (flake) is broken into fairly large pieces by a "flake breaker" and subsequently crushed to obtain particles of the desired size. If the sheet is brittle it is usually crushed in a hammer mill. If it is soft and plastic the sheet should be cured until it hardens and then crushed in a special roll-type mill (disc crusher). The product sized particles are usually tumbled in a drum to remove any sharp corners and thus reduce further abrasion and dust.

Fertilizer compaction is influenced by many factors which affect the selection of the various pieces of equipment and the operating conditions. However, by careful selection of equipment and operating procedures, most fertilizers can successfully be granulated by the compaction method.

Advantages of the compaction process are: (1) its power consumption is low, (2) it requires no liquid binders, (3) it can handle feeds of various compositions, (4) it can process feeds with a wide range of particle sizes, (5) it can be used in plants of almost any size, and (6) it can be operated continuously or intermittently, thereby allowing considerable flexibility in operation.

Introduction

In agriculture the nutrients nitrogen (N), phosphate (P_2O_5), and potash (K_2O) are removed from the soil by harvesting and these must be replaced by adding fertilizers. Formerly, the only fertilizers used were organic materials that contained mineral substances, nitrogen, available humus, bacteria, and carbon dioxide. Today's intensive farming, though, requires additional natural or synthetic mineral fertilizers.

Besides single component fertilizers which contain only one nutrient, N, P (P_2O_5), or K (K_2O), mixed fertilizers are offered which contain two or more nutrients, for example, NP, NK, PK, or NPK. Some of these may also include CaO, MgO, or trace elements which, for plant growth, have similar functions as vitamins.

To guarantee full utilization of the individual nutrients, these mixed fertilizers are formulated according to the needs of the particular soil and crop. In the face of a fast growing world population and decreasing acreage of high quality land dedicated to farming, multicomponent fertilizers which provide the best possible crop yields in modern mechanized farms are growing in importance.

Critical factors that affect the usage of fertilizers are their storage, transportation, and handling characteristics. Until the 1920s fertilizers were exclusively applied as powders. Except for advantages during mixing of the components, the use of powders did present a number of disadvantages such as segregation, uncontrolled agglomeration, unsatisfactory flow characteristics, and losses during application because of dusting and runoff. These disadvantages were largely reduced by the development of processes for grain-size enlarging, the so-called granulation processes.

Several fertilizer granulation techniques were developed which are based on either wet agglomeration or binderless pressure agglomeration with subsequent crushing and sizing into the final granular size. In addition, some fertilizer materials can be melted and dispersed by spraying and cooling in a tower (1,2).

In the wet agglomeration of finely divided particulate matter, liquid binders cause green strength by capillary forces. During subsequent drying, chemical reactions between the components or crystallization of dissolved substances form solid bridges between the particles that make up the agglomerate. Typical equipment for this technology includes drums, discs, and mixers followed by dryers and coolers as well as fluidized beds (3,4).

Binderless, pressure agglomeration is a competing technology which, in most cases, does not rely on the

material bridges between the particles forming the agglomerate. Rather, granule strength is caused by molecular forces. Because of the short range of these attraction forces the particles must be close together and this requires the application of external pressure by either extrusion (material is pressed through fixed diameter orifices) or compression (material is pressed between two surfaces). If compression takes place in the nip between two counter-rotating smooth or slightly profiled rolls, this process is called (roller) compaction (5).

In the following pages, this technique which includes crushing and sizing of the compacted sheet into the granular product will be discussed in more detail.

First, the principle of compaction/granulation systems will be introduced. The heart of such systems, the compaction process with roll presses, will then be described briefly. Afterward, the parameters that influence fertilizer compaction will be investigated. And finally, some typical examples of application will be given to illustrate the compaction/granulation system.

Principle of Compaction/Granulation Plants

General Description of Plant

The general flowsheet of a fertilizer compaction/granulation plant is shown in Figure 1.

The system is made up of four groups of machines and apparatus for the following process steps:

1. Storage, proportioning, and mixing.
2. Compaction.
3. Size reduction and classification.
4. Finishing.

By means of various transportation devices, such as bucket elevators, belt conveyors, and drag chain conveyors, the material is moved from one part of the system to the other.

Storage, Proportioning, and Mixing

The number of bins as well as the sophistication of proportioning and mixing operations depends on the number of fertilizer components to be incorporated into the final product.

In systems designed for the production of different mixed fertilizers, batch mixing is preferred. Components are metered into a weigh bin. After formulation, the contents are discharged into a batch mixer. A surge bin between the discontinuous formulation equipment and the rest of the system allows for continuous operation of all other equipment.

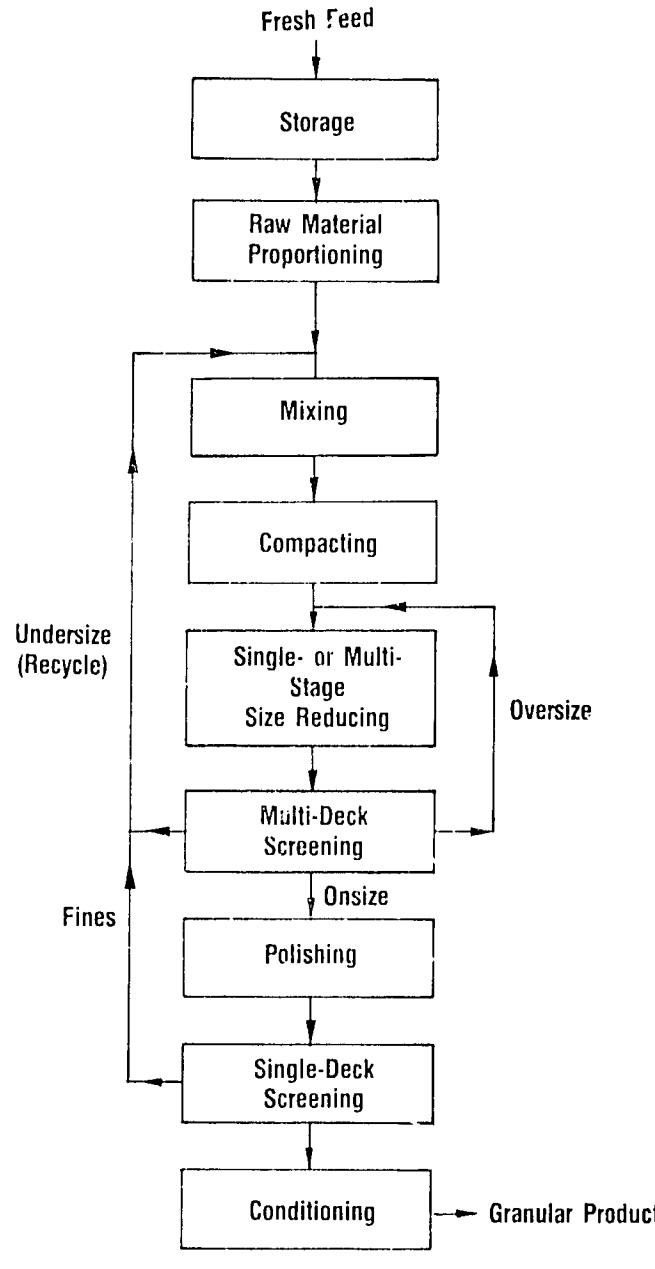


Figure 1. **General Flowsheet for a Fertilizer Compaction/Granulation Plant.**

Systems that granulate only one multicomponent fertilizer product are normally equipped with continuous metering and mixing devices such as belt-type scales feeding into the mixer.

No matter which operation is used, selection of the type of mixer depends on the composition of the fertilizer. For example, to guarantee the uniform distribution of trace elements, a high intensity mixer must be used.

In addition to the fresh feed, recirculating undersized material from the crushing and sizing circuit is fed into a double-shaft paddle mixer (Figure 1). Typically the ratios of recycle to fresh feed is between 1:1 and 2:1.

Compaction Unit

The homogeneous fertilizer mixture is fed to the compaction process described below.

For this process, roll presses are available that utilize the principle of pressure agglomeration. In such machines particulate material is introduced into the nip of two counter-rotating rolls by means of a vertical feed screw. As the material is compacted, pressure in the mass increases, reaches a peak just above the line of closest approach between the rolls, and then drops quickly to zero (Figure 2). During this process the apparent density of the mixture is increased by a factor 1.5 to 3 because of decreasing the volume of voids in the bulk material.

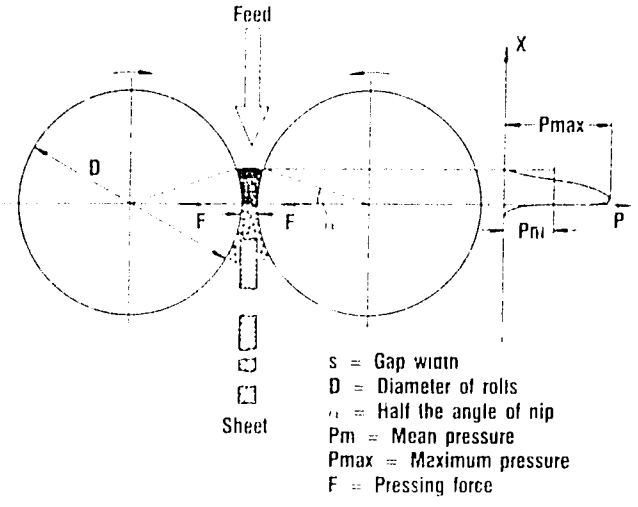


Figure 2. **Principle of Roll Compaction.**

The product is typically a flat sheet 5-20 mm thick. Selection of the size and design of the roll press depends on numerous parameters which in turn are dependent on the material and normally must be determined experimentally.

Size Reduction and Classification

The sheet (flake) produced in the roll press must be crushed and classified into the desired particle-size fractions.

Often, the first crushing step takes place in a specially designed flake breaker which is installed directly below the roller press. The sheet is broken into smaller pieces which can be easily handled and are a perfect feed for subsequent crushers.

The material is separated into oversize, product size, and undersize on a multideck screen. The undersize (passing through the lower screen deck) is recirculated to the mixer and thence to the compactor. The oversize material which fails to pass through the upper screen of the double-deck screen must be further reduced in size.

Selection of the secondary crusher depends on the characteristics of the compacted fertilizer. If the compacted material is brittle, as is the case with potash, it should be crushed by impaction. In these high intensity crushers all softer parts of the sheet are pulverized resulting in granular particles of high strength and excellent resistance to abrasion. Products from such plants will not abrade during handling and field application.

Many mixed fertilizers, particularly those containing phosphates and/or urea, initially produce relatively soft and plastic sheets. They harden during aging. Therefore, in such plants, curing bins should be installed between the screen and secondary crushers. Even then, the use of special roller mills, called disc crushers, is beneficial. Such equipment handles the softer products more delicately than impact or hammer mills. The granular product may still gain strength during further aging.

Another criterion for the selection of secondary crushers is the minimum particle size of the product. For particles with diameters less than 1 mm impact crushers must be used while for particles with diameters greater than 1 mm disc crushers can be used.

The selection of the screen also depends on the characteristics of the fertilizer material. Not only the separation characteristics must be considered but also such parameters as the abrasiveness of the particles, their tendency for blinding, and their flow characteristics. In cases where screening difficulties are anticipated, tests must be carried out to determine the optimum operation.

Correct selection of crushing and sizing equipment is of utmost importance for the economics of a fertilizer compaction/granulation system. Besides determining the particle shape, which normally should be cubic, and the size range, for example, 1-5 mm or 2-4 mm, the crushing and sizing equipment determines the yield and the capacity of a given plant.

Finishing

Often the product is subjected to one or two finishing steps. The irregularly shaped particles are sometimes tumbled in an abrasion drum to slightly round the sharp edges and corners. Fines produced in this step are removed by screening (single-deck screen) and recirculated. A further finishing step may be the conventional conditioning with anticaking agents.

The final product of the system is a granular fertilizer with a certain particle size distribution in a defined range (for example, 2-5 mm) and a specific granule strength. In case of mixed fertilizers, individual particles have practically the same composition as the bulk mixture.

Whether the strength reached will be adequate can be determined by test methods which have been developed especially for fertilizers (6).

Compacting Equipment

In the operation of a compaction/granulation plant the compacting process which is of central importance takes place in roller presses.

Roller presses consist essentially of:

1. The frame.
2. The two rollers.
3. The hydraulic pressure system.
4. The drive.
5. The material feed equipment.

The rollers are carried in self-aligning roller bearings whose housings are supported in the frame of the press. Each roll consists of a roller body on which the tools – for example, rings or segments – are mounted. For compacting fertilizers usually rings with smooth or profiled surfaces are used; these are shrunk onto the roller body. One of the rolls is immovably mounted in the frame (fixed roll), whereas the other roller is movably mounted, allowing lateral displacement by hydraulic rams.

The hydraulic system serves primarily to check the pressing force between the rolls. If a foreign body enters the gap between the rolls, a relief valve allows the rams to get rid of the excess pressure and thus enables the movable roll to "give." In addition, the hydraulic system is equipped with nitrogen-filled compensating accumulators which bring about changes in the gaps between the rolls in response to slight variations in the amount of material being fed to the unit. In this way the pressure exerted by the rolls is kept constant and thus the quality of the product (sheet) remains suitably uniform.

A reduction gear unit with two output shafts provides the relatively low rotating speeds for the rolls in the range of 5 to 40 revolutions per minute. Torque is transmitted from the gearbox output to the rollers through special toothed couplings the dimensioning of which is so flexible that the floating roll has sufficient clearance of motion. In addition, a torque safety coupling is interposed between the drive motor and the gearbox. Infinitely variable speed control can be obtained by mechanical means, but may alternatively be obtained very advantageously by means of a thyristor-controlled D.C. motor or a frequency controlled three-phase A.C. motor.

The type of material feed equipment employed – gravity feeder or screw feeder – will depend on the properties of the material such as bulk density and flow characteristics. In principle, a uniform and continuous material feed should be aimed at in order to attain a satisfactory filling of the press.

If the material is of good fluid quality, a check plate with adjusting tongue will suffice for changing the free-space sectional area. When sufficient filling by gravity feed cannot be achieved because the bulk density is too low or the filling capacity is insufficient, screw feeders must be used. These screws force the feed into the filling section, thus effecting a sort of precompaction of the feed material. The screws are always equipped with a variable speed drive in order to be able to adapt the feed capacity to the throughput capacity of the press. In general, screw feeders are used for fertilizers.

Parameters of Fertilizer Compaction

Fertilizer compaction is influenced by many factors which determine the size of a roller press and its operating conditions.

These parameters can be divided into three groups:

1. Raw material characteristics such as brittleness, hardness, abrasion index, and density.

2. Properties associated with the condition of the compacted fertilizer such as bulk density, moisture content, temperature, particle shape, particle size distribution, and material flow conditions.

3. Characteristics of the equipment such as specific pressing force and roller speed.

Material Characteristics

The materials used for compacted fertilizer essentially belong to the formerly mentioned four groups:

1. Nitrogen fertilizers.
2. Phosphate fertilizers.
3. Potash fertilizers.
4. Mixed fertilizers.

Ammonia is the most important raw material for nitrogen fertilizers. Typical nitrogen fertilizers are:

1. Ammonium sulfate.
2. Ammonium nitrate.
3. Sodium nitrate.
4. Potassium nitrate.
5. Calcium nitrate.
6. Calcium cyanamide.
7. Urea.

Raw materials for the production of phosphate fertilizers are phosphate rock and phosphorus-containing iron ores. The phosphorus nutrient is always water-

insoluble apatite (calcium phosphate). Therefore, it is necessary to decompose the apatite. This is normally accomplished with acids, by heat treatment, or sometimes electro-thermally.

In most cases sulfuric acid is used but sometimes nitric acid is also employed. Decomposition with sulfuric acid results in superphosphate (single superphosphate or SSP), a mixture of soluble calcium hydrogen-phosphate and calcium sulfate. For the production of double (DSP) and triple (TSP) superphosphates phosphoric acid is used.

During the reduction of iron ore, phosphorus contained in the ore is oxidized and concentrated in the slag. This so-called Thomas slag together with the added silicic acid is called Thomas phosphate and after grinding (Thomas meal) is available as a phosphate fertilizer.

Other important phosphorus-bearing fertilizers are monoammonium phosphate (MAP) and diammonium phosphate (DAP).

Potash fertilizers are manufactured from raw potash rock mostly by dissolution and subsequent crystallization or by flotation. The most important potash fertilizers are:

Potassium chloride (muriate of potash, MOP)
Potassium sulfate (sulfate of potash, SOP)
Potassium nitrate (nitrate of potash, NOP)

The fertilizer industry offers a large number of mixed fertilizers which contain two or three of the primary nutrients together with CaO and MgO. Sometimes other nutrients and possibly trace elements are added. Each is characterized by its formulation. Examples are:

Amsup	Ammonium sulfate + superphosphate
Kaliammonsaltpetre	Potassium nitrate + ammonium chloride
Amsupka	Ammonium sulfate + superphosphate + potassium chloride
Nitrophoska	Ammonium sulfate + diammonium phosphate + potassium nitrate

Table 1 shows a summary of important fertilizers with their major nutrient contents.

Table 1. **Some Important Fertilizers and Their Nutrient Contents**

Fertilizer Name	Formula	Nutrient Content (%)
Nitrogen Fertilizers		**N**
Ammonium sulfate	$(NH_4)_2SO_4$	21
Ammonium nitrate	NH_4NO_3	34
Ammonium chloride	NH_4Cl	25
Sodium nitrate	$NaNO_3$	15-18
Potassium nitrate	KNO_3	13 (+44% K_2O)
Calcium nitrate	$Ca(NO_3)_2$	15-18
Calcium cyanamide	CaNCN	20-21
Urea	$CO(NH_2)_2$	46
Phosphate Fertilizers		**P_2O_5**
Phosphate rock		Up to 36
Single superphosphate (SSP)	$Ca(H_2PO_4)_2 + CaSO_4$	16-18
Double superphosphate (DSP)	Concentrated SSP	18-45
Triple superphosphate (TSP)	$Ca(H_2PO_4)_2$	46
Thomas meal	$5CaO \cdot P_2O_5 \cdot SiO_2$	16-25
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	48 (+11% N)
Diammonium phosphate (DAP)	$(NH_4)_2 HPO_4$	46 (+18% N)
Potash Fertilizers		**K_2O**
Potassium chloride (muriate of potash, MOP)	KCl	40-60
Potassium sulfate (sulfate of potash, SOP)	K_2SO_4	50

The many different fertilizer components used result in a broad spectrum of material characteristics. Their influence on compaction must be determined experimentally.

In the case of mixed fertilizers the material characteristics of one component can positively or negatively change the compactibility of the mixture. For example, because of the low melting temperature of urea or the softening under pressure (thixotropic behavior) of superphosphate, both materials can become binders if added in small amounts. The same characteristics cause soft and plastic sheets if too large amounts are used in a mixed fertilizer formulation. Only after long and uneconomical aging periods do they become brittle enough for granulation. For optimum and continuous operation of a compaction/granulation system, the sheets must harden within less than 30 minutes on a belt or in an aging bin. Ideally the consistency of the sheet should be suitable for granulation directly after leaving the roller press. The optimum, minimum, and maximum amounts of individual components in a fertilizer mixture must be determined experimentally.

The mineralogical hardness of the fertilizer components determines the pressure required and, therefore, the energy consumption. In the case of mixed fertilizers an average hardness is obtained which depends on the formulation. It is possible, for example, that a small percentage of a hard component is embedded in the large amount of a softer matrix and only insignificantly influences energy consumption. On the other hand, mixtures containing large amounts of relatively hard components, such as kieserite, ammonium phosphate, or potassium sulfate, need high pressure for the production of a strong sheet.

In principle, an increasing hardness and brittleness of a material will result in the breaking of single particles instead of plastic deformation. This causes new pore spaces (cavities) which cannot be closed again. At the same time, elastic deformations will occur by which shear stresses are produced in the newly formed agglomerate.

If the stresses exceed the tensile strength of the agglomerate, a pressure relief will cause breaking. There are obviously two opposite procedures overlapping—comminution and compaction.

With hard and brittle feed materials, the high pressure exerted by the rolls will shatter most of the feed. In such cases the feed will not have enough plastic deformation to bring the individual grains or fragments close enough together to permit the van der Waals attraction to form strong agglomerates. This difficulty can be partially overcome by the application of binders (solutions that dissolve part of the material and recrystallize to form "bridges" between different particles of material).

An important material property of a fertilizer component is its abrasion index which, together with the specific pressing force, causes wear of the roller surfaces. To obtain an acceptable life of the wear parts, even in the case of very abrasive fertilizer materials such as Thomas slag, the roller sleeves can be manufactured from highly wear-resistant special steels.

The true density of fertilizer components determines the apparent density of the sheet and the throughput of a roller press. In the case of mixed fertilizers the apparent density of the sheet depends on the true densities of the components and on their percentage in the mix. Therefore, the capacity of a given roller press varies when the fertilizer formulation is changed.

Material

Particle Shape and Particle Size Distribution—The shape of particles, for example, spherical, cubic, flake, or needle-like and their size distribution are important characteristics for any agglomeration process since they influence the binding mechanisms. In case of multicomponent fertilizers, particle shapes and particle size distributions may vary significantly. Again, the question as to how these characteristics influence compactibility must be answered experimentally.

For compaction it is a general rule that, together with coarser particles, enough fines should be available to fill in the larger pores or open spaces. In such a structure molecular attraction forces become more active and this results in greater strength. If the particles are shaped so that they can interlock during compaction, an additional beneficial binding mechanism is obtained.

The van der Waals attraction alone is often not sufficient to produce adequate strength. In the case of fertilizers other binding mechanisms are also possible which somehow mobilize natural binders within the material itself; among these are: formation of a crystal bridge between the particles, chemical reactions among the components of the mixture, and pressure welding.

For many single component fertilizers such as potassium sulfate (with particle sizes less than 0.5 mm) crystal bridges play an important role (7). They are obtained by adding a small amount of water to the feed which dissolves minute quantities of the material. Subsequently the dissolved solid recrystallizes during the drying operation to form a strong agglomerate with low porosity.

Other raw materials, such as phosphate rock and Thomas slag, do not dissolve in water and, therefore, do

Table 2. **Pressing Force, Moisture Content, and Feed Particle Size of Various Compacted Fertilizers**

Fertilizer	Specific Pressing Force, kN/cm (based on roll diameter 1,000 mm)	Moisture Content (%)	Feed Particle Size (mm)
Ammonium sulfate	100-120	0.5-1	<1
Potassium chloride (60% K_2O) (120°-140°C)	50	Dry	<1 (3% < 0.06)
Potassium chloride (60% K_2O) (20°C)	70	Dry	<1 (3% < 0.06)
Potassium chloride (40% K_2O) (90°C)	60	Dry	<1
Potassium sulfate (70°-100°C)	70	1	<0.5
Potassium nitrate	100	0.5-1	<1
Calcium nitrate	60	Dry	<1
Urea	30-40	Dry	2-3
Calcium cyanamide	60	Dry	<0.4
NPK fertilizers (not containing phosphate rock and Thomas meal)	30-80	<1	<1
NPK fertilizers (containing phosphate rock and Thomas meal)	80 or more	<1	<1
Urea-based NPK fertilizers	30-40	<1	<1

not produce compacts of sufficient strength. In such cases, a binder component should be added.

It is also possible to make use of the plasticity of some fertilizer materials; this property may be increased by using elevated feed temperature. This binding mechanism, which results in very dense compacts, is used, for example, in the compaction of potash (feed size less than 1 mm).

In the case of mixed fertilizers, chemical reactions between components can promote binding. Also, as mentioned before, components which alone do not produce compacts of sufficient strength or cannot be compacted because of their stickiness may be incorporated in multicomponent formulations, for instance, phosphate rock incorporated in urea. In this formulation less phosphate rock than urea should be used in the mixture.

The most advantageous mixing ratio of phosphate rock and urea is 15:35; the remainder is diammonium phosphate and potash. It appears that when high percentages of urea – about 20% or more – are used in the mixture, another component which neutralizes the very plastic properties of urea is needed.

If the proportion of urea is less than the proportion of rock phosphate, a significant drop of quality is recorded. A very disadvantageous mixing ratio of phosphate rock and urea is 46:38, the remainder being potash.

A third binding mechanism of importance with many dry and one-component fertilizers, potash, for example, is the close proximity of particles that are subject to plastic deformation. This closeness leads to a homogeneous connection similar to press welding.

Table 2 presents data on the feed particle size of various fertilizers.

Temperature – The temperature of the fertilizer feed often determines its plasticity. In comparison with colder material, a warmer feed may require less pressure (energy) to obtain a product with a given strength and density or, at the same energy input, to produce a product with greater strength and density. Examples are potash which requires a pressing force of 70 kN/cm at room temperature but only 50 kN/cm at 120°-140°C and potassium sulfate which can only be compacted at temperatures of 70°-100°C using a pressing force of 70 kN/cm (Table 2).

Elevated temperatures are also beneficial for the formation of crystal bridges because more salt is available for recrystallization.

Moisture Content – Generally, the compaction of fertilizers can be classified as a dry agglomeration process. As mentioned before it may be beneficial to dissolve some material in small amounts of a liquid to facilitate the formation of crystal bridges which increase the compact strength. However, the moisture content seldom exceeds 2% by weight (Table 2). While potassium sulfate feed often contains more than 1% water, the compaction of potassium chloride takes place in an essentially dry state. Some fertilizers, such as urea, are highly hygroscopic and tend to absorb moisture from the air. For salt mixtures with urea the critical relative humidity is lower than for the individual components. Since this results in con-

siderable stickiness, measures must be taken to handle urea in a dry environment which may involve drying of plant air in humid climates.

Characteristics of the Equipment

Specific Pressing Force – One of the most important parameters of compaction is the specific pressing force which is defined as: total pressing force per active roller width. To obtain a compact that is dense and strong enough, a specific pressing force is required which must generally be determined during tests in large-diameter equipment. The scaleup to production size equipment with wider rollers is easy and can be done arithmetically.

For compacting fertilizers with rollers of 1 m in diameter, the specific pressing forces are generally between 30 and 140 kN/cm. If hard, nonwater-soluble components such as phosphate rock or Thomas slag are present in the mixture, the specific pressing forces will be 80 kN/cm or more while for other feed materials pressures less than 80 kN/cm are often sufficient. Table 2 summarizes typical specific pressing forces for various materials.

Roller Speed – The circumferential speed of the rollers is limited by the deaeration behavior of the feed material.

Finely divided particulate matter like a fertilizer contains air in the bulk volume which must be expelled during compaction. For example, if potassium chloride with a bulk density of 1,000 kg/m^3 is compacted into a sheet with an apparent density of 2,000 kg/m^3 at a capacity of 50 mt/h, approximately 7 liters of air must be removed each second. In order to maintain steady-state press operation, the air must be able to escape upwards from the roller gap, in a direction opposite that of the flow of material introduced from above. Depending on the air escape rate, the bed of solids directly above the rolls will assume different phases, for example, solid when the circumferential speed of the rollers is low; fluidized when the speed is increased above the loosening point; and pulsating/fluidized when the speed is further increased.

The bed of feed material contains a large number of very narrow passages that function like an effective labyrinth seal and offer a certain resistance to the flow of the rising air. This resistance is greater when the passages are narrower or the particles are finer. If the air expulsion rate is just equal to the rate at which air can flow away without difficulty through the passages, the solids bed will be comparable to a bed of particulate matter in which the individual particles are in contact and derive support from one another. Further increase in roller speed causes more material to be drawn into the gap, so that more air is displaced from the voids between the particles than can escape through the passages. The solids bed will then be loosened up by aeration, thus becoming comparable to a fluidized bed. In this phase the air outflow velocity is so high that the particulate matter is fluidized.

If the speed of the rollers is still further raised and the rate of air expulsion increases even more, the deaeration of the feed material becomes noticeably disturbed. In this phase, which can be described as critical, air bubbles are formed directly above the rollers, so that the material then behaves like a pulsating fluidized bed. The feed material making its way down into the gap between the rollers will, however, prevent the fluidized bed from developing fully, so that the air bubbles cannot rise further. Instead, they collapse and pass, together with the fluidized feed material, through the gap. This phenomenon is periodically repeated, so that pulsations occur which have an unfavorable effect on the operation of the roller press. As a result there occurs irregular filling, which causes marked variations in the quality of the sheet, resulting in deficiencies in the strength, density, and composition of the agglomerated product. Another indication of inadequate deaeration consists in the amount of fine (nonagglomerated) material that emerges from the press along with the sheet.

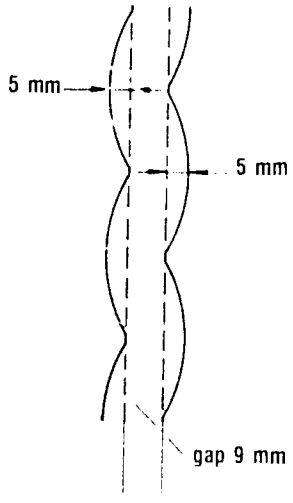
The deaeration problem and the resulting fluctuations in press operation can be monitored by observing the power consumption and the pressure applied. If these two quantities are plotted on a graph, they will both display a synchronous undulating pattern of increases and decreases.

If the circumferential speed of the rollers and thus the amount of air to be removed from the feed material is still further increased, the pulsation results in an audible sharp knocking which causes severe impact loads in the machine, especially in the bearings and gears, so that their service life is reduced.

In view of the deaeration problem outlined here it is meaningful to define the working width of a roller press in terms of the possible specific throughput that can be calculated from the sheet volume and the rotational speed of the rollers. For a certain sheet volume the throughput depends only on the maximum permissible roller speed. Taking into account the roller diameter, there can thus be determined a maximum permissible circumferential speed. In compacting fertilizer typical values of the critical circumferential speed are 0.6-0.7 m/s (8).

The deaeration problem is particularly acute with smooth roller surfaces so attempts were made to remedy the condition by using roller surfaces having different profiles. Suggestions for different corrugations included both those in axial and those in circumferential direction (9).

In the last analysis waffled surfaces for the rollers turned out to be most effective. A waffled surface means that it contains pockets similar to those used in briquetting machines. The difference, however, is that they are not matching but axially and circumferentially shifted against each other and they also have a reduced pocket depth. Figure 3 depicts the cross section of a sheet made with a waffled roll surface.



Resulting Mean
Sheet Thickness: Approx. 13 mm

Figure 3. **Cross Section of a Compacted Sheet Made With a Waffled Roller Surface.**

The land (raised portion of the surface) facilitates the formation of canals through which the air can escape. At the same time the nipping conditions are improved which results in a thicker sheet and consequently a significant increase (at least 15%) in the capacity. Moreover, because of this roller surface design for the first time it was possible to produce a sheet which covers the whole working width and therefore fully utilizes the entire roller width.

For exceptionally difficult cases containing a very fine-grained material, the compaction of which is rather difficult, a division of the roll width into two waffled sections is recommended. This enables air to escape laterally at two additional areas, thus providing for a better deaeration.

Power Consumption – As is well known, calculation of the specific power requirements for compacting has to be based on the power input and the product throughput. Whereas the throughput is, in general, a preset value, the power input has to be ascertained, depending on the torque (proportional to the specific pressing force) and on the roller speed (revolutions per minute), using data which have to be determined by experiments.

Comparative tests between dry (pressure) granulation and wet granulation indicate that even a most unfavorable dry granulating system will be much better than the best wet granulating system with regards to the energy consumed. This is mainly due to the additional energy required for heat treatment (drying) needed for the wet granulation processes (10). Typical energy consumption data are given in Table 3.

Table 3. **Specific Power Requirement for Potash and Mixed Fertilizer Compaction**

Material		Specific Power Consumption: Compactor	Specific Power Consumption: Total Plant
		--- (kWh/mt) ---	
Potassium chloride	Sheet	7	24
	Granulate	14	
Mixed fertilizers	Sheet	13	55
(100-120 kN/cm)	Granulate	36	
Mixed Fertilizers[a]	Sheet	9-11	36-45
(less than 80 kN/cm)	Granulate	18-25	

a. In case of urea based mixed fertilizers the specific power consumption can possibly be reduced substantially.

Examples of Applications in the Fertilizer Industry

Compaction/Granulation of Potash

The typical compaction/granulation system that instantly produces a strong and brittle sheet includes impact mills working in a closed loop with double-deck screens. The impact mills crush the prebroken sheet into an abrasion resistant granulate having a density of about 2,000 kg/m^3. For a gross (throughput) capacity of 80-100 mtph of potash a large compactor with rollers having a 1-m diameter and 1.25-m width is available. The roller press feeder is equipped with five screws. The yield of granular product depends on the desired particle-size distribution and the type of feed. For a particle size range of 1-4 mm the production capacity of the system is between 35 and 55 mtph, depending on whether the feed being compacted has been derived from flotation or crystallization.

Compaction/Granulation of Mixed Fertilizers

Figure 4 represents a typical flowsheet for the compaction of mixed fertilizers in a process which is characterized by the production of a soft and plastic sheet.

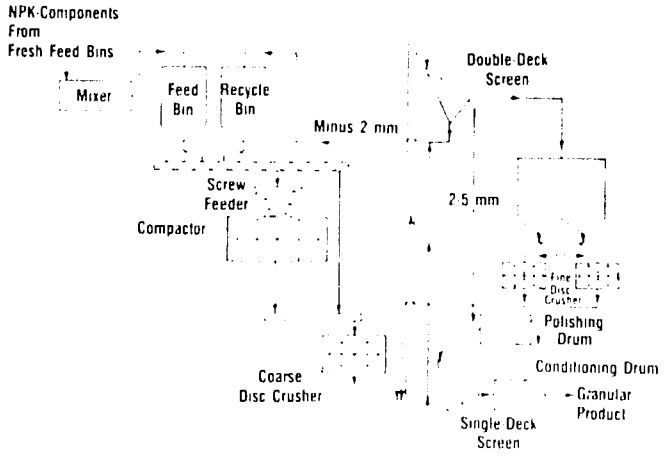


Figure 4. **Flowsheet for a Compaction/Granulation Plant for Mixed Fertilizers.**

Because the still soft sheet must be handled and crushed delicately, special roller mills (disc crushers) are used to cut, shear, or bend the sheet. Additionally, it is often beneficial to age the material in a curing bin before it is crushed.

A plant such as this is in operation at Chemische Fabrik Uetikon in Switzerland. The press features a roller diameter of 650 mm and a width of 560 mm. It is equipped with a twin screw feeder. Fertilizer raw materials such as superphosphate, triple superphosphate, ammonium sulfate, urea, potash, kieserite, and trace elements are combined in different formulations to produce fertilizers for specific applications. Therefore, operation of the plant is characterized by frequent changes of the product mix. The gross capacity of the compactor varies with the formulation from 20 to 26 mtph. Granular products with a size range of 2-5 mm are produced at a rate of 8-12 mtph.

These capacity values were only reached after the smooth roller surfaces were changed to waffled surfaces. With smooth rollers the unit had a throughput capacity of approximately 16 mtph.

Conclusions

Today's intensive farming requires mineral fertilizers which can be applied as single- or multicomponent types. Besides the chemical and physical properties of the fertilizers, their mechanical characteristics play an important role in the fertilizer technology.

Therefore, granulation techniques have been developed to transform the pulverized material into a shape suitable for handling and final use by means of enlarging the grain size. One of these techniques is the binderless (dry) compaction process with subsequent crushing and sizing.

Within a compaction/granulation system the compaction process is of much importance. The compaction process is influenced by a number of parameters including (1) material characteristics, (2) properties associated with the condition of the material (for example, moisture and temperature), and (3) characteristics of the equipment.

The method of (dry) granulation of fertilizers by compaction has proved to have the following advantages:

1. Low power consumption.
2. Elimination of the need for liquid binders.
3. Flexibility in composition of feed.
4. Applicability for a wide range of feed particle sizes.
5. Applicability for all capacities.
6. Possibility for shift (intermittent) operation.

Although sometimes the irregular shape of the particles of compacted granular fertilizers is considered to be a disadvantage, it has been shown that the shape of the particle has no influence on the following requirements for a fertilizer:

1. Sufficient strength.
2. Proper particle size with practically no dust.
3. No caking.
4. Narrow particle size distribution.
5. Free flowing.

Summarizing all the mentioned aspects, it is not surprising that the interest in compaction/granulation technology has increased considerably, as has been documented in a number of new plants in various countries.

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Establishing an NPK Compaction/ Granulation Plant in Guatemala

Larry Taylor, President, The A. J. Sackett & Sons Co.

Introduction

Compaction/granulation is a relatively new and exciting low-cost alternative for producing NPK fertilizers. This paper will discuss three important factors: (1) why use compaction, (2) how to use compaction, and (3) what kinds of fertilizers can be made with compaction.

In order to discuss the design of a compaction plant in Guatemala, I feel it is necessary to discuss the background of the most recent NPK compaction plant and the events leading up to its development.

Background – Compaction/Granulation in Guatemala

Guatemala is a fairly small country in Central America with a population of approximately 8 million. The country is about 400 km wide by 600 km long and it is located in the tropics. Guatemala's climate varies from tropical coastal regions to fairly arid mountain regions. The country produces a wide range of crops. Guatemala does not have any sizable quantities of fertilizer raw materials and imports all of its fertilizer requirements.

Until the early 1970s Guatemala has purchased virtually all of its fertilizer requirements from the United States or Europe. These products were imported in bags and only two or three formulas were available to the farmers.

In the early 1970s, the owners of what is now The FERQUIGUA Group began importing these fertilizers in bulk and bagged the products locally. Shortly after, the same group established their first bulk-blending plant. Since that time bulk blending has been widely accepted throughout the country and is presently the major NPK production method used in Guatemala with approximately 60% of the market share – the remainder being split about evenly between straight materials and imported NPKs from Europe.

By 1985 market penetration for bulk blends had reached its peak, and there was strong opposition from the remaining users of chemically granulated NPK products to use blends. Changing these farmers to bulk blends was perceived as a difficult and highly improbable task in the short term. Unwilling to continue losing this market, the owners of FERQUIGUA decided to look for an alternative method of producing NPKs that would meet the requirements of the farmers and would be economical. Their objective was to be able to produce an NPK that was homogeneous in color and was cost competitive with the products being imported from Europe. After investigating available methods of producing NPKs at the required production rate of approximately 100,000 mtpy, they concluded that compaction was the only alternative that offered the advantages they required at an acceptable investment cost.

The advantages that they saw in compaction were:

1. Production of one color NPK products that would be acceptable to the farmer.
2. Relatively low investment cost. Since this project was funded by private money, this meant a cost that would allow a reasonable return on investment and could produce the required products at a competitive price.
3. Flexibility in terms of raw materials used and final products produced.
4. Simplicity in the maintenance and operation of a plant that was going to be located in a somewhat remote area.
5. Relatively low operating and maintenance costs.
6. Relatively low-energy consumption.
7. Minimization or elimination of significant plant effluents.
8. Plant would complement the existing bulk-blending operations.

Basic Design Criteria

The following criteria were used in determining the plant design:

1. The plant was to be built in the tropics and planned to use urea as a raw material.

2. Plant design needed to incorporate the maximum flexibility in operation and production. From a production viewpoint it was known that supply and cost would dictate the kinds of products made and that these factors would be constantly changing. It was felt that both multinutrient and single nutrient products, as well as micronutrients, would be needed.

3. Screening and crushing was particularly important because farmer acceptance of a "compacted" fertilizer was a major concern.

4. The plant design needed to be such that bulk blending and/or compaction was a possibility.

5. The heat generated at the compactor needed to be dissipated quickly because this affects the product hardness and potential for caking problems.

After a thorough evaluation of these considerations, the following process flow was finalized (Figure 1).

The A. J. Sackett & Sons Company was selected to design the plant and supply most of the equipment except for the compactors. The compactors were purchased from Koppern of West Germany. Some equipment, such as hoppers and structural steel, was fabricated locally according to Sackett's design and drawings. A more detailed discussion of the project is given in the following paper.

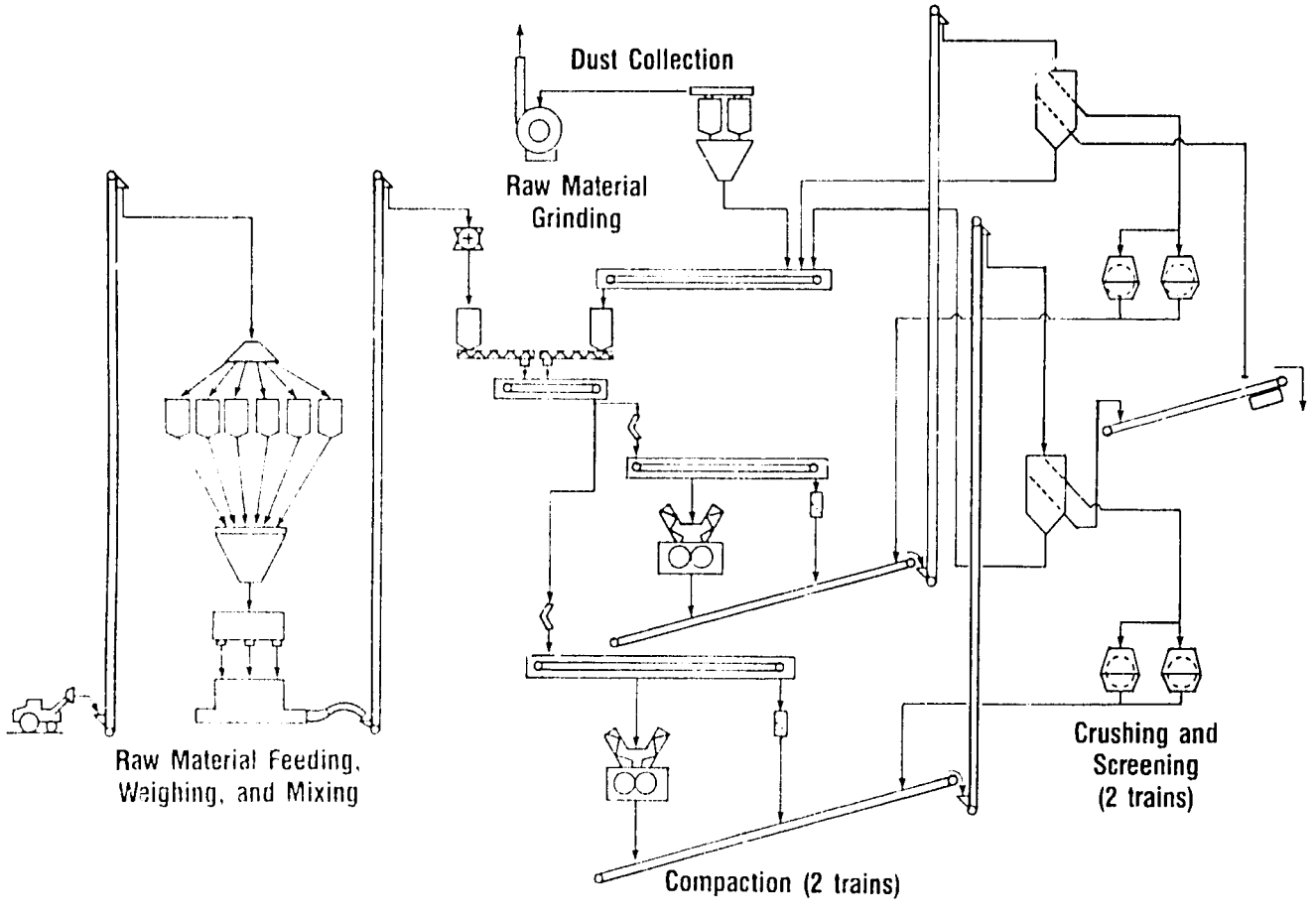


Figure 1. Flowsheet of the FERQUIGUA Fertilizer Compaction/Granulation Plant.

Compaction of NPKs in Guatemala

Cristian Rodriguez, General Manager, FERQUIGUA

Introduction

Our fertilizer group is now 11 years old. The oldest bulk-blending plant was built in 1977 on the south coast of Guatemala in Escuintla. Granular bulk materials were imported through El Salvador to our first plant which has a bulk raw material storage capacity of 6,000 mt and a bagged product storage capacity of 20,000 mt. This plant rapidly became too small for supplying the market when FERTICA abandoned the Guatemala market and when blended products were immediately accepted by our customers. Therefore, a second facility was constructed on the same site and was on stream by 1979. It has a bulk raw materials storage capacity of 17,000 mt and a bagged product storage capacity of 35,000 mt.

Due to political problems in El Salvador, which continue to this day, using the Acajutla port of El Salvador became dangerous; consequently, in 1980 a port facility was constructed 5 km from the Guatemalan Atlantic port of Santo Tomas. Not only did this facility supply the Escuintla plants with raw materials, but this plant opened new markets, including the Del Monte Banana Company, whose installations are 45 km from our plant. This plant also made possible the construction of a new blending plant in Tecuiutan, which began operations in 1987. The Atlantic facility holds 10,000 mt of bulk materials and 3,000 mt of bagged product. It can receive up to 3,000 mt daily from the port using our own discharging equipment and can load 8,000 mt of bulk or bagged product. After an expansion in 1987, the Tecuiutan plant holds 16,000 mt of bulk product and 6,000 mt of bagged product. Our present modus operandi calls for the Tecuiutan plant to supply all blends for intensive vegetable crops using 13 different raw materials while Escuintla covers the south coast and highlands plus bagging urea and ammonium sulfate imported through the Pacific port. The Atlantic facility bags urea, muriate of potash (MOP), and ammonium sulfate. Present production for all facilities is about 40,000 mt of NPKs produced in Tecuiutan, 40,000 mt of NPKs and 50,000 mt of bagged product in Escuintla, and 60,000 mt bagged in Santo Tomas.

Compaction/Granulation Plant

Even though bulk blends have a wide acceptance in Guatemala, especially with the progressive farmer, a small segment of the market never has accepted blends, preferring the uniform colored homogeneous NPKs from Europe. Until 1984 our company imported small quantities of these NPKs to satisfy this demand. One reason for the rapid acceptance of our blends was that even in our low-analysis NPKs, we never used an inert filler; instead, we used granular ammonium sulfate as a source of nitrogen and filler, combined with granular urea, MOP, and diammonium phosphate (DAP). Nonetheless, our competition has had success in exploiting this lack of confidence in bulk blends.

Therefore, in 1986 studies were started on the feasibility of producing a homogeneous NPK fertilizer in a plant economically compatible with the Guatemalan NPK market while also trying to capture the 20% of the NPK market that never bought from us. Other considerations were (1) obtaining lower raw material costs by buying standard instead of granular materials, (2) lower final product costs by using a filler containing local raw materials, (3) complementing our existing bulk-blend plants by producing fillers, and of course (4) being able to make money operating such a plant. After much discussion, compaction was decided to be the best alternative and after visiting existing facilities in Canada, Ohio, and Europe, Koppern of West Germany was contracted to supply the compactors. The A. J. Sackett and Sons Company of the United States has been with our company from the beginning 11 years ago; all our blending and discharging equipment was bought from Sackett and assembled in Guatemala by our personnel. We wanted to take advantage of this special relationship with Sackett; therefore, the final contract called for Koppern to supply two 750-mm diameter by 420-mm wide roller presses with

accompanying equipment (for example, screw-type force feeders, hydraulic pumps, and grease pumps), while Sackett supplied the engineering and critical raw material feed and in-process material handling/processing equipment. Our group assembled the plant and fabricated hoppers, ducts, bucket elevator segments, and such equipment on location in Tecuilutan. Construction of a prestressed concrete structure for the process equipment, raw materials, and bagged product storage was begun in 1985 and production of NPKs began in March 1987.

Table 1. Typical Screen Analysis at Various Points FERQUIGUA – Guatemala[a]

Primary Feed Hopper Below Cage Mill (Point 1)			Recycle Feed Hopper (Point 2)		
Mesh	% Retained	% Accumulated	Mesh	% Retained	% Accumulated
6	0	0	6	1.07	1.07
10	0.15	0.15	10	10.11	11.18
14	0.55	0.70	12	6.12	17.30
16	0.60	1.30	14	11.63	28.93
18	1.06	2.36	16	3.72	32.65
20	1.66	4.02	18	13.01	45.66
30	1.91	5.93	20	9.56	55.22
45	13.67	19.60	30	10.30	65.52
60	34.17	53.77	45	23.49	89.01
80	25.18	78.95	80	9.32	98.33
100	13.67	92.62	80	0.37	98.70
−100	7.38	100.00	−100	1.30	100.00

Entering Chain Mill (Point 3)			Leaving Chain Mill (Point 4)		
Mesh	% Retained	% Accumulated	Mesh	% Retained	% Accumulated
¼ in	74.57	74.57	¼ in	25.75	25.75
4	7.16	81.73	4	9.94	35.69
6	13.38	95.11	6	22.71	58.40
10	3.88	98.99	10	17.94	76.34
12	0.38	99.37	12	5.88	82.22
14	0.30	99.67	14	12.75	94.97
16	0.11	99.78	16	1.51	96.48
18	0.22	100.00	18	3.09	99.57
			20	0.43	100.00

Finished Product (Point 5)		
Mesh	% Retained	% Accumulated
6	0.41	0.41
8	16.94	17.35
10	67.94	85.29
12	8.64	93.90
14	3.38	97.28
16	1.33	98.61
18	0.93	99.54
20	0.46	100.00

a. Refer to Figure 1 for location of sample point. Mesh sizes refer to Tyler series.

The cost of the final compaction/granulation/storage installation can be broken down as follows:

1. 4,700 m² prestressed concrete building covered with mineral/cement sheeting to house machinery and 25,000 mt bulk product, 5,000 mt bagged product; ground work, civil work, and miscellaneous – US $600,000.

2. Koppern: compaction equipment consisting of two compactors, accessories, and spare parts – US $950,000 (based on 2.70 DM/US $1.0).

3. Sackett: related process equipment and engineering – US $800,000.

4. Electrical installation and miscellaneous – US $200,000.

Total: US $2,550,000.

After many fits and false starts, the plant started production in March of 1987 and compacted 23,000 mt of NPKs until October 1987. After 2 months of maintenance and some corrective engineering, we began our 1988 season and have produced 50,000 mt to date (October 1988). Acceptance of the product has been so good that our monthly capacity of 8,000 mt has been exceeded by sales three times, therefore in peak season we cannot produce enough to cover the demand. In 1990 we are considering expanding to three production lines by adding another train of equipment.

Now I would like to describe the compaction plant to give you a better idea of the concept and workings of the FERQUIGUA plant.

The flowsheet of the plant (refer to Figure 1) starts with front end loaders (1) that feed a bulk conditioner, which in turn feeds six material bins (2). A Toledo batch computer prepares the individual 3-ton batches, feeding the product into a weigh hopper (3) first, then to a 4-ton rotary blender (4). A second elevator raises the product to a double-row cage mill (5) which grinds the product to minus 60- plus 100-mesh and discharges it into a primary hopper. Recycle product and primary product are mixed in a double-shaft pug mill (6) before passing over magnetic humps and splitting into two production lines, where

two chain-type drag conveyors feed the screw-type force feeders of the compaction units (7). An overflow is needed to ensure sufficient flow of product to the compactors; overflow product from the chain conveyors is connected to the flake conveyor beneath the compactors. After compaction the flakes are fed through two elevators to the double-deck screens (8), currently minus 4- plus 8-mesh. The screens divide the material into oversize that is routed to the chain mills (9), undersize that is returned to the pug mill by a recycle conveyor, and onsize product that passes directly to the bagging or bulk hopper. Refer to Table 1 for typical material size data at various points in the process.

Fans with dry-type cyclones (10) are located in the middle of the plant area to collect all dust from the dust-producing areas. This dust is returned to the process by the recycle conveyor. Emissions to the outside environment are practically nil, as is product loss from the system.

All process conditions are closely monitored and recorded including the large number of variables controlled by the operator including (1) velocity (quantity) of fresh feed to the cage mill, (2) production of fresh versus recycle feed to the pug mill, (3) velocity or RPM of the screw-type force feeders, (4) hydraulic pressure on the floating roller of the compactor, (5) speed of the chain mills, and (6) size of the final product (by changing screen size if needed). Upon changeover from one product to another, many of these variables change due to the different raw material composition of the formulas.

When I spoke earlier of fits and false starts in 1987 during startup operations, I was referring basically to all these adjustments and the learning process involved in teaching our employees to correctly operate the plant. After almost 2 years of operating the plant, we have learned a lot about compaction and the plant has responded beyond our dreams to most of our objectives.

A summation of the major advantages we have found in compaction/granulation compared with other granulation methods follows.

Flexibility—We thought that we would have production runs of 2-3 days per formula and consequently would have to maintain large stocks of bagged product. However, we have run as low as 10 tons of product through the plant and can calculate closely a certain formula down to as little as 200 bags, each containing 46 kg. Changing

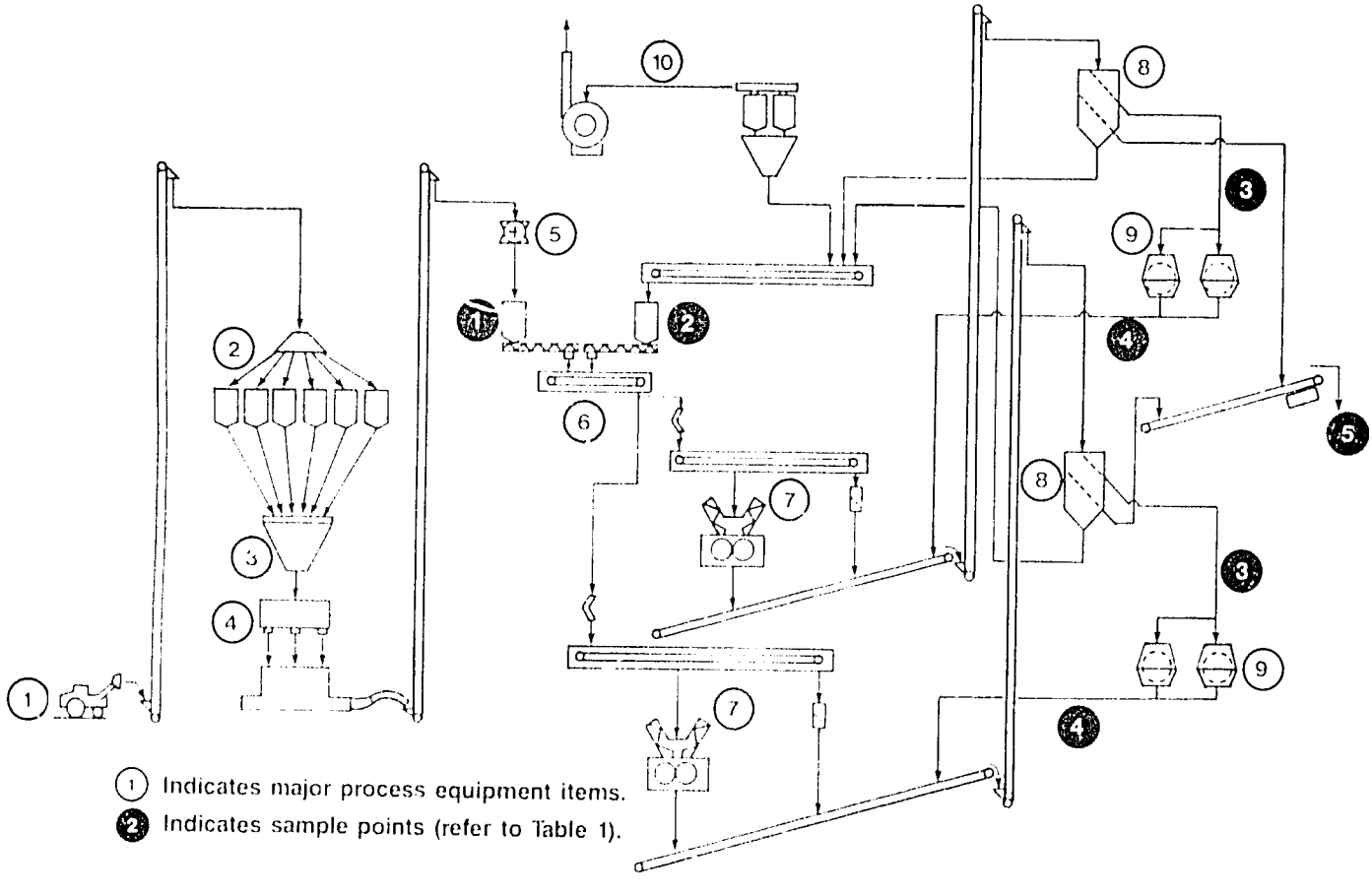


Figure 1. **Flowsheet of the FERQUIGUA Fertilizer Compaction/Granulation Plant.**

products is not the headache we expected; we stop feeding primary product and compact recycle material until it is gone. A turnaround in product grade can be accomplished in as little as 20 minutes.

Prescription Sales – We can use many raw materials; at present we use urea, ammonium sulfate, phosphate rock, MOP, monoammonium phosphate (MAP), kieserite, boron compounds, zinc oxide, K-Mag, gypsum, dolomite, and various other micronutrients. With this mix of raw materials we can make fertilizers for different crops in different areas. Coffee and cardamom are excellent examples of crops grown in areas where phosphate rock is a viable and cheap manner of obtaining slow-release phosphorus. Boron is a very expensive raw material deficient in practically all Guatemalan soils but in differing ranges. We can add 0.5%, 1%, or 2% boron (B_2O_3), depending upon the necessity of the crop and farmer. For basic grains it is easy to alter concentrations of phosphorus and potassium and at the same time add micronutrients.

Bulk Blending/Compaction Plant Compatibility – There are some raw materials that we cannot compact economically at this time. Our blending plants have traditionally used granular ammonium sulfate as filler in traditional formulas such as 16-20-0 or 20-20-0. Now we can make a substitute filler using urea, MAP, and gypsum, which is much cheaper than ammonium sulfate. We can also compact different types of phosphorus to obtain different agronomic reactions, such as MAP and phosphate rock. The flexibility offered to the farmer by having both plants together is enormous; we have made more than 200 different combinations of NPK plus micronutrients. We also have enormous flexibility in using different raw materials to make the same fertilizer, taking advantage of price fluctuations in the international marketplace.

Remember that Guatemala is a small country about the size of Ohio that plants bananas, coffee, sugarcane, melons, tobacco, tomatoes, strawberries, flowers, and more, at elevations from the Atlantic to the Pacific of sea level to 10,000 ft, in soils that range from volcanic to tropical rain forest, with rainfall from 5 inches to 300 inches per annum.

Guatemala is not different from many tropical countries; using four or five different NPK fertilizers is not agronomically correct. We are proud to note that we handle 22 different raw materials and we believe that flowability and customer satisfaction are the way to correctly supply a tropical country with fertilizer. A large wet-type/chemical granulation plant for all Central America would not be appropriate for the individual farmer needs and such huge plants only contribute to the debt burden on these countries. The Third World countries need to modernize their agricultural production not only to feed their people but to export produce to the industrialized countries. The only way to produce for the U.S. market, for example, is to be flexible with lots of fertilizer raw materials for producing export crops such as melons, mangoes, cucumbers, tomatoes, and to adapt to changing conditions from one day to another, that's agriculture. With our bulk-blend/compaction complex, we can meet that demand.

Emissions – The FERTICA plants in Central America have had problems with air pollution, and one of our major objectives was to have no environmental problems in this process. With the dedusting system now in place, we have no emissions from our stack.

Operating Costs – We were most concerned about electrical costs in the operation of the plant because comparing our bulk-blending plant with the compaction plant in transformer capacity, we note a difference of 375 kV compared with 3,000 kV. We had estimated an electrical cost of US $2.50/mt, but in reality we are spending only US $0.53/mt or 11.9 kWh/mt. All labor costs amount to US $3.00/mt; therefore, even though these costs are higher than in our bulk-blending facilities, they are much lower than expected.

Low Downtime/Simple Maintenance – Last year we shut down the plant for 2 months for repairs and maintenance; this year due to higher demand for our products our shutdown time will be 1 month. This year we worked full capacity in the plant for 100 consecutive days and the downtime during that period was less than 5%. There are 50 different machines in the process, but they are all basically simple, and most spare parts are shelf items that can be readily obtained in Guatemala. With a good preventive maintenance program, downtime can be kept to a minimum. After 10 years' experience with Murphy's Law, the consensus was to construct two separate production lines, therefore two small compactors were bought instead of one larger model. This factor alone gives us tremendous help in those instances when repairs must be made because stopping the process and accumulating product in

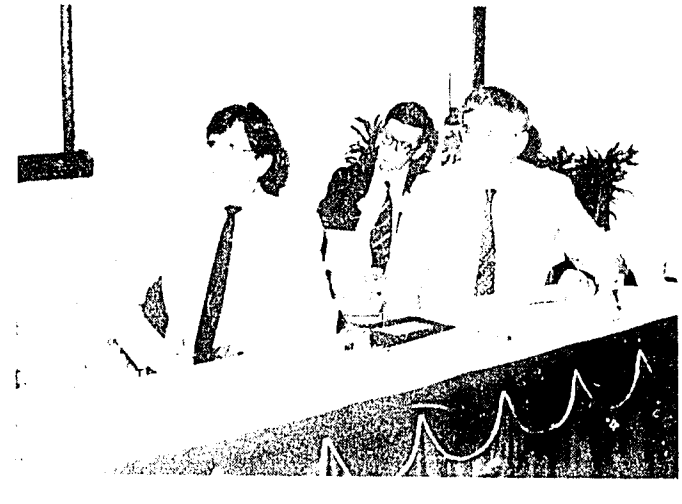
hoppers is a sure headache; therefore, we can shut down the flow to one line and keep the product in the hoppers moving.

Difficulties/Disappointments—There are some things that are difficult in the plant, such as compacting any material that is wet. Some raw materials compact better when they have 1% or 2% water added to enhance the compactibility of the product. But generally speaking any product with 4% or more water is very difficult to work.

After passing the product through the double row cage mill, basically where we grind the urea since all other raw materials are fine, the product is very hygroscopic, and any time we stop the production process it is very difficult to start again. Also any dust that escapes the dust collection system rapidly turns to water due to the urea content in the NPKs. Therefore, it's difficult to maintain this plant as clean as the bulk-blending plant, for example. However, after seeing quite a few fertilizer plants, I consider our complex cleaner than most.

We've also had problems with the dust collection system due to the hygroscopic nature of the products. Dust sticks to the ducts and upon turning off the fans for any reason, any product deposited inside the ducts rapidly becomes very moist and very difficult to recycle.

However, we consider these problems minor, and even though difficult to solve, we can easily live with them. In synthesis we are so happy with the system that we would like to offer our plant to anyone for tests of the compactibility of different products. We would also be willing to help anyone with the design of a similar compaction plant and/or the transfer of our knowledge and experiences to other plants. Feel free to contact us directly or through Sackett for any consultations or trials that interest you. Our plant is not a pilot operation, therefore we need time to set up any trials that you might have, and from October until February is our slack season, when we have time for any such trials.



Raw Material Requirements for Quality Bulk Blends

Mabry M. Handley, Director of Technical Services, IMC Fertilizer, Inc.

Abstract

A high-quality bulk-blend fertilizer should have the correct analysis, be free-flowing, thoroughly mixed, essentially nonsegregating, and nonhygroscopic. To obtain a bulk-blend fertilizer of such high quality it is necessary to choose raw materials of known chemical composition, mix only materials that are compatible, and closely match the particle size of the various components. Whenever the particle size of one or more of the components diverges 10% or more from the average particle size of the other constituents, excessive segregation will most likely occur.

Introduction

The selection of raw materials for the production of quality bulk-blended fertilizer is a subject that has been explored in great detail in the past, but is also one that deserves review periodically because of the rapid changes taking place in the use and distribution of bulk-blended fertilizers.

A high-quality bulk blend has certain important properties.

It should be free-flowing.
It should have the correct analysis.
It should be thoroughly mixed.
It should be essentially nonsegregating.
It should be essentially nonhygroscopic.

Therefore, the first steps in selecting materials are to chose those with a known chemical analysis, mix only those known to be compatible and select materials which are closely matched in particle size. Even when the operating procedures and equipment are perfect, if the nutrient contents of the raw materials are not correct or if the materials are not size-matched within certain limits, the final product will not meet guarantees.

Properties of Raw Materials That Influence Bulk Blends

Each of the N, P and K raw materials used in bulk-blended fertilizers has unique chemical and physical properties which must be taken into consideration when planning methods of handling and storing these materials.

Nitrogen Raw Materials

The major sources of nitrogen used in bulk-blended fertilizers are:

1. Ammonium nitrate
2. Urea.
3. Ammonium phosphates.
4. Ammonium sulfate.
5. Potassium nitrate.

All of these products are relatively easy to transport, store, and handle. They can be shipped in barge, ship, boxcar, hopper cars, and trucks, in either bulk or bags. Storage can be provided in any type of building that has a substantial floor such as treated concrete or asphalt and has weatherproof roof and walls. They can be handled with short augers, draglines, belt conveyors, or front-end loaders.

All solid nitrogen products will absorb moisture from the atmosphere when the atmospheric relative humidity exceeds the critical relative humidity (CRH) of the product. Table 1 shows the CRH of some nitrogen materials at 30°C.

Table 1. **Critical Relative Humidity of Some Nitrogen Fertilizers**

Material	Critical Relative Humidity at 30°C (%)
Ammonium nitrate	59.4
Urea	72.5
Ammonium sulfate	79.2
Potassium nitrate	90.5
Monoammonium phosphate	91.6

Whenever two or more sources of solid nitrogen are combined the critical relative humidity for the combination is usually lower than that of the individual salts.

Table 2 shows the critical relative humidity of some nitrogen mixtures at 30°C.

Table 2. **Critical Relative Humidity of Mixtures of Nitrogen Materials**

Material	Critical Relative Humidity at 30°C (%)
Urea and potassium nitrate	65.2
Ammonium sulfate and ammonium nitrate	62.3
Ammonium nitrate and potassium nitrate	59.0
Urea and ammonium sulfate	56.4
Ammonium nitrate and urea	18.1

Some nitrogen materials will react with other plant food sources to create severe caking problems in bulk or bagged storage. An example of a reaction of this type is one that may occur when triple superphosphate and ammonium sulfate are combined.

$$Ca(H_2PO_4)_2 + (NH_4)_2SO_4 \rightarrow 2NH_4H_2PO_4 + CaSO_4$$

Monocalcium phosphate — Ammonium sulfate — Monoammonium phosphate — Gypsum

When this reaction occurs in a pile or bag, severe caking may result.

Several other combinations can also have reactions. A chart developed by the Tennessee Valley Authority (TVA) shows chemical compatibility of some common blend materials.

Phosphate Raw Materials

The major sources of phosphate used in bulk-blended fertilizers are:

1. Ammonium phosphates.
2. Triple superphosphate.
3. Normal superphosphate.

These products are easy to handle and store in a granular form. They are not so hygroscopic as nitrogen products such as ammonium nitrate and urea and unless they are stored under very severe conditions of humidity, they will usually remain free-flowing.

The most common grades of ammonium phosphates used in blending are:

1. 18-46-0.
2. 16-48-0.
3. 12-48-0.
4. 12-36-0.
5. 11-52-0.
6. 10-50-0.

Diammonium phosphate (18-46-0) can release small amounts of free ammonium under conditions of high atmospheric temperature and high humidity. If this ammonia is released in the presence of triple superphosphate, a reaction can take place which causes the mixture to "cake." Usually, however, this reaction is of little consequence in bulk blends.

Potash Raw Materials

The most common forms of potash used in blending are:

Muriate of potash, usually sold to bulk blenders as a coarse or granular material in the form of natural crystals, compacted product, or crystals formed from dissolving and recrystallizing muriate salts. The coarse material usually falls in the size range of minus 8- plus 28-mesh, and the granular muriate is usually in the size range of minus 6- plus 20-mesh. Both of these products are easy to handle and store.

The critical relative humidity for granular and coarse muriate of potash is 83.0% at 30°C.

Sulfate of potash is sold to bulk blenders as a granular material in the size range of minus 6- plus 20-mesh. This product has a critical relative humidity of 96.3% at 30°C.

Potassium nitrate is sold as a prilled product in the size range of minus 6- plus 20-mesh. This product has a critical relative humidity of 90.5% at 30°C.

Sulfate of potash-magnesium is sold to blenders as a coarse product in the size range of minus 6- plus 28-mesh. This product has a critical relative humidity of 92.0% at 30°C.

Physical Properties of Raw Materials That Influence Bulk Blends

Particle Size

Segregation of bulk blends is a continuing problem in the fertilizer industry. It is usually considered to be the result of incomplete mixing or subsequent unmixing of the plant food materials. When such segregation occurs a sample taken will not have the guaranteed chemical com-

position. This, of course, presupposes that all of the proper amounts of plant food were introduced into the formula and none were lost during the mixing process.

It is important to recognize that many recorded deficiencies are a direct result of improper formulations, for example, failure to add the correct quantities of constituents or the loss of some of the plant food values during the mixing step. It is equally important to recognize that sampling techniques can lead to apparent segregation or deficiencies in analysis. How and where a sample is taken and the way the sample is prepared have a definite bearing on the analysis. Many deficiencies are believed to reflect problems with uniformity rather than actual deficiencies in average composition.

Now that segregation has more or less been defined, one more basic fact should be considered. Some segregation is virtually impossible to avoid in manufacturing mixed fertilizer. To completely avoid it, the current method of manufacturing mixed fertilizers would require homogeneous materials rather than the heterogeneous ones we must use. Any mixture of heterogeneous products will show tendencies toward segregation. All that can be done is to work to reduce this tendency to acceptable tolerances.

It is generally known, from studies at TVA and by others, that differences in particle sizes between blending materials have a much greater effect on segregation than any other parameter, including density and particle shape. Closely size-matched materials produce a blend having a low tendency to segregate.

The real problem in segregating materials is how closely the material must be size matched to prevent problems. TVA field experiences indicate that if each particle size fraction of materials used in blends is within 10% of the average particle size of all the materials used in the blend, significant segregation is unlikely to occur. If the size fractions are within 20% of each other, segregation may not occur to any great extent provided the blends are carefully handled and anti-segregation devices such as baffles are used. Any difference greater than this is very likely to cause problems. For really reliable control of size, a blender needs to obtain complete and reliable screen analyses on all of his blend materials from the suppliers, or run his own screen analyses. The compatibility of a typical diammonium phosphate with a coarse grade of muriate of potash as well as that of DAP with a granular muriate of potash can be determined graphically. An easy way to compare the different materials is to plot their screen analyses on a graph. The closer the materials are in size the closer the curves will be and the less the tendency for segregation.

In conclusion, one can predict the segregation tendencies of fertilizer blends. The smaller the divergence in particle size the less is the chance of segregation. Again, blends with no more than 10% divergence show good field stability, those of between 10% and 20% differences will be acceptable if handled gently. Any greater variation in particle size may cause the mixture to segregate after it has been blended. Size matching of materials is very important in the production of quality bulk blends.

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Comparative Advantages and Disadvantages of Blended and Granulated NPK Fertilizers

James J. Schultz, Fertilizer Production Specialist, International Fertilizer Development Center

Abstract

NPK fertilizer plants based on bulk blending cost less to build and are easier to operate than comparable sized granulation plants. Bulk-blend plants have more flexibility than granulation units, both in changing formulations and in the number of formulations that can be made. However, because of the tendency of mixtures of dry materials to segregate during handling unless all the components are well matched with respect to particle size, bulk-blended fertilizers are often less homogeneous than granulated products. This paper discusses the technical and economic advantages and constraints of bulk blending and granulation.

Introduction

Bulk-blended fertilizers offer certain economic, technical, and agronomic advantages over homogeneous granular fertilizers (compounds). However, blends are also beset with some disadvantages. The advantages and disadvantages are sometimes exaggerated or distorted depending upon one's point of view or objective. This paper will attempt to objectively appraise the relative merits of these two basic forms of multinutrient (NPK) fertilizer (blends and compounds).

Economic Factors

In discussing the economic merits relative to the production of blends and compounds, it is important to look at the major economic components of each production method – these include (1) fixed capital investment, (2) working capital required for raw materials, (3) fixed and variable conversion costs, and finally (4) raw material costs. A discussion of each component follows.

Capital Investment

Fixed Capital – As illustrated in Table 1, the fixed capital portion of the total investment required for a grass roots bulk-blending facility is only about 20% of that required for an equivalent ammonium phosphate-based NPK granulation unit. In this example, both plant investment estimates are based on a grass roots facility (cost of land not included) at an assumed water port location. An annual production of 200,000 mt at 80% capacity utilization is assumed. In both cases, storage facilities for raw materials and finished products represent a considerable percentage of the total fixed investment – about 56% for the blending plant and about 20% for the granulation plant. Since these investment estimates assume importation of all raw materials to the plant site, the storage facilities are quite large to accommodate large shipments and provide a reasonable degree of supply security.

Table 1. **Capital Investment Estimate – Bulk Blending and Chemical Granulation**

Cost basis: Mid-1987 US $
Plant location: Caribbean Region
Plant capacity: 200,000 mtpy at 80% capacity utilization

Item	Estimated Cost, US $ millions	
	Bulk Blending	Chemical Granulation
Bulk blending unit, battery limits	0.5	-
Granulation unit, battery limits	-	12.0
Bulk storage and handling facilities (raw materials and products)	2.3	1.9
Liquid storage and handling facilities (ammonia, sulfuric acid, and phosphoric acid)	-	2.2
Auxiliary and support facilities	0.8	2.3
Total installed cost	3.6	18.4
Project management and plant startup	0.2	0.9
Interest during construction	0.3	1.5
Total fixed investment	4.1	20.8
Working capital	5.0	3.8
Total Capital Investment	9.1	24.6

Working Capital

The relatively large inventory of raw materials and products, of course, has a significant influence on the required working capital which amounts to about US $5 million for the blending plant (about 55% of total capital investment of US $9.1 million) and US $3.8 million for the granulation plant (about 15% of total capital investment of US $24.6 million).

Production Cost

The estimated total production cost for a 15-15-15-2Mg-4S-1B product produced by blending and by granulation is shown in Table 2. Raw material consumption data (production formulas) for this product produced by blending and granulation are shown in Tables 3 and 4. In each case the production cost consists of two major components: (1) raw material cost and (2) conversion cost. The conversion cost is further broken down into fixed and variable items. For the purpose of this discussion, the cost of raw materials is estimated on the basis of the average f.o.b. U.S. Gulf Coast prices plus delivery to the plant site. The prices have also been adjusted upward to correct for the current depressed price structure which is assumed to be temporary. The individual components of these production cost estimates may vary quite widely from one location to another. However, the purpose of this comparison is to illustrate the approximate differential one could expect with the two production methods.

Technical Factors

Process Simplicity

Most people are already well aware of the relative simplicity of bulk blending compared with the more complex technical requirements of ammonium phosphate-based or other chemical granulation methods. Bulk blending, as can be observed from the above investment data, requires relatively simple equipment and operating procedures. As a result the skills and cost required for operation and maintenance of bulk-blending units are quite modest compared with those needed for the more complex chemical granulation route (about US $2.1/mt for blending, not including interest on working capital or fixed capital recovery, and about US $14.1/mt for granulation).

Product and Raw Material Flexibility

Since bulk blending involves only the weighing and mixing of dry materials (except perhaps the use of some special liquid binders), it is a relatively simple matter to quickly change from one product (nutrient ratio and composition) to another. This capability is perhaps the major advantage of blending over granulation. The ability to quickly and economically change products is further facilitated by the batch-type method of mixing used by most bulk blenders. In most cases the batch size is in the range of 1 to 5 mt.

Table 2. **Production Cost Estimate – Bulk Blending and Chemical Granulation**

Material[a]	Estimated Cost: Bulk Blending	Estimated Cost: Chemical Granulation
	(US $/mt 15-15-15-2Mg-4S-1B)	
Prilled urea 46-0-0 (US $130/mt)	-	26.9
Granular urea 46-0-0 (US $140/mt)	28.3	-
Granular diammonium phosphate 18-46-0 (US $180/mt)	59.4	-
Standard sulfate of potash magnesium 0-0-22-11Mg-22S (US $75/mt)	-	13.7
Granular sulfate of potash magnesium 0-0-22-11Mg-22S (US $85/mt)	15.5	-
Standard muriate of potash 0-0-60 (US $75/mt)	-	14.0
Granular muriate of potash 0-0-60 (US $85/mt)	15.9	-
Ammonia 82-0-0 (US $125/mt)	-	8.8
Phosphoric acid 52% P_2O_5 (US $150/mt)	-	43.8
Borax 11% B (US $260/mt)	-	23.7
Solubor® 20% B (US $560/mt)	28.0	-
Conditioning powder (US $40/mt)	0.6	0.6
Liquid binder wax/oil (US $300/mt)	1.5	-
Granular filler (US $30/mt)	0.9	-
Subtotal	150.1	131.5
Variable Conversion Costs		
Electricity (US $0.04/kWh)	0.2	2.0
Steam (US $10/mt)	-	0.3
Water (US $0.50/mt)	-	1.0
Process fuel (US $8.0/million kcal)	-	0.6
Miscellaneous chemicals and supplies including mobile equipment fuel	0.3	0.5
Subtotal	0.5	4.4
Fixed Conversion Cost		
Operating labor	0.5	2.5
Overhead and general expenses	0.5	2.5
Maintenance (labor and materials)	0.4	3.7
Insurance and taxes (1% of fixed investment)	0.2	1.0
Interest on working capital (15% of working capital	3.8	2.9
Fixed capital recovery (17.1% of fixed investment)	3.5	17.8
Subtotal	8.9	30.4
Total Production Cost	159.5	166.3

a. Refer to Tables 3 and 4 for material consumption per metric ton of product (production formula).

Table 3. **Bulk Blend Formula for 15-15-15-2Mg-4S-1B**

Material[a]	kg/mt	N	P_2O_5	K_2O	Mg	S	B
		(kg/mt)					
Urea 46-0-0	202	93					
Diammonium phosphate 18-46-0	330	59	152				
Sulfate of potash magnesium 0-0-22-11Mg-22S	182			40	20	40	
Muriate of potash 0-0-60	187			112			
Solubor® powder 20% B	50						10
Filler	29						
Conditioning powder	15						
Liquid binder (oil or wax)	5						
	1,000	152[b]	152[b]	152[b]	20	40	10

a. All materials are granular except as noted.
b. Typical overformulation to account for process variations.

Table 4. **Chemical Granulation Formula for 15-15-15-2Mg-4S-1B**

Material[a]	kg/mt	N	P_2O_5	K_2O	Mg	S	B
		(kg/mt)					
Prilled urea 46-0-0	207	95					
Phosphoric acid 0-52-0	292		152				
Ammonia 82-0-0	70	57					
Standard sulfate of potash magnesium 0-0-22-11Mg-22S	182			40	20	40	
Standard muriate of potash 0-0-60	187			112			
Borax 11% B	91						10
Conditioning powder	15						
Product moisture	5						
	1,049						
Water evaporation	-49						
	1,000	152[a]	152[a]	152[a]	20	40	10

a. Typical overformulation to account for potash variations.

Bulk blending is also very flexible with respect to the number of grades and nutrient ratios that can be prepared from a few basic raw materials. This is illustrated in Table 5. In this example seven nutrient ratios can be prepared from three basic raw materials – urea, diammonium phosphate (DAP), and muriate of potash (KCl). Likewise, since no chemical processing is involved, a relatively large number of raw materials can be used to produce a given product provided the materials are chemically and physically compatible.

A chemical granulation plant is operated on a continuous basis and is much more restricted with regard to the number of grades that can be produced and the raw materials that can be economically processed.

In a typical NPK granulation plant about 4-12 hours are required for the plant to come to equilibrium when changing from one grade to another. This "grade change period" varies quite widely depending upon the magnitude of the change and the specific process and operating parameters. The change is usually made without totally interrupting the operation. However, during the grade change period the production rate is usually decreased and the raw material feed rates are adjusted to bring about the desired change in analysis (grade) as quickly as possible. During the grade change period, the product is continually discharged to storage and is usually routed to one of three locations – (1) the former (old) product bin, (2) the new product bin, or (3) an off-specification or "rework" bin. However, in most cases the accumulation of

off-specification (rework) product is avoided for obvious reasons.

Table 5. **Example of Bulk Blends That Can Be Prepared From Three Raw Materials**

Nominal Nutrient Ratio	Maximum Grade			Quantity of Raw Material Required[a]		
	N	P_2O_5	K_2O	Urea	DAP	MOP
	- - - - - (%) - - - - -			- - - - - - (kg/mt) - - - - -		
1:1:1	19	19	19	261	418	321
1:1:3	11	11	35	159	255	586
1:2:1	15	30	15	75	669	256
2:1:1	26	13	13	482	293	225
2:2:1	22	22	11	310	499	191
3:1:1	31	10	10	601	226	173
4:1:1	34	8	8	676	184	140

a. Raw material analysis: urea 46% N, DAP 18% N and 46% P_2O_5, and MOP 60% K_2O.

Flexibility in Capacity

Blending plants are also very flexible with respect to capacity. Since the process is usually operated on a batch basis and no process chemistry is involved, it is a relatively simple matter to change the daily or annual capacity simply by changing the length of the workday. For example, a 5-mt batch blending plant could produce from about 250 mtpd to about 750 mtpd depending upon the number of hours the unit is operated. Such flexibility in capacity would be very uneconomical to achieve in a granulation plant.

Incorporation of Micronutrients

The uniform incorporation of micronutrients into granular bulk blends is quite difficult because of the small quantity usually required (often about 1-10 kg/mt) and the lack of certain micronutrient sources that are of the proper particle size—be it a fine powder or a granular material.

On the other hand, granulation offers a very effective method for incorporating a wide variety of secondary and micronutrients into a homogeneous and stable product. However, even with granulation certain precautions must be taken to avoid unwanted reactions that may adversely effect the solubility of the micronutrient and its possible agronomic effectiveness.

Product Quality

The quality of bulk blends is almost completely determined by the quality and compatibility of the raw materials. For this reason, it is essential that the raw materials used for blending be chemically compatible, properly matched with respect to size, and sufficiently durable to resist degradation during handling. Although the required high-quality raw materials for bulk blending are available in the international marketplace, often, for economic reasons they are not always used. Substitution of less costly raw materials that do not meet the relatively rigid specifications required for the production of high quality bulk blends almost always leads to segregation and other problems related to product quality and agronomic performance.

Most granulation plants, on the other hand, are not so restrictive relative to raw material quality. Such plants, in fact, require nongranular raw materials for optimum results. The ability of most NPK granulation plants to use a wide variety of less costly nongranular and sometimes off-specification raw materials is a major advantage of such plants. However, as indicated in Table 2, the cost of processing the lower cost raw materials into high-quality homogeneous granular products may partially or completely offset the savings in the cost of raw materials.

Agronomic and Marketing Factors

Agronomic Performance

It is important to emphasize that the agronomic performance of fertilizers can be significantly affected by the method of production. In the case of blends, free flowing homogeneous mixtures are essential for optimum performance on most crops. Caking and segregation caused by incompatible sizes and/or inadequate particle size distribution or other technical faults will often result in an erratic crop response to the applied nutrients. The erratic response is more apt to occur on the shorter growing season food crops than on the longer term tree crops such as rubber and oil palm.

Likewise, in the case of granulation, the solubility of the nutrients may be adversely altered by unwanted chemical reactions and other unfavorable process conditions. The solubilities of phosphate and certain micronutrient compounds are most likely to be altered if care is not taken in the selection and control of the granulation process. Even with granulation, segregation of the nutrient sources (especially potash) can occur if care is not taken in selecting and controlling the particle size of the raw materials fed to the process.

Appearance and Farmer Acceptance

The raw materials (nutrient sources) used to make bulk blends are often quite contrasting in color—ranging from white to shades of brown and red. The difference in color of the individual nutrients, and therefore the multicolor appearance of blends, often causes some initial resistance from dealers and farmers who are accustomed

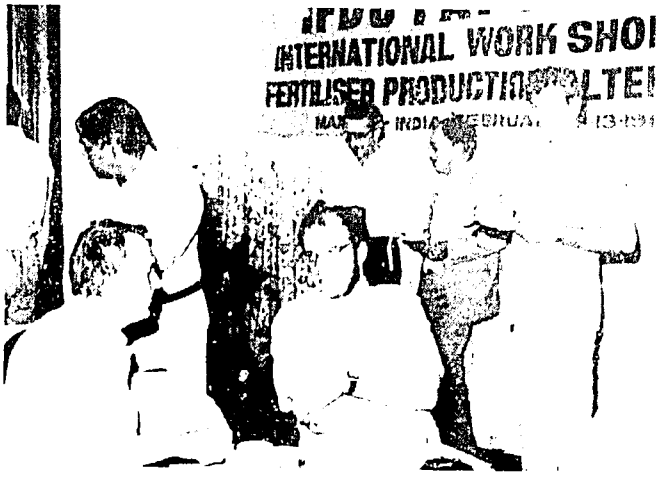
to a homogeneous granular product that is uniform in color. On the other hand, the visibility of the individual nutrients in a blend may offer some assurance to the farmer that he is receiving the product described on the label. This visual assurance is especially of value if the farmer suspects that the fertilizer may have been adulterated. Coloring agents are sometimes added to blends to achieve a more uniform color or to relate a particular blend to a certain crop - for example, blue for soybeans or green for maize. In any case, the successful introduction of bulk blends into the marketplace must take into consideration the appearance of the product as well as its performance. The issue of appearance becomes less important once the farmer becomes convinced that the product's performance equals or exceeds his expectations.

Field Application

Uniform application of applied nutrients is a prerequisite to optimizing agronomic performance and therefore farmer acceptance. Well-manufactured (nonsegregating) blends and homogeneous compounds would be expected to perform the same whether point- or band-placement methods are used. However, if spinner-type broadcast application techniques are used, inferior results may result from some blends. This is because of the difference in the ballistic characteristics of the individual raw material particles due to variations in density, shape, and surface texture. The individual particles (granules) of homogeneous compounds are more uniform with respect to density, shape, and surface texture; therefore, a more uniform distribution of the nutrients would be expected with most compounds.

Conclusion

From this discussion it becomes clear that blends and compounds exhibit important advantages and disadvantages with regard to economics of production, production technology, and farm-level use. The relative importance of each advantage and disadvantage is often highly dependent upon local conditions. Nevertheless, a thorough understanding of the possible problems that may be encountered when introducing bulk blended products to the farmer is needed to ensure the greatest level of success.



Economic Comparisons of Selected NPK Fertilizer Production Alternatives

James J. Schultz, Fertilizer Production Specialist, and
Nam D. Le, Chemical Engineer (Project Analyst), International Fertilizer Development Center

Abstract

World production of all fertilizer products currently amounts to about 400 million tonnes annually containing about 136 million tonnes of nutrients ($N + P_2O_5 + K_2O$). Of this amount, about 50% is produced in some form of granule. The granule size of individual products varies quite widely depending upon the production process and location (market preference). However, in most cases the particle size range of "granular" fertilizers is usually between 1 and 5 mm.

This paper will examine, in a comparative way, the economics of four basic methods (production technologies) commonly used to produce a major portion of the world's multinutrient (NPK) products which amount to about 15% (about 60 million tonnes annually excluding binary products such as ammonium phosphate) of total world fertilizer production.

Brief Description of Selected NPK Production Technologies

A very brief description of the four basic NPK production technologies examined in this paper follows. A more full examination and discussion of a broad range of variations of these basic technologies will occur during the course of this workshop.

Bulk Blending

This technology refers to the physical mixing (blending) of granular fertilizer materials (raw materials) without the intentional introduction of chemical reaction or modification (enlargement) of the particle size. The raw materials used for bulk blends are usually granular in form and are also often sold as finished products, for example, urea, diammonium phosphate (DAP), and muriate of potash (MOP). In some instances, nongranular or semigranular materials are used to prepare blends; however, this practice usually leads to a lower quality product. In the context of this discussion, a distinction is also made between "prilled" and "granular" urea. While technically both products are granular, the particle size of most prilled urea is too small (often less than 1 mm) to remain homogeneously mixed with other common granular materials such as DAP and MOP which are significantly larger in particle size (often about 2.5 mm average).

Compaction Granulation

In this process mechanical force is used to form dense particles (granules) from finely divided (nongranular) solid raw materials. With compaction granulation the dry materials are first proportioned and thoroughly mixed to achieve the desired nutrient ratio (fertilizer grade). The mixture is then continuously fed to a pressure-roll compaction machine which forms the powdered mixture into a dense, hard sheet of material usually about 2-3 cm thick. The sheet is subsequently crushed in a controlled manner to form smaller particles. The crushed material is screened to obtain the desired product-size fraction. The reject material is returned (recycled) to the compaction machine after first being thoroughly mixed with the fresh raw material feed. As with bulk blending, no chemical reaction is involved in the process although the raw material properties (especially chemical compatibility, thermal characteristics, and plasticity) have a major influence on the performance of the process.

Steam Granulation

The raw material feed requirements, especially particle size, and method of proportioning and mixing for steam granulation are very similar to those of compaction granulation. However, with steam granulation heat and moisture (steam and/or water) are introduced to the granulation equipment (usually a rotary drum-type or pugmill-type granulator) to provide sufficient liquid phase and plasticity to cause the dry raw materials to agglomerate and compact into particle-size granules. In some cases ammonia may also be added during granulation to react with superphosphate, for example, to aid in granulation and improve product quality. The moist and plastic granules are dried in a rotary drum-type, fuel-fired dryer, and screened to remove the product-size fraction. The reject material is recycled to the granulator. In some cases it is also necessary to cool the material either before screening or after screening depending upon the fertilizer grade and local conditions. If cooling is required, it is

usually performed in a rotary drum-type unit that is very similar to the rotary dryer.

Chemical Granulation

Chemical granulation is the most complex of the four methods evaluated in this paper. The chemical granulation process is very similar to the previously described steam granulation process except that most of the liquid phase required to achieve granulation is obtained by reacting ammonia with phosphoric acid and/or sulfuric acid. Some processes also involve a significant reaction between ammonia and superphosphate. Much of the ammonia-acid reaction is often performed outside the granulator either in a tank-type vessel (preneutralizer) or in a pipe-type reactor. In many cases steam, water, and additional ammonia and acid are also fed to the granulator to optimize the granulation characteristics for each particular formulation. In most NPK chemical granulation plants, a significant amount of solid raw materials is also used. The relationship between the consumption of solid and liquid raw materials is determined by a number of variables, including (1) required nutrient ratio and solubility (fertilizer grade), (2) liquid phase requirements, (3) heat of reaction and temperature limitations, and (4) process plant equipment capacity and operating criteria.

Economic Comparisons

The four basic NPK production technologies: (1) bulk blending, (2) compaction granulation, (3) steam granulation, and (4) chemical granulation are compared in terms of (1) fixed capital investment, (2) conversion cost (not including raw materials), and (3) production cost (conversion cost plus raw material cost). The premises and assumptions used in this evaluation together with a discussion of the main economic characteristics follow.

Premises and Assumptions

All estimates (mid-1987 US $) are based on a grass-roots production facility in a developing country location with an existing industrial infrastructure where the investment cost is assumed to be about the same as that of a U.S. Gulf Coast location. Convenient access to an ocean port is assumed and the cost of land is not included. All raw materials are assumed to be purchased from international sources at the indicated f.o.b. prices which, of course, can vary quite widely. The f.o.b. prices were increased by US $30/tonne for solid materials and US $40/tonne for liquid materials to arrive at an assumed delivered cost to the plant site. Storage facilities (capacity) for dry and liquid raw materials are based on importation of raw materials in 3,000- to 5,000-tonne lots and an approximate 2-month inventory at the plant site.

The base case capacity of each NPK production unit is 120,000 tonnes/year at 75% capacity utilization. This translates to 160,000 tonnes/year at 100% capacity utilization assuming 330 days per year.

Fixed Capital Investment Estimates

As indicated in Table 1 and Figure 1 the estimated fixed capital investment for the four production schemes

Table 1. **Estimated Fixed Capital Investment for Various NPK Production Processes – 120,000 Tonnes Per Year at 75% Capacity Utilization**

	NPK Production Process			
	Bulk Blending	Compaction Granulation	Steam Granulation	Chemical Granulation
	(US $ x 1 million)			
Battery-limits process unit	0.4	4.6	5.9	9.4
Bulk storage (dry raw materials and products)[a]	1.6	1.6	1.6	1.1
Bagged product storage[b]	0.5	0.5	0.5	0.5
Liquid storage (ammonia, phosphoric acid, and sulfuric acid)[c]	-	-	-	1.6
Auxiliary and support facilities[d]	0.4	1.0	1.2	1.9
Total Installed Cost	2.9	7.7	9.2	14.5
Project management and startup[e]	0.1	0.4	0.5	0.7
Interest during construction[f]	0.2	0.6	0.7	1.2
Total Fixed Capital Investment	3.2	8.7	10.4	16.4

a. 22,000 tonnes total, except 15,000 tonnes for chemical granulation.
b. 5,000 tonnes total.
c. 3,000 tonnes each for ammonia, phosphoric acid, and sulfuric acid.
d. 15% of cost of process unit and total storage facilities.
e. 5% of total installed cost.
f. 8% of total installed cost

Table 2. **Estimated Conversion Cost for Various NPK Production Processes – 120,000 Tonnes Per Year at 75% Capacity Utilization**

	NPK Production Process			
	Bulk Blending	Compaction Granulation	Steam Granulation	Chemical Granulation
	(US $/tonne product)			
Fixed Cost[a]				
Operating labor	1.4	2.9	2.9	3.5
Overhead and general expenses[b]	1.4	2.9	2.9	3.5
Maintenance (labor and materials)	0.5	2.6	3.1	4.8
Insurance and taxes[c]	0.2	0.6	0.8	1.2
Fixed capital recovery[d]	4.6	12.4	14.8	23.3
Subtotal	8.1	21.4	24.5	36.3
Variable Cost				
Electricity (US $0.04/kWh)	0.2	2.0	1.2	2.0
Steam (US $10.0/tonne)	0.0	0.0	0.6	0.3
Water (US $0.5/tonne)	0.0	0.0	0.5	1.0
Fuel (US $8.0/million kcal)	0.0	0.0	1.4	0.8
Bags	10.0	10.0	10.0	10.0
Contract labor (bagging)	1.0	1.0	1.0	1.0
Miscellaneous chemicals and supplies	0.3	0.5	0.7	1.0
Subtotal	11.5	13.5	15.4	16.1
Total Conversion Cost (not including raw materials)	19.6	34.9	39.9	52.4

a. Refer to Table 1 for total fixed capital investment estimates.
b. 100% of operating labor.
c. 1.0% of total installed cost.
d. 17.1% of total fixed capital investment (15 years at 15% annual interest rate).

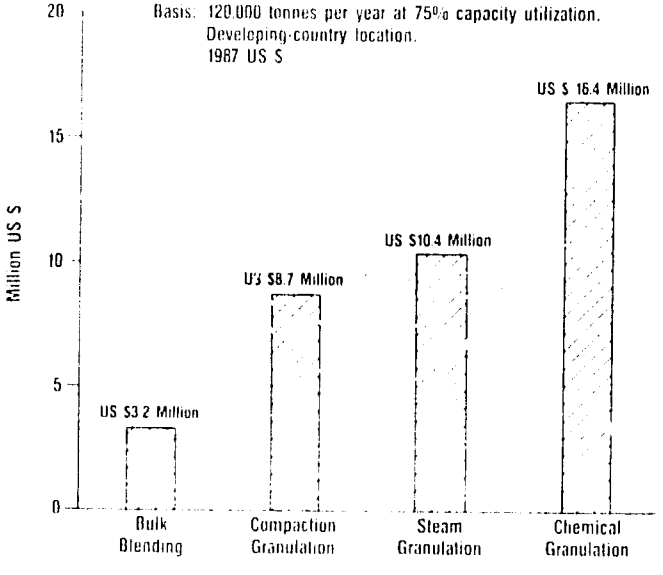


Figure 1. **Approximate Fixed Capital Investment for Various NPK Production Processes.**

varies from a low of US $3.2 million for the bulk-blending plant to a high of US $16.4 million for the chemical granulation facility. In the case of the bulk-blending plant the storage facilities represent about 65% of the total fixed capital investment, whereas storage facilities account for only about 20%-24% of the total fixed investment in the more costly compaction, steam, and chemical granulation units.

Conversion Cost Estimates

The estimated conversion costs (not including raw materials) for the four NPK production processes are summarized in Table 2 and Figure 2. The conversion cost, based on 120,000 tonnes/year and including bagging but not raw materials, varies from about US $20/tonne for bulk blending to about US $52/tonne for chemical granulation. In all cases fixed capital recovery (based on a 15-year plant life and a 15% annual interest rate) represents the largest fixed conversion cost item and ranges from about 23% of the total conversion cost for bulk blending to about 44% for chemical granulation. The cost of bags represents the largest variable cost item (excluding raw materials).

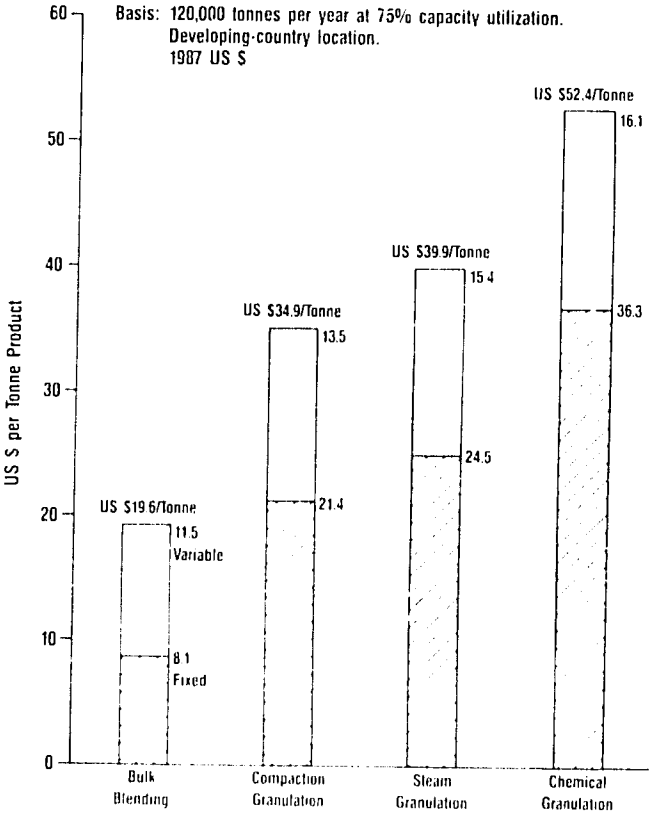


Figure 2. **Approximate Conversion Cost (not including raw materials) for Various NPK Production Processes.**

Estimated Raw Material Cost

It is difficult to precisely evaluate the cost of raw materials for the four NPK production processes examined in this paper because of relatively large variations in prices caused by international market conditions, quantity of purchase, ocean freight rates, and a variety of time- and site-specific conditions. However, for the purpose of this evaluation average mid-1987 international prices (f.o.b. Western Europe and United States) were used as a base. As previously indicated, these prices were increased by US $30/tonne for solid materials and US $40/tonne for liquid materials to arrive at an assumed delivered cost to the plant site. These data are summarized in Table 3 using 15-15-15 as an example product. The 15-15-15 product was used because it is one of the most common NPK products manufactured and sold on the world market. Typical production formulas (raw material consumption) for the NPK 15-15-15 produced by the four processes are shown in Table 4. According to these criteria the cost of raw materials is the highest for bulk blending (about US $139/tonne of 15-15-15). The raw material cost for compaction, steam, and chemical granulation is about US $10-$12 less (about US $127-$129/tonne of 15-15-15).

It is important to emphasize that the compaction, steam, and chemical granulation processes offer considerable potential for raw material cost savings if the

Table 3. **Estimated Raw Material Cost for Various NPK Production Processes – 15-15-15 Product in Developing Country Location**

Raw Material[a,b]	NPK Production Process: Bulk Blending	Compaction Granulation	Steam Granulation	Chemical Granulation
	(US $/tonne 15-15-15)			
Prilled urea – 46-0-0 (US $125/tonne)	-	16.6	16.6	13.1
Granular urea – 46-0-0 (US $130/tonne)	5.2	-	-	-
Nongranular monoammonium phosphate – 10-50-0 (US $200/tonne)	-	60.8	60.8	-
Granular diammonium phosphate – 18-46-0 (US $215/tonne)	71.2	-	-	-
Standard ammonium sulfate – 21-0-0 (US $80/tonne)	-	23.0	23.0	-
Granular ammonium sulfate – 21-0-0 (US $95/tonne)	33.7	-	-	-
Standard muriate of potash – 0-0-60 (US $95/tonne)	-	24.3	24.3	24.3
Granular muriate of potash – 0-0-60 (US $105/tonne)	26.7	-	-	-
Ammonia – 82-0-0 (US $135/tonne)	-	-	-	17.1
Sulfuric acid – 96% H_2SO_4 (US $80/tonne)	-	-	-	20.8
Phosphoric acid – 52% P_2O_5 (US $170/tonne)	-	-	-	51.5
Conditioning clay (US $40/tonne)	0.6	0.6	0.6	0.6
Conditioning binder (US $300/tonne)	1.5	1.5	1.5	1.5
Total	138.9	126.8	126.8	128.9

a. Indicated raw material prices based on 3,000-5,000 tonne lots delivered to plant site (mid-1987 international f.o.b. prices plus US $30/tonne for solid materials and US $40/tonne for liquid materials).
b. Refer to Table 4 for raw material consumption data.

Table 4. **Typical Production Formulas (Raw Material Consumption) for 15-15-15 – Various NPK Production Processes**[a]

Raw Material	NPK Production Process				
	Bulk Blending	Compaction Granulation	Steam Granulation	Chemical Granulation Feed Basis	Chemical Granulation Product Basis
	(kg/tonne)				
Prilled urea – 46-0-0	-	133	133	105	105
Granular urea – 46-0-0	40	-	-	-	-
Nongranular monoammonium phosphate – 10-50-0	-	304	304	-	-
Granular diammonium phosphate – 18-46-0	331	-	-	-	-
Standard ammonium sulfate – 21-0-0	-	288	288	-	-
Granular ammonium sulfate – 21-0-0	354	-	-	-	-
Standard muriate of potash – 0-0-60	-	255	255	255	255
Granular muriate of potash – 0-0-60	255	-	-	-	-
Ammonia – 82-0-0	-	-	-	127	127
Sulfuric acid – 96% H_2SO_4, 4% H_2O	-	-	-	261	251
Phosphoric acid – 52% P_2O_5, 20% H_2O		-	-	303	242
Conditioning clay	15	15	15	15	15
Conditioning binder	5	5	5	5	5
Total	1,000	1,000	1,000		1,000

a. Nutrient content of product (as formulated) is about 2% higher than theoretical to compensate for process and raw material variations.

opportunity for buying distressed, off-specification, or byproduct raw materials exists. Such materials can often be purchased at a significant discount and, then by processing, can be upgraded to high-quality NPK products. Bulk blending does not usually offer this advantage because the production of high-quality blended NPKs is highly dependent upon the use of high-quality granular raw materials that are priced accordingly. However, the combination of compaction granulation and bulk blending at the same facility may be helpful in transferring some raw material economies to bulk blending. This strategy is a topic that will be examined during the course of this workshop.

Estimated Total Production Cost

A summary of the estimated total production cost for the four processes using 15-15-15 as an example is shown in Table 5 and Figure 3. These costs include all fixed and variable conversion cost items (including raw materials and bagging) and vary from a high of about US $181/tonne for chemical granulation to a low of about US $159/tonne for bulk blending.

Table 5. **Estimated Total Production Cost for Various NPK Production Processes – 15-15-15 Product in Developing Country Location**[a]

	NPK Production Process			
	Bulk Blending	Compaction	Steam Granulation	Chemical Granulation
	(US $/tonne 15-15-15)			
Fixed conversion cost	8.1	21.4	24.5	36.3
Variable conversion cost (less raw materials)	11.5	13.5	15.4	16.1
Raw material cost	138.9	126.8	126.8	128.9
Total (Bagged Product)[b]	158.5	161.7	166.7	181.3

a. Refer to Tables 2 and 3 for estimated conversion and raw material cost details.

b. Mid-1987 f.o.b. (West Europe) price of bagged 15-15-15: US $145/tonne plus US $40/tonne freight and handling equal US $185/tonne (for comparative purpose only).

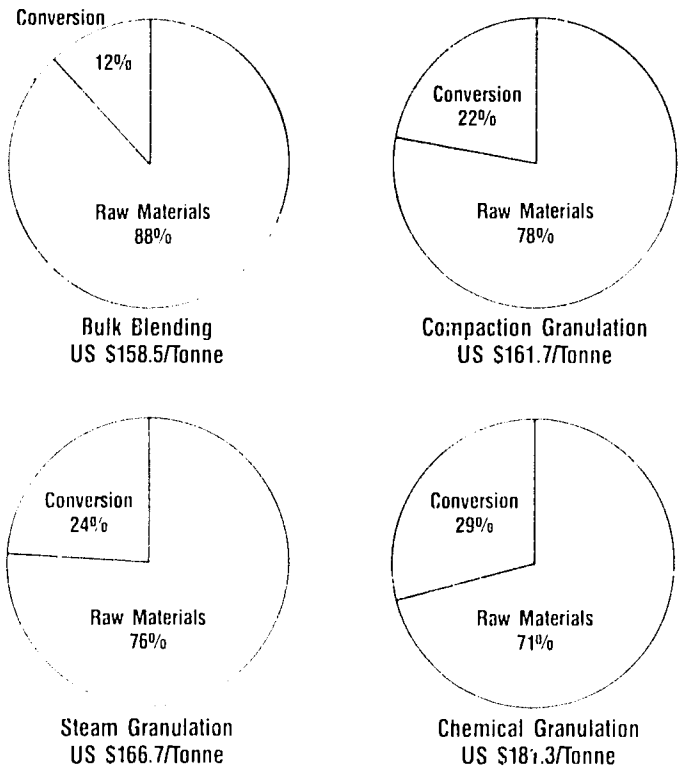


Figure 3. **Approximate Distribution of Production Cost for Various NPK Production Processes – 15-15-15 Product.**

Impact of Capacity Utilization

The above production cost data are based on an annual production of 120,000 tonnes while operating at 75% capacity utilization. The effect on the conversion cost and the total production cost (including bagging) caused by increasing or decreasing the annual plant capacity is shown in Figures 4 and 5, respectively. In the most capital-intensive plant (chemical granulation) a decrease in capacity utilization to 50% (80,000 tonnes/year) increases the total production cost to almost US $200/tonne compared with about US $181/tonne at the base case condition (Figure 5). The bulk-blending plant, because of its low fixed capital investment, is least affected by changes in capacity utilization while the compaction and steam granulation units are moderately affected compared with the other process.

Conclusion

This paper clearly illustrates that the fixed capital investment and conversion costs (not including raw materials) varies widely depending upon the NPK production process. It also indicates that the cost of raw materials from imported sources is quite high and does not vary much from one process to the other. However, it is important to recognize that the feasibility of bulk blending, while indicated as the most cost-effective in this examination, is highly dependent upon the availability of high-quality granular raw materials and acceptance of the blended products in the marketplace which traditionally has been dominated by homogeneous (complex) granular products. The granulation processes offer the greatest flexibility in raw material choices, a feature that can, in some cases, lead to significant savings in raw material cost when compared with the bulk-blending alternative. The relative economics of the four NPK processes may favor chemical granulation if the NPK granulation plant is located adjacent to the production facilities of the required liquid raw materials (ammonia, phosphoric acid, and sulfuric acid).

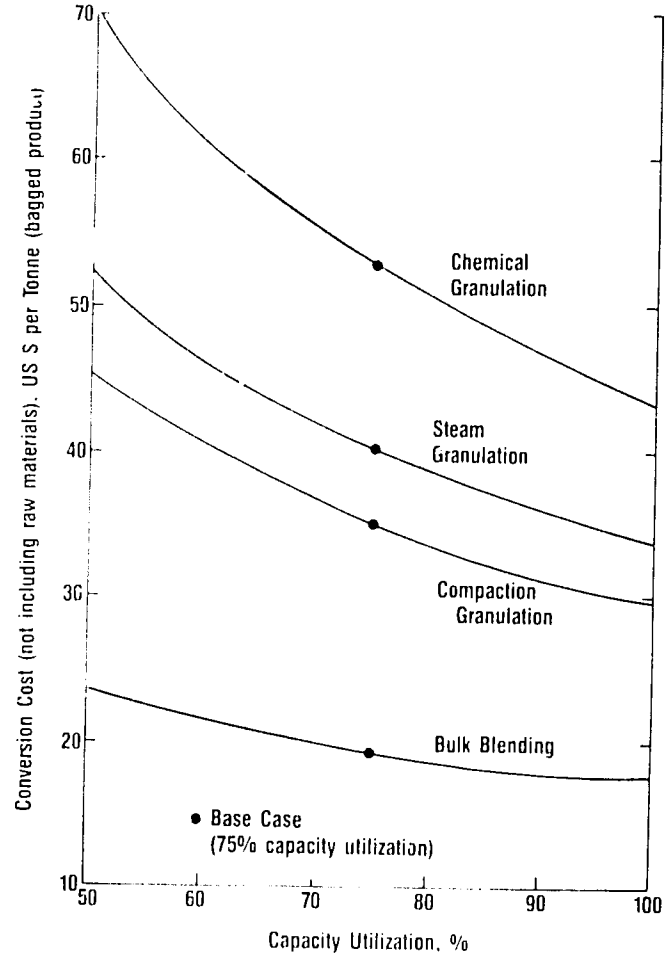


Figure 4. **Impact of Capacity Utilization on Conversion Cost (not including raw materials) for Various NPK Production Processes.**

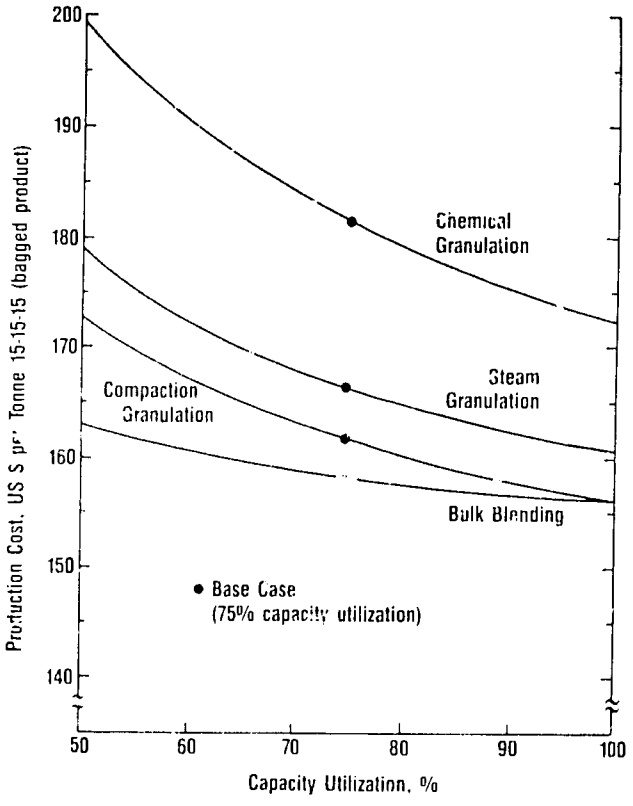
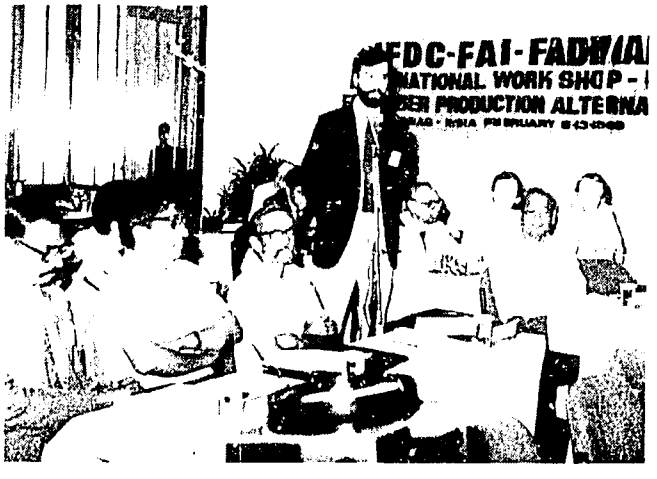


Figure 5. **Impact of Capacity Utilization on Production Cost for Various NPK Production Processes.**



Practical Experiences in the Granulation of Urea/Ammonium Phosphates

David Ivell, Senior Chemical Engineer, Norsk Hydro Licensing

Abstract

This paper discusses the practical experiences that Norsk Hydro Licensing (NHL) gained during the startup and subsequent operation of a urea-based granulation plant in Turkey. Powdered monoammonium phosphate, produced on the site, is converted into NP and NPK compounds in a granulation plant. Merchant grade phosphoric acid, ammonia, and potash are purchased on the world markets. Prilled urea is obtained from a Turkish manufacturer and sand—used as a filler—is available locally.

The monoammonium phosphate (MAP) plant consists essentially of an ammonia vaporizer, a pipe reactor, a spray tower, and an off-gas scrubber.

The granulation plant is made up of a rotary-drum granulator, a dryer, screening equipment, a cooler, and a coating drum, along with the usual conveying and dust removal equipment. It was designed to produce 1,000 mtpd of 15-15-15, 18-18-18, 27-27-0, or 20-20-0 at a recycle ratio of 2:1.

Preliminary operation of the complex was excellent. Overall efficiencies were high: 99% for nitrogen and 99.5% for P_2O_5 during the performance test. Some problems were encountered with buildup in the granulator and in the bag filters in the dust recovery system but these were solved.

It was concluded that for plants that must import raw materials the powdered MAP process together with low-recycle granulation offers a simple, efficient, and economical means of producing high-quality granular fertilizer.

Introduction

Norsk Hydro Fertilizers (formerly Fisons) has always been at the forefront of developments in rotary drum granulation techniques.

In the United Kingdom most of the work has been concentrated on the granulation of compounds based on ammonium nitrate as the major source of nitrogen. However in many parts of the world, particularly outside Europe, urea is a cheap, agronomically acceptable form of nitrogen. The process licensing department of Fisons (now Norsk Hydro Licensing, Levington) realized the potential for processing routes to complex fertilizers that incorporate urea as the major nitrogen source. In the 1960s, therefore, they embarked upon a program of work to develop suitable processes. This work subsequently resulted in a large number of licenses being granted throughout the world. Of particular current interest is the granulation of urea/ammonium phosphate mixtures to produce high nutrient content complex fertilizers.

In this paper we discuss some of the practical experience gained during the startup and subsequent operation of a urea-based granulation plant owned by Toros Fertilizer and Chemical Industries in Turkey.

Background Information on Toros Fertilizer and Chemical Industries—Turkey

In 1978, although there were several existing fertilizer manufacturers in Turkey, demand outstripped production capacity. Tekfen Construction and Installation Company of Istanbul formed a new company, Toros Fertilizer and Chemical Industries, in which they were to have a 50% holding. The new company was formed to produce fertilizer mainly for the cotton producing area around Adana in Southern Turkey.

The process operations at the complex involve the incorporation of powdered monoammonium phosphate produced on site into NP and NPK compounds in the granulation plant.

The process units were commissioned during the first 4 months of 1981 and the complex was officially opened in May 1981. As well as the two process units, it includes port facilities, a liquids terminal for refrigerated ammonia, sulfuric acid and phosphoric acid, storage buildings for

solid raw materials and finished product, bagging facilities, offsites, and utilities. Constructors of the complex were the Tekfen Construction and Installation Company. NHL of the United Kingdom supplied the process and "front-end" engineering for the two process plants and also acted as a consultant to Tekfen for the utilities and offsites. Foster Wheeler, Iberia, assisted with the detailed engineering and procured the equipment.

Operations at the factory are based on the importation of merchant-grade phosphoric acid, ammonia, and potash purchased on the world market, prilled urea from a Turkish manufacturer, plus locally available filler. The intake and bagging facilities were also designed to handle imported, granular fertilizers such as DAP and TSP for local distribution.

The granulation plant was designed to produce 1,000 mtpd of nominal 15-15-15, 18-18-18, 27-27-0, or 20-20-0 at a recycle ratio of 2:1.

The NHL low recycle process was chosen because:

1. The low recycle results in significant savings both in capital and operating costs.

2. Production of a powdered MAP intermediate results in a more flexible operation and greater plant availability.

3. No complicated ammonia recovery systems are required which greatly simplifies the operation.

Features of the Process Units

Powdered MAP Plant

The flowsheet of the Toros powdered MAP plant is shown in Figure 1.

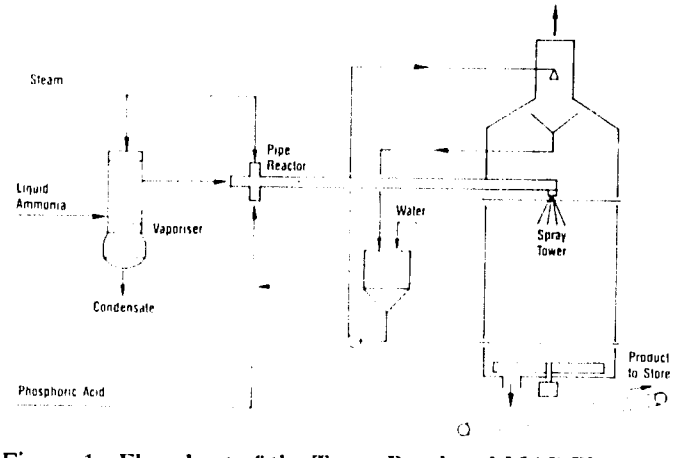


Figure 1. **Flowsheet of the Toros Powdered MAP Plant.**

Gaseous ammonia from a vertical shell-and-tube vaporizer is fed to a pipe reactor where it reacts with phosphoric acid to form MAP. With the use of merchant grade acid there is a surplus of heat in the system. This is removed by the addition and evaporation of a controlled amount of water.

The pipe reactor discharges into the top of a short, natural draught tower. A specially designed nozzle is fitted to give a good spray pattern while at the same time avoiding the formation of encrustations.

The tower is a simple structure which can normally be installed within an existing process unit building. The tower walls are fabricated from a plastic covered canvas which is loosely attached to a supporting structure at the various intermediate floor levels. The walls of the tower are thus able to flex naturally to prevent the buildup of solid material.

The MAP solution from the pipe reactor quickly solidifies after leaving the nozzle. As the powder falls down the tower it is cooled by the flow of air so that it can be easily handled at the base of the tower. The base of the tower is fitted with removable doors, to control the intake of ambient air for cooling, and a simple rotary scraper is provided for product recovery.

The top of the tower is vented to atmosphere through a simple recirculating water scrubber to recover entrained dust. The scrubber solution is fed to the pipe reactor together with the phosphoric acid to control the moisture content of the product.

As can be seen there are very few items of equipment, all of which are very simple. As expected therefore the plant is extremely easy to operate and causes very few problems.

NPK Granulation Plant

The flowsheet for the granulation plant is shown in Figure 2. The main features are discussed.

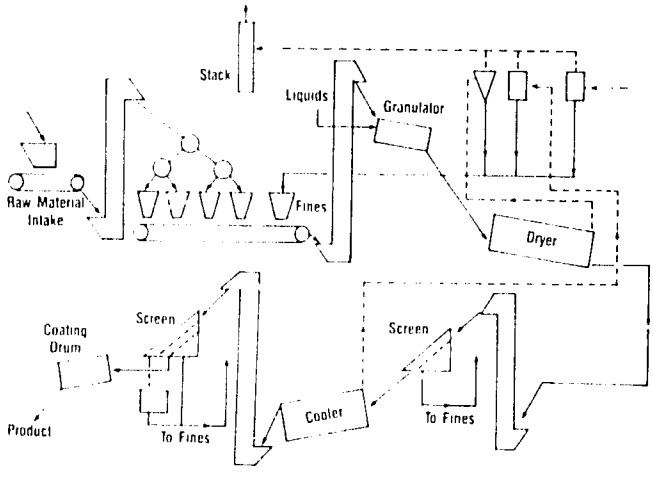


Figure 2. **Flowsheet of the Toros NPK Granulation Plant.**

Raw Materials – Pulverized urea prills, powdered MAP, and sand for 20:20:0 manufacture are taken from the individual hoppers at a steady and controlled rate by fixed speed weighbelts specially designed for the duty. Tight contr l is required to ensure that the analysis is maintained within the narrow, statutory limits of tolerance.

Granulation – Raw materials are fed together with recycled fines to the rotary-drum granulator.

The process operates with a low recycle rate and is therefore granulation-efficiency controlled; this means that the rate of production is determined by the capability to convert the powdered raw materials to granular product of acceptable size during each pass through the granulator.

Granulation efficiency is a function both of the physical properties of the raw materials and of the conditions of temperature, moisture content, and pH of the rolling bed in the granulator. The physical properties of the feed cannot be controlled once the raw materials have been selected for a particular NPK formulation. Achievement of high granulation efficiency therefore depends on the employment of optimum conditions in the granulator, which involves the use of small quantities of steam, sulfuric acid, and ammonia. These granulation aids are added to the rolling bed of material in the drum.

Drying – Urea/ammonium phosphate grades are very temperature sensitive and therefore low air temperatures are used for drying. Accurate control of these temperatures is particularly important if blockages are to be avoided. A conventional oil-fired air heater is used with individual automatic controls for the oil and dilution airflow rates.

To control buildup inside the dryer specially designed, pneumatically operated hammers are installed. These have been found to be more reliable and more effective than mechanical hammers that are often used.

Material leaving the dryer is screened and the undersize stream is returned to the granulator at about the same temperature as the exgranulator material. The use of hot fines enables higher granulation temperatures to be reached. As a general rule, the higher the granulation temperature the lower the exgranulator moisture required for maximum granulation efficiency, and the higher the absolute value of that efficiency. This in turn reduces the drying load which enables the dryer size to be minimized.

Screening and Crushing – All screens are of the inclined screen cloth, electromagnetically vibrated type. The angle of the screen and the magnitude of the cloth vibration are variable so that screen performance can be optimized. It has been found that this type of screen gives the greatest degree of control over particle separation efficiency. Screening efficiency is of course crucial in low recycle plants such as this.

Oversize material is cooled before being crushed because problems can be encountered with buildup in the pulverizers, particularly when NPK grades are being produced, if the material is crushed immediately after it leaves the dryer.

High-speed hammer/low-speed drum type pulverizers are used. This type of pulverizer produces particles of approximately 1-2 mm rather than dust. The pulverizers are located directly on top of the fines hopper to prevent dust emission.

Environmental Controls – No liquid effluents are allowed to leave the plant and therefore it was necessary to remove dust from the process airstreams by dry methods.

Within the granulation plant, dust extraction points are fitted where material is being transferred from one item of equipment to another. This ensures a clean working environment in the process building. The dust entrained in this airstream is recovered in a bag filter and returned to the fines hopper.

Another bag filter is used to recover dust from the cooler airstream. This air is now recycled to the dryer which reduces fuel consumption up to about 50%.

In the case of the dryer, high efficiency cyclones were originally used to avoid any possible problems with moisture pickup in bag filters. Since the startup of the Toros plant, however, the Norsk Hydro Group has gained considerable experience in the use of bag filters. Bag filters are now in use in its own plants to recover dust from dryer airstreams and we are now confident that with the correct design features bag filters are practical.

Plant Performance

The powdered MAP section of the plant is a very simple and efficient operation. The process commissioning was completed in only 11 days operation, which included the 72-h guarantee test. Both nitrogen and P_2O_5 efficiencies were in excess of 99.5% during the test run and the plant was free of liquid effluents.

A variety of merchant-grade phosphoric acids have been processed in the plant and naturally analysis of the final product varies according to the acid source. However, a typical dry basis analysis is 11.5% N and 56.0% P_2O_5. The product generally contains about 6%

water. A production rate of 110% of design capacity has been maintained for all acids used.

Originally the reactor on the plant was a pressurized vessel. Performance of the reactor was excellent in all respects and caused no problems. However, Toros was interested in the concept of a pipe reactor and wished to investigate the performance of such a device. In 1984, therefore, a pipe reactor facility was provided. The use of the pipe reactor helped to further simplify the operation, particularly during startup and shutdown. In addition it was found that the P_2O_5 water solubility dramatically increased. Around 99% water solubility is now achieved with both Moroccan and South African acids.

All the powdered MAP manufactured has been used in the associated granulation plant. Since startup, production, in response to the demands of both the local and export markets, has been largely 20-20-0 and 15-15-15 with some 15-45-0, 23-23-0, 24-24-0, and 26-13-0.

The commissioning and plant optimization phase of the granulation plant was completed within the first 3 months of process operation. A successful 72-h guarantee test was carried out at the end of this period; during the test, the average production rate was 105% of design capacity. The plant now achieves a daily output rate of up to 140% of design capacity and monthly production figures in excess of 26,000 mt are regularly recorded.

The factory has quickly become one of, if not, the most successful in Turkey with over 300,000 mtpy being produced on several occasions.

Some on-stream time data are presented in Table 1, showing that annual plant utilization is typically around 85%, which compares very favorably with most other NPK plants in Turkey.

During the commissioning period 20-20-0 was produced exclusively. Table 2 shows the averaged production data measured during the guarantee test.

The most striking feature of the formulation for 20-20-0 is undoubtedly the large filler content – over 25% – making it a difficult grade to granulate. It was necessary, therefore, to investigate fully the effect of the available operating parameters on granulation efficiency, in order to produce material at the design rate.

The following parameters were found to be important in the granulation of 20-20-0.

Granulation Temperature

In general, it was found that the hotter the granulation temperature, the more efficient the granulation. Sulfuric

Table 1. **Utilization Data for Toros Fertilizer and Chemical Industries, 1983-85**

	1983	1985
Annual production, mt	300,006	332,495
Operating time, h	6,945	6,681
Average production rate, mtph	43.2	49.8
Downtime Analysis (hours)		
Mechanical	327	250
Electrical/instrumentation	90	115
Process	128	102
Other	101	55
Planned maintenance	786	839
Power failures	160	36
Lack of raw materials	121	511
Offsites	101	172
Total	1,815	2,079
Overall utilization, %	79 (289 dpy)	76 (278 dpy)
Plant utilization (granulation plant), %	83 (303 dpy)	83 (303 dpy)

Table 2. **Production of 20-20-0 Granulated Fertilizer at Toros Plant**

Granulator	
Urea prills, kg/mt	296
Powdered MAP, kg/mt	349
Filler, kg/mt	262
Ammonia, kg/mt	29
Sulfuric acid, kg/mt	46
Steam, kg/mt	14
Recycle ratio, mt/mt of product	1.9
Recycle temperature, °C	70
Outlet temperature, °C	82
Outlet moisture, %	1.8
Outlet pH	6.1
Dryer	
Inlet air temperature, °C	132
Outlet air temperature, °C	86
Product size, +4 mm, %	9.1
Product size, -4 mm +1.5 mm, %	41.6
Product size, -1.5 mm, %	49.3
Product	
Production rate, mtph	43.1
H_2O, %	0.41
N, %	19.86
P_2O_5, %	19.44

acid was added, at around 5% of the formulation, together with ammonia to supply heat from the reaction. The temperature of the recycle fines was maximized at 70°C by using higher dryer temperatures than were strictly necessary for drying, and minimum cooling.

Granulator pH

The pH of the material in the granulator also plays an important role in increasing the solubility of the product and thereby inducing granulation. The addition of excess ammonia to obtain a pH of just over 6 was found to be very important in obtaining efficient granulation.

Urea Crushing

Urea crushing was found to be beneficial to granulation. Material under 1 mm in size gave the best results. At those times when uncrushed urea prills were used it was difficult to incorporate them to produce uniform granules. However, because of size of the urea prills, the production rate could be maintained while uncrushed urea was being used but urea was visible in the product, which was of poor quality.

A hot recycle together with the use of sulfuric acid and ammonia gives a temperature, at the outlet of the granulator, in excess of 80°C. At this temperature the optimum moisture for granulation is less than 2%. This situation has several advantages:

1. The hot recycle leads to a reduced cooling load.

2. The high temperature and low moisture of the material leaving the granulator results in a low fuel usage.

3. The high temperature in conjunction with ammoniation in the granulator results in highly efficient granulation; 42% of the product is in the size range of 1.5 to 4 mm at the dryer outlet causing the recycle ratio to be under 2:1.

All utility consumptions have in fact been low, leading to low operating costs per metric ton of product. Averaged values are given below:

Utility	Amount Used
Water	nil
Steam	14 kg/mt of product
Electricity	19 kWh/mt of product
Fuel oil	5 kg/mt of product

Product quality is high. The granules have an excellent uniform appearance, shape, and size. Storage properties, even in the humid conditions prevalent in Southern Turkey, are excellent.

The elimination of wet scrubbing and the use of bag filters means that the plant is completely free of liquid effluents. Overall plant efficiencies are high; 99% and 99.5% were measured for nitrogen and P_2O_5, respectively, during the performance test.

Operational Problems

Granulator Internals

The major problem faced during the commissioning period was associated with the granulator internals. Originally steam, sulfuric acid, and liquid ammonia were all added in the granulator through drilled pipe spargers supported beneath the rolling bed. This arrangement resulted in several problems.

Very heavy buildup quickly accumulated on the pipes themselves and on the main support beam and support legs. The buildup was particularly heavy on the support leg closest to the inlet end of the granulator. This buildup caused a physical restriction to the flow of material, resulting in back-spillage. All three sparger pipes became bent. In addition the spargers were rapidly corroded which, in combination with the bending caused the pipes to fracture after only a few weeks of operation. This was particularly true of the sulfuric acid sparger even though it was made of Hastelloy C.

The problems were eventually overcome by making a number of stepwise modifications. First the sulfuric acid sparger was removed from beneath the bed and suspended beneath the main support beam so that the acid "streamed" onto the base of the bed. Second the steam sparger was changed from a long drilled pipe to an open-ended piece of armoured rubber hose, the end of which was flattened and extended beneath the rolling bed. After these modifications the support legs, which were relatively bulky, could be cut down because only the ammonia sparger required support beneath the bed. These modifications completely solved the corrosion problem and markedly reduced buildup since the amount of metal under the bed was substantially reduced. The last modification involved installing an inflatable rubber shroud over the top of the main support beam. An automatic timer was fitted to a compressed air line feeding the shroud so that it periodically inflated and deflated thus dislodging buildup.

Granulation Efficiency

Although the formulation for 20-20-0 includes 25% sand thus making granulation difficult, design rates were

achieved fairly swiftly within the commissioning period by optimizing the operating conditions within the granulator. As indicated in Table 2 the recycle ratio during the guarantee test averaged 1.9:1 and the production rate averaged 1,035 mtpd (43.1 mtph).

The Turkish size specification called for 90% of the product to be between 1 and 4 mm. When the fines screens were fitted with cloths having 1.5-mm mesh openings the following approximate product size resulted:

+4 mm	1.5%
-4 mm +2 mm	45%
-2 mm +1.5 mm	30%
-1.5 mm +1 mm	16%
-1 mm	6.5%
	99%

Although this size analysis was considered acceptable for the local market, a reduction in the quantity of 1-2 mm material was necessary for the export market. Screen cloths with a larger mesh size were therefore fitted to the fines screens in 1983 with the expectation that in order to achieve the tighter size specification production rate might well fall. In fact the 2 mm-mesh production rate actually rose by almost 20% while the recycle ratio dropped to around 1.5:1. The following product size resulted:

+4 mm	3.5%
-4 mm +2 mm	80%
-2 mm +1.5 mm	13%
-1.5 mm +1 mm	3%
-1 mm	0.5%
	100%

The increase in production rate was attributed to improved fines quality (size) which significantly increased granulation efficiency. With a still larger fines mesh size, the recycle ratio began to rise once more although of course a further improvement in product size was achieved.

Bag Filters

Originally the plant was supplied with bag filters operating on the low-pressure reverse air system. Each filter contained a number of cells each of which comprised five envelope-shaped filter bags. The bags were cleaned, one cell at a time, with air supplied by a small fan. All the bags were made in Dralon felt.

Efficiency-wise, the performance of the filters was excellent. However both units tended to clog up over a period of time and required manual cleaning every couple of months. This procedure was very difficult because of the weight of the large envelope-shaped bags, particularly when they were badly built up with solids. In addition to being time consuming, it was difficult to clean the bags without damaging them.

As mentioned previously the Toros plant was designed in 1978. Since that time NHL's experience with operating different types of bag filters has grown considerably. Bag filters are now used to recover dust from the airstreams of various granulation plants throughout the Norsk Hydro Group. As a consequence NHL is now able to specify not only which type of bag filter is most suited for a particular duty but also what detailed design features are necessary for the successful application of bag filters in fertilizer plants.

On NHL's recommendation Toros placed an order with AAF Limited of the United Kingdom for one of their high-pressure, reverse air pulsejet units to replace the original filter used in the Toros plant to remove dust.

This dedusting duty was potentially quite difficult since the process airstream temperature is generally only 40°-50°C and therefore quite high relative humidities are possible. NPKs with high urea contents have very low critical relative humidities, of course.

The AAF filter contains 216 cylindrical bags arranged in 18 rows. Two rows at a time are pulse cleaned with compressed air (pressure of about seven bars). The frequency of cleaning and duration of the pulse are adjustable so that optimum cleaning performance can be obtained. Total filtration area is 322 square meters. The bags themselves are polypropylene with a special glazed finish to enhance the dust release properties.

Among the detailed design features incorporated are steam heated panels on the hopper and a startup/shutdown heater. The heater system includes a small fan which circulates heated air around the filter housing during the startup and shutdown periods.

Since the filter was commissioned in July 1987 it has not been necessary to either manually clean or replace any of the filter bags. Pressure drop across the unit has remained steady at 80-100 mm water gauge.

Conclusions

The experience at Toros has confirmed that, particularly for a manufacturer whose production is based on imported raw materials, the powdered MAP and low-recycle granulation processes offer a simple, high utilization, economical route to high quality granular fertilizer. The flexibility of the process enables the manufacturer to adapt easily to changes in his market requirements and raw material supply.

NPK Compound Fertilizer Production

Chong Kok San, Fertilizer Plant Manager, Chemical Company of Malaysia Berhad, Shah Alam Works

Abstract

The Chemical Company of Malaysia produces compound NPK fertilizers mostly for cash crops such as rubber, oil palm, and cocoa. Granular compound fertilizers are made from ammonium nitrate, Christmas Island phosphate rock, muriate of potash, kieserite or calcined magnesite, and occasionally diammonium phosphate. Imported ammonia is oxidized to produce nitric acid which is then neutralized with more ammonia to make ammonium nitrate. All raw materials except the nitric acid and ammonium nitrate are imported. Thirteen different grades are made. The plant complex has a capacity of 240,000 tpy and an availability of more than 80%.

The manufacture of ammonium nitrate entails certain hazards that derive from its acidity and its sensitivity to excessive temperatures, high pressures, and contamination. Measures are taken to obviate these hazards. Fertilizers containing ammonium nitrate are subject to three types of decomposition – spontaneous heating in the pile; "fume off," a vigorous reaction that occurs when the product contains chloride; and a self sustained decomposition called "cigar burning," which is catalyzed by chlorides. These three types of decomposition can be coped with by use of proper operating procedures.

Major environmental pollution control systems for the plant consist of (1) fugitive dust removal units, (2) cyclones and wet scrubbers for extracting dust from the various exhaust gases, (3) a centrifuge-type dewatering unit for alleviating water balance problems, and (4) a low-emission neutralizer for reducing the losses of ammonia and ammonium nitrate when manufacturing an ammonium nitrate solution.

Introduction

The Chemical Company of Malaysia Berhad, Shah Alam Works, or CCM-SAW, as it is popularly known, is a member of the Imperial Chemical Industries (ICI) worldwide group of companies. In Malaysia, the ICI group has been in business for 60 years, supplying a wide range of products and raw materials to agriculture and industry.

The CCM factory is located on a 72-acre site at Padang Jawa, some 30 kilometers southwest of Kuala Lumpur and it is strategically located with respect to road and rail services.

Other than manufacturing granular compound fertilizers, the company also manufactures chlor-alkali products, herbicides, and animal feed supplements.

The CCM factory started operations in 1965 producing chlor-alkali products. Subsequent additions were nitric acid/NPK compound fertilizer production (1966), gramoxone formulation (1971), paraquat dichloride production (1979), phosphate rock grinding (1980), and animal feed supplements (1980).

The factory at Padang Jawa provides direct employment for over 500 Malaysians.

Fertilizer Market In Malaysia

Malaysian agriculture is dominated by the export of cash crops like rubber and oil palm and to a lesser extent cocoa. Hence, the growth and the demand for fertilizer will invariably follow the nutrient requirement of these crops closely. Currently the fertilizer market in Malaysia is approximately 1.2 to 1.3 million mtpy of which the compound fertilizer requirement is 350,000 mt to 450,000 mt. The rest is made up of fertilizer mixtures (nongranular blends) and straights. It is envisaged that the fertilizer consumption in Malaysia will continue to grow in the long term in line with the growth and development of agricultural land as promoted by the Malaysian Government.

The CCM-SAW Manufacturing Process

General

The CCM-SAW compound fertilizer plant was designed and commissioned by ICI, UK in 1966. Local agronomic requirements were incorporated in the choice of formulations and raw materials.

The granular compound fertilizers of CCM are made from ammonium nitrate, ground Christmas Island rock phosphate (as the soils in Malaysia are acidic, ground

phosphate is used rather than soluble ammonium phosphate), muriate of potash, kieserite or calcined magnesite, and occasionally diammonium phosphate. The raw materials are accurately and proportionally fed to the plant in accordance with the desired nutrient ratio of the product. Trace elements for special requirement are also incorporated whenever appropriate.

Details of the Process

Initially, ammonia reacts with air over a platinum-rhodium catalyst to form oxides of nitrogen which are absorbed in water to form nitric acid in the nominal 250 mtpd nitric acid plant. The 55% nitric acid produced reacts with more ammonia to form ammonium nitrate which is then mixed with Christmas Island rock phosphate dust, muriate of potash, and kieserite or calcined magnesite in the blunger. For water-soluble phosphate compounds, diammonium phosphate is also added. The resulting fertilizer mass is dried in a rotary dryer and screened. Oversize and fines are recycled to the blunger and product-sized material is cooled. The cooled product is treated with an anti-caking agent, passed through automatic weighing machines, and packaged in polythene bags.

Table 1. **Standard Range of Formulations**

	Formulation			
CCM No.	N	P_2O_5	K_2O	MgO
CCM 11	[illegible]	18	4	3
CCM 15	10	16	9	2.5
CCM 22	18	11	5	2.5
CCM 33	15	7	18	3
33P	13	6	18	4
CCM 44	12	6	22	3
CCM 45[a]	12	12	17	2
CCM 55[a]	15	15	6	4
CCM 65[a]	15	15	15	
CCM 66	14	14	14	
CCM 77	17	8	17	
CCM 88	10	13	15	2.5
CCM 99	11	14	16	
R3	10	12	13	
NK	14	-	32	

a. One-third of total P_2O_5 is water soluble.

Range of Formulations

The granulation plant was initially designed to manufacture two main formulations, a potassium sulfate-based 11-18-4-3 MgO and a potassium chloride (MOP)-based 11-11-4-3 MgO for rubber trees. However, CCM currently manufactures 13 standard formulations, 3 complex formulations (with one-third water soluble P_2O_5) and 1 straight-nitrogen formulation. The range of formulations is given in Table 1.

The three "complex" formulations (CCM 45, CCM 55, CCM 65) have DAP incorporated to produce a material in which one-third of its P_2O_5 is water soluble. This product was introduced in 1983. Other non-standard-range compound fertilizers are also made if a substantial quantity is required.

Product Quality and Standards and Industrial Research Institute of Malaysia (SIRIM) Specifications

The granular products are free-flowing and have at least 90% of their weight within the size range of 1 mm to 4 mm. They have a consistent analysis and the individual component raw materials do not segregate in storage. Nutrient levels are kept within very strict limits by means of rigorous quality control. An automatic sampler picks up fertilizer from the product conveyor continuously at 5-minute intervals and the composite samples are analyzed hourly by a set of auto-analyzers and an atomic absorption spectrophotometer. The product which does not conform to standards is rejected.

The CCM formulations are the only locally manufactured compound fertilizer that comply with the standards established by SIRIM and explained in Specification MS 49, 1984 (first revision).

Plant Capacity

The plant has a maximum operating rate of 45 mtph for 60% of the formulations while the rate for the others varies from 28 to 40 mtph either because of ammonium nitrate limitations or granulation limitations. The capacity is 240,000 mtpy based on the current mix of formulations.

Plant Availability

Currently, the plant availability – or the percentage of the total time that the plant was in operation – is 83%.

Maintenance

Since 1976, CCM has incorporated a maintenance planning system to improve the plant availability. This has shifted the emphasis from breakdown maintenance to preventive maintenance and eventually to predictive maintenance.

Raw Materials

Sources of Raw Materials

The sources of raw materials are given in Table 2

Table 2. **Sources of Raw Materials**

Raw Material	Consumption[a] (mtpy)	Source
Ammonia (NH_3)	30,000	Esso, Port Dickson
Nitric acid (55% HNO_3)	60,000	Manufactured on site
Ammonium nitrate (98%)	75,000	Manufactured on site
Phosphate rock (34% P_2O_5)	60,000	Imported in bulk from Christmas Island
DAP (18-46-0)	5,000	Imported in bulk from U.S.A., Jordan, Korea
MOP (60% K_2O)	50,000	Imported in bulk from Russia, West Germany, Jordan
Calcined magnesite (84% MgO)	5,000	Imported in bags from Spain or China
Clay	10,000	Local

a. Based on 205,000 mtpy of compound fertilizer produced.

Ground Rock Phosphate

The rock phosphate is ground in a roller-type mill to 75% minus 120-mesh size before it is pneumatically transferred to the plant. Part of the ground phosphate is also bagged for use in mixtures and for straight sales.

Granulation

Fundamentals

Granulation is essentially any process used to produce a granular solid. At CCM, the main feature involved in the granulation of compound fertilizer is agglomeration. Molten ammonium nitrate is the main liquid phase needed to facilitate agglomeration. Other raw materials are ground phosphate rock, muriate of potash, and calcined magnesite or kieserite. A unique feature in this granulation process is the direct injection of the ground phosphate rock into the granulation loop, which makes it all the more difficult to process the mixture into granules. Some steam and scrubber liquor are also added to provide enough liquid phase for granulation. Basically, granulation takes place in the blunger by binding together the raw materials with the aid of surface tension forces set up within the thin layers of liquid within the granule. These surface tension forces are then replaced by stronger crystal bonds when the granules are dried and the water is removed. The two main factors affecting granulation are:

a. The amount of solution phase present in the blunger, the solution phase itself being in turn dependent on the moisture content of the material in the blunger and the chemical composition and the temperature of the mixture.

b. The particle size distribution of the solids fed to the blunger.

Operation and Control

All CCM formulations are granulated with approximately 1%-4.0% water in the blunger while maintaining recycle ratios of 1.5:1 to 3.5:1, depending on the formulations. In general, the plant should be operated with as little water as possible in the liquor feed so as to minimize the amount of oversize produced and the amount of drying required. On the other hand, insufficient water results in an excessive amount of fines, which causes high recycle ratios that make it difficult to produce good granules. Hence accurate control of the liquid phase is essential for good granulation.

An automatic recycle ratio controller affords a degree of control over the particle size of the blunger feed. Other control parameters are the rate of scrubber slurry fed to the blunger and the granulation temperature. The slurry rate is a more convenient control parameter and provides a quick and effective means of controlling the granulation. On the other hand the temperature of the blunger solids is less effective and has a slow response, being largely governed by the recycle ratio and the recycle temperature, which in turn is dependent on the temperature of the solids leaving the dryer.

Equipment

Blunger–The blunger or pugmill used at CCM-SAW is a twin shaft mixer in which each shaft is equipped with 48 Type 304 stainless steel paddles that have been hard faced with tungsten carbide. The shafts are operated at 40 rpm and are driven by a 150-hp motor.

Solid raw materials and recycle fines are fed into the inlet end of the blunger while the ammonium nitrate melt is fed through a distributor box that distributes it throughout the length of the unit. Some scrubber liquor is also fed through the distributor box. Steam is injected

under the bed and is especially necessary in high potash formulations.

Dryer – An oil-fired rotary dryer is used to dry the product to 0.7% moisture. The unit is 14 ft in diameter and 112 ft long and is operated at 3.4 rpm. The residence time is 18 minutes.

There are no lifting flights in the initial 40 feet of the dryer which is coated with a stainless steel metal powder containing 13% chrome. This coating was applied by use of the Metco process to provide a smooth surface which would facilitate granulation, minimize buildup in the front end, and prevent corrosion. This metal coating, which was sprayed on during the annual shutdown in November 1985, has not yielded encouraging results. During the recent annual shutdown in November 1987, it was noticed that the wear rate was high so CCM-SAW is considering other alternative methods of protecting this inlet section of the dryer.

In order to prevent thermal decomposition of the products in the dryer, there are two temperature controls which limit the upper temperature of the dryer gases.

Screens – There are four Hummer-type double-deck vibrating screens each 4 ft wide and 15 ft long, inclined at 30 degrees to the horizontal. The oversize mesh is slotted and is 3.68 mm by 32 mm while the product size mesh is 1.96 by 32 mm. The long dimension of the slot is placed at a right angle to the material flow.

The vibrators have variable frequency and amplitude.

Oversize Pulverizers – There are two 36-inch by 72-inch Jeffrey Diamond swing hammer units operating at 1470 rpm. The cast steel hammers have Souda Metal Supercrom as a buffer layer for the tungsten carbide hard facing. This buffer layer ensures effective bonding.

Environmental Pollution Control

Dust Removal System

The plant was originally equipped with two central dedusting systems (Viscobeth) – one for the raw material area and one for the granulation area. With the development of pulse-jet dedusting units which are more efficient, CCM-SAW started installation of these individual units in 1980 and has installed up to date, a total of four such units on various strategic pieces of equipment that needed additional dedusting. This has decreased the dust concentration levels in the plant.

Scrubbing System

The dust laden exhaust air from the major pieces of equipment (dryer, product cooler, and fluid-bed cooler) is passed through cyclones before being scrubbed with Doyle wet scrubbers which operate on the impingement principle; the air is subsequently exhausted through the main stack.

The scrubber liquor which contains mainly insoluble phosphate dust is used in the blunger. Some scrubber liquor is also sent to the centrifuge dewatering unit to help improve the overall process water balance.

Centrifuge Dewatering System

In 1980, a centrifuge dewatering system was installed to help improve the water balance problem.

The centrifuged sludge (mainly insoluble phosphate) is used in the blunger, while the filtrate is used to further rework wet spillage.

A tight control on water addition is necessary to ensure a manageable water balance.

Low-Emission Neutralizer

A low-emission ammonium nitrate neutralizer was commissioned in December 1984. This unit incorporated MCC (Mississippi Chemical Corporation) technology to reduce the ammonia and ammonium nitrate emissions at the source, and it precludes the need for any external filtering or scrubbing operation as is required in a number of other plant locations within the ICI Group.

In the MCC neutralizer (Figure 1) nitric acid of sufficiently low concentration is reacted with ammonia in such a manner as to inhibit the vaporization of the nitric acid. Under these conditions, fumes and vapor losses are minimized. The neutralizer has an internal annular chamber to produce recirculation of ammonium nitrate solution and nitric acid within the vessel.

Five weeks after the successful commissioning of the new neutralizer, ammonium nitrate began to fall out from the neutralizer exhaust stack, gently at first but it became so severe in late May 1985 that it was better described as a blow out. The ammonium nitrate solution was being blown out of the neutralizer stack which is 40 feet high to a height of 30-40 feet beyond the top of the stack. The hot solution sprayed on the surrounding area creating a hazardous situation.

There was an initial suspicion of possible ammonium nitrate decomposition because of the high amount of

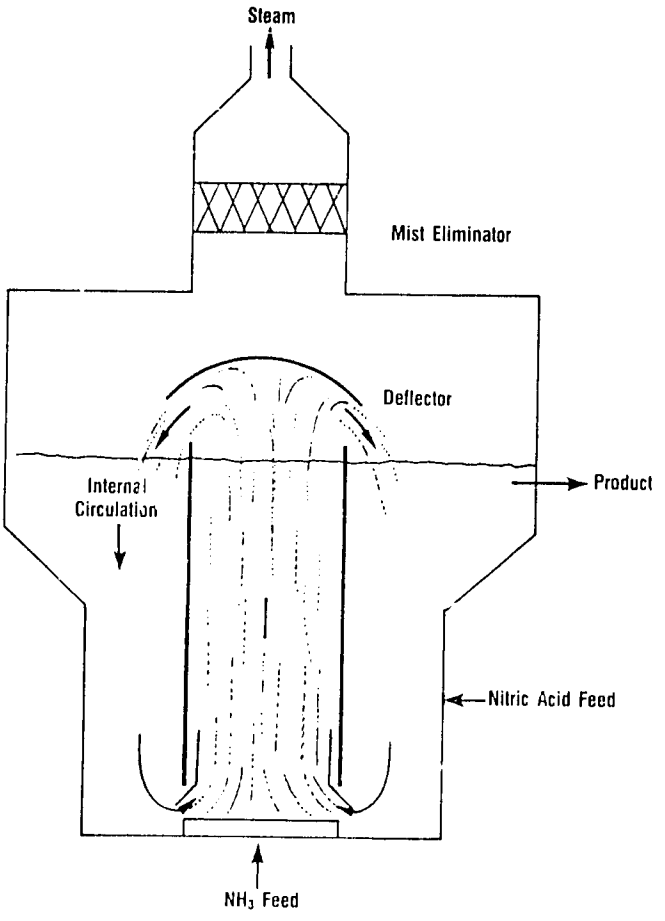


Figure 1. **Mississippi Chemical Corporation Ammonium Nitrate Neutralizer.**

energy judged to be necessary to raise and eject the solution to such heights. A thorough check was made of oil and other contaminants. No abnormal levels of organic contamination were found. Three sight glasses were then installed on the neutralizer to allow observation of its contents near the overflow level. It was observed that there was a lot of turbulence, and gas bubbles were building up well above the dip tube-type overflow point. It was the formation of these excessive amounts of thick and stable bubbles which reached the demister pad and caused a blockage. This resulted in a high pressure build-up which eventually led to the observed ammonium nitrate "blow out." A steam sparger was fitted just below the demister pad to break up the bubbles, while a second overflow line (not dipped) was added to facilitate the removal of ammonium nitrate solution and hence allowed more vapor space to accommodate the thick layer of bubbles formed.

The cause of change in the behavior of the bubbles was traced to the presence of fine iron oxide particles in the ammonia feed. Under normal circumstances the mixing and scrubbing action of gas would produce an abundant number of gas bubbles near the deflector plate above the internal annular chamber. But these bubbles would not have caused the problem because they would normally break up before reaching the demister pad. However, with the presence of the iron contamination, the foaming became more severe because the bubbles became more stabilized and did not break up readily. This allowed the bubble layer to increase substantially and reach the demister pad, thereby causing the phenomenon described.

The fine iron particles had actually come from the ammonia vaporizer which was subjected to a cleaning operation a few weeks before, but the unit could not be cleaned thoroughly because of poor access. The fine iron particles must have come from the loosened debris of oil/iron sludge at the base of vaporizer. The neutralizer is now operating satisfactorily although excessive amounts of bubbles can still be observed in the sight glasses now and then. Table 3 shows the reduction achieved in the emission of both ammonia and ammonium nitrate.

Ammonium Nitrate Safety

Neutralizer

The production of ammonium nitrate by neutralization has certain safety hazards that need to be considered.

The maximum concentration of ammonium nitrate solution that can be safely produced and stored in bulk

Table 3. **Neutralizer Stack Losses – Ammonia and Ammonium Nitrate**

	Old Neutralizer (A)		MCC Design		Achieved Results (B)		Reduction Factor (A/B)
	(kg/mt)	(gm/m³)	(kg/mt)	(gm/m³)	(kg/mt)	(gm/m³)	
Ammonia	1.78	2.25	0.90	1.14	0.35	0.45	5-fold
Ammonium nitrate	7.0	8.87	0.45	0.57	0.05	0.06	148-fold

tanks is 87%. Therefore, the neutralizer section has been designed with this in view. The main sources of danger in handling ammonium nitrate solution arise from its acidity, excessive temperature, confinement (which allows high pressure to build up), and contamination with chlorides or organic materials.

In general, the occurrence of any one of these conditions is unlikely to lead to hazardous conditions, but the combination of any two or more of them can cause a severe explosion. It is in relation to these points that emphasis on good supervision is required, both in ensuring that the nitrate section is started up and shut down correctly and that the proper procedures are strictly adhered to.

Acidity - Acidic ammonium nitrate solutions must never be evaporated to strengths greater than 87% and highly acidic solutions (pH less than 1.5) should never be produced at all. The rates of ammonia and nitric acid fed to the neutralizer are automatically controlled by a ratio controller with the ratio being set by the pH measurement of the liquor produced. The pH controller is fitted with a mechanism which interrupts the nitric acid supply when the pH becomes too low.

High Temperature - The ammonium nitrate is produced in the neutralizer as a boiling solution and its concentration is therefore dependent on its temperature. The neutralizer is fitted with three temperature indicators that have a high temperature alarm and tripping device (with a voting system) set at 140° to 142°C which shuts off the nitric acid supply when the temperature becomes too high. In the event of a further rise in temperature of 3° or 4°C, which could indicate the onset of a catalytic decomposition reaction, the alarm system then opens a valve which floods the neutralizer with condensate (water).

Confinement - The possibility of a blockage of the demister in the main 16-inch vapor vent line causing a pressure build up in the system is eliminated by having on the top of the vessel a water-sealed safety device set to open at 2.5 psig. If the vent on the pumping tank should get choked, the overflow line on the tank would act as a safety valve which would open.

Contamination - The only likely source of chloride contamination is from water supplies. Although the normal level of chloride in ordinary water is probably too low to constitute a hazard, there is always the possibility of a local concentration in the system because of recycling. Therefore, all the water used for washing out lines and vessels and for dilution purposes is supplied from a condensate head tank in which a level is always maintained by condensate from the main steam system. The head tank is fitted with a low-level alarm to ensure that it is never allowed to become empty. Only the greatest possible care in good housekeeping can prevent contamination with organic materials such as paper, grass, string, sawdust, oil, and other materials. Special emphasis must be placed on inspection after any of the vessels or lines have been opened for maintenance work.

Evaporator

The evaporator which is designed to concentrate 18 mtph of ammonium nitrate from 85% to 99% is of the falling-film type. This type of evaporator consists of a large number (320 in this case) of tubes inside a steam chest. The liquor to be evaporated passes down the tubes as a thin film on the walls and water is boiled off by the heat transferred from the steam jacket. An important reason for selecting this type of evaporator is that it has a very short residence time, and therefore there is only a very small quantity of highly concentrated nitrate liquor present at any time.

Decomposition Hazards

When heated above a certain temperature, fertilizers that contain ammonium nitrate and potassium chloride can decompose, liberating toxic gases and a dense white fume. The instability of these mixtures is due to a catalytic effect of the chloride on the decomposition of the ammonium nitrate. Because the decomposition reaction itself liberates heat, the fertilizers may continue to decompose after the external source of heat has been removed. Ammonium nitrate itself does not decompose at temperatures of less than 170°C but chloride catalyzed decomposition can occur at temperatures as low as 110°C.

During the decomposition chlorine, nitrogen, and oxides of nitrogen are almost invariably present in the gases liberated, although the brown fumes, typical of the oxides of nitrogen, may not usually be visible unless the chloride content of the fertilizer is low.

It is most important that no attempt is made to suppress this type of decomposition by suffocation, for example, by excluding air, since this will not stop the reaction and could lead to a violent explosion caused by the buildup of high pressure gas. Exclusion of air will not stop this type of reaction because the ammonium nitrate contains sufficient oxygen to support the reaction without the need for an external source.

A quench-water system is available for supplying hydrant water to the pieces of equipment that may contain a large quantity of decomposing material (for example, the dryer, blunger, and product cooler).

Types of Fertilizer Decomposition - There are three types of decomposition of nitrate fertilizers which are important. They are described briefly as follows:

1. Spontaneous Heating in the Pile (Pile Self Heating)
   Ammonium nitrate-based fertilizers can, at storage temperatures, undergo spontaneous heating due to slow reactions between the nitrate and organic matter occurring in the pile. Normal CCM fertilizers do not undergo this type of reaction, but there may be small stock piles of reject material which are contaminated with organic materials such as paper and string. It is therefore possible that spontaneous combustion can occur in the pile, particularly if some of the fertilizers have been made from incompletely neutralized nitric acid.

2. Fume Off
   At higher temperatures (above about 100°C) the more vigorous decomposition, usually described as "fume off," can take place with all nitrate-based fertilizers which contain chloride. This type of chloride catalyzed decomposition has a temperature-dependent induction period. During this induction period, the fertilizer remains comparatively stable, but at the end of this period, very rapid decomposition occurs, accompanied by a rise in temperature and the evolution of dense white fumes that consist primarily of ammonium chloride and contain toxic gases such as oxides of nitrogen. This phenomenon normally takes place during the manufacturing process. To avoid "fume off" fertilizer material should be kept neutral or alkaline and below 110°C.

3. Self-Sustained Decomposition (Cigar Burning)
   Some fertilizers also undergo a self-sustaining decomposition under certain conditions. This phenomenon is normally initiated by localized heat and is often referred to as "cigar burning," since the decomposition zone of a mass of fertilizer moves forward at a definite rate somewhat like the way a cigar slowly burns along its length. This burning propagation is accompanied with the generation of toxic fumes. Clearly this behavior can convert a local small incident into a major disaster. In fact, several major disasters of this type have been reported.

The initial work on cigar burning of compound fertilizers made in CCM was done by A. B. Parker of ICI (UK) in 1965. The result was tabulated in a triangular diagram (Figure 2). Although this was for a three-component system (NPK), its application to CCM's four-component system was justified on the grounds that the fourth component (kieserite) constituted only a small part of the total (less than 10%). It was used to distinguish potential cigar burners at the initial formulation stage in the early days. The diagram provides a fairly good method of distinguishing between cigar burners and non-cigar burners. It does not, however, include the rate of burning to establish the order of severity of the cigar burners.

Subsequent work was done by George Hunter in 1968 and again by K. Sivapathy, the Laboratory Manager of CCM-SAW in 1970-71. Sivapathy used a series of open-tray tests to establish the burning rates of the range of CCM-SAW's formulations. This work showed a similar order of severity and the transition line between continuous burners and those that stop. Both sets of results confirmed Parker's earlier triangular diagram. The results were depicted as iso-velocity lines for the burning rates in the affected area so that the degree of cigar burning could be assessed. It was found that low-K_2O formulations are the more severe burners.

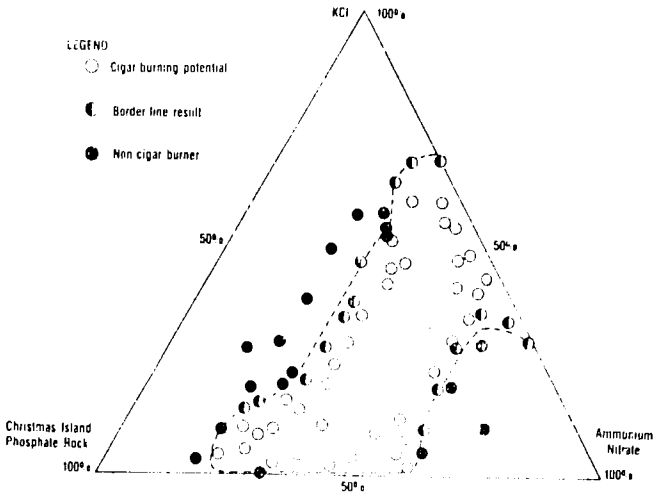


Figure 2 **Cigar-Burning Potential Based on Laboratory-Scale Beaker Tests.**

Further work by Sivapathy in 1971, however, indicated that the severity of cigar burning in CCM-SAW's continuous burners such as formula numbers 11, 22, 25, and 66 can be reduced by using ground MOP as shown in Table 4.

It is believed that since cigar burning is an insidious, chloride-catalyzed exothermic reaction, the use of fine MOP (finer than 60% through a 60 mesh screen) which has a greater surface area to facilitate greater heat dissipation, actually reduces the cigar burning severity. Although this offers a method of reducing cigar-burning severity, it is not the method currently used by CCM.

Acid Scavenging Effect on Cigar Burners – Chloride-catalyzed cigar-burning reactions are acidic in nature. This is evidenced by the fact that copious amounts of nitrous fumes are generated during the process. If these fumes are scavenged at the source then the onset of exothermic cigar-burning reactions will be greatly reduced. This is the current thinking at CCM-SAW. The idea was first developed by Sivapathy in 1970 while CCM-SAW was

making TSP-based compound formulations. Sivapathy found that alkaline ammonium nitrate actually resulted in an acidic end product which was both dangerous to manufacture and store, while the use of acidic ammonium nitrate would yield an end product which was less acidic and consequently safer to manufacture and store.

Table 4. **Severity of Cigar Burning of Compound Fertilizers Containing Ammonium Nitrate and Muriate of Potash (MOP)**

CCM Formulation	Burning Rate, cm/h	Duration
Ordinary MOP		
11	12.0	Continuous
22	6.4	Continuous
25	8.0	Continuous
66	9.0	Continuous
Ground MOP		
11	7.5	Continuous
22	4.0	Continuous
25	4.0	Stop
66	4.0	Stop

When ammonia is added to TSP, one of two reactions takes place. Ammonia reacts with the free acid in TSP to form an ammonium phosphate product:

$$\underset{\text{free acid in TSP}}{NH_3 + H_3PO_4} \rightarrow \underset{\text{water-soluble product}}{NH_4H_2PO_4} \quad [1]$$

Ammonia also reacts with TSP to form water insoluble calcium hydrogen orthophosphate:

$$\underset{\text{TSP}}{NH_3 + CaH_4(PO_4)_2} \rightarrow \underset{\text{water insoluble product}}{CaHPO_4} + \underset{\text{water soluble product}}{NH_4H_2PO_4} \quad [2]$$

Laboratory investigations reveal that reaction [2] proceeds much faster than reaction [1] and results in the reversion of soluble P_2O_5 to the insoluble form without measurable change in pH or reduced acidity.

In the absence of ammonia, the TSP will behave somewhat differently as follows:

$$\underset{\text{phosphate rock}}{Ca_3(PO_4)_2} + \underset{\text{free acid in TSP}}{4H_3PO_4} \rightarrow \underset{\text{TSP}}{3CaH_4(PO_4)_2} \quad [3]$$

The free acid in TSP is scavenged by the alkalinity of the insoluble rock phosphate to produce a TSP/rock phosphate mixture of lower acidity but higher soluble P_2O_5, making a product which is safer to manufacture and has improved storage properties.

The net effect of this can be seen in the cigar-burning characteristics of the formulation 16-16-8 where the burning rate when using alkaline ammonium nitrate is 14.7 cm/h, while the rate with acidic ammonium nitrate is 8.0 cm/h.

The fact that acid scavenging helps to decrease cigar burning has led to the use of calcined magnesite which can be used as a source of magnesium in place of kieserite.

Calcined Magnesite Helps to Reduce Cigar-Burning Severity—Calcined magnesite is a rich source for magnesium but it is not water soluble and hence it has not gained acceptance as a source for MgO especially when kieserite is available which is relatively water soluble. Fortunately, calcined magnesite has a trace of carbonate. It will therefore require only a trace of acid to break up this carbonate. This action not only makes MgO become available but also removes the trace of acid, which is purported to bring about cigar burning. This is illustrated as follows:

$$\underset{\text{(from calcined magnesite, no available MgO)}}{\text{Trace of Carbonate}} + \underset{\text{(from insidious cigar-burning reactions)}}{\text{Trace of Acid}} \rightarrow \underset{\text{(reduced cigar-burning severity)}}{\text{Available MgO}}$$

The end result of this practice has been to reduce the cigar-burning formulations from eight to three and to lower the severity of burnings (Table 5).

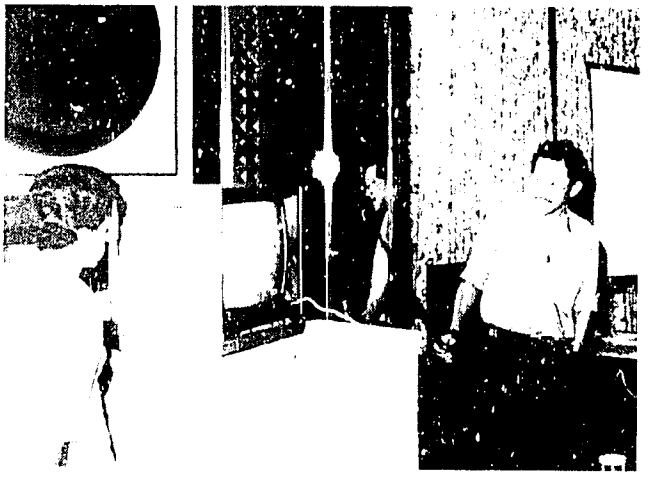
Table 5. **Current List of Cigar-Burning Formulations at CCM-SAW**

CCM-SAW Nomenclature	Formulation	Trigger Time (minutes)	Rate (cm/h)	Remarks
CCM 15/R1	10-16-9-2.5	40	2	Non-continuous
CCM 22	18-11-5-2.5	10	0	Non-burner
CCM 25/R2	14-13-9-2.5	40	3	Non-continuous
R3	10-12-13	30	3	Non-continuous
CCM 33	15-7-18-2	40	2	Non-continuous
CCM 44	12-6-22-3	40	2	Non-continuous
CCM 45[a]	12-12-17-2	35	1	Non-continuous
CCM 55[a]	15-15-6-4	25	6	Continuous
CCM 65[a]	15-15-15	20	12	Continuous
CCM 66	14-14-14	40	3.5	Non-continuous
CCM 77	17-8-17	40	5	Continuous
CCM 88	10-13-15-2.5	40	2	Non-continuous
CCM 99	11-14-16	40	3	Non-continuous

a. One-third of total P_2O_5 is water soluble.

Note:

1. At CCM-SAW, the cigar-burning rate is determined by heating one end of a trough 25 cm x 30 cm x 40 cm high containing about 30 kg of fertilizer with a bunsen burner.
2. Non-continuous means the burning does not propagate itself. It extinguishes itself; these formulations are not considered cigar burners.
3. Continuous means the formulations are cigar burners. These can propagate themselves; among them are CCM-SAW Nos. 55, 65, and 77.
4. Among the burners CCM 65 is the worst at 12 cm/h.



Granular NPKs Based on Superphosphate and Ammonium Phosphate

John L. Medbery, Consultant to IMC Fertilizer, Inc.

Abstract

Granulation of solid fertilizer materials requires a proper liquid-to-solids ratio in order to form agglomerates of the desired size. In granulating ammonium phosphates, phosphoric acid is partially neutralized with ammonia in a preneutralizer to an $NH_3:H_3PO_4$ mole ratio of either 0.6 or 1.45 because the solubility of the ammonium phosphate is maximized at these points. The preneutralizer liquor is then added to the dry solids in the granulator where the mole ratio is adjusted to a less soluble level by adding either ammonia or phosphoric acid. The amount and characteristics of the recycle fed to the granulator also affect the liquid-to-solids ratio. Steam and water are often used to overcome minor upsets caused by variations in the recycle system.

The use of the pipe-cross reactor results in the rapid removal of most of the water from the neutralized or partially neutralized slurry (melt) of ammonia and phosphoric/sulfuric acid and causes it to quickly solidify without adding much liquid phase to the process. The liquid phase can be prolonged by adjusting the mole ratio to provide greater solubility of the compounds in the melt.

Highly soluble salts such as ammonium nitrate and urea can be incorporated in granular NPK products. Little water is required for granulation. The products are very heat-sensitive; therefore, the slightest change in the dryer temperature can cause problems. Nevertheless, many plants use ammonium nitrate or urea to supply a significant part of the nitrogen in the products.

Superphosphate, which is a mixture of several chemical compounds, can be easily granulated by ammoniating it in a rotary drum. The ammonia is added through a drilled pipe-type sparger placed beneath the rolling bed of superphosphate in the drum. Liquid phase (granulation efficiency) can be controlled with the addition of water and/or steam. Superphosphate can also be granulated by itself, without the addition of other fertilizer materials, simply by adding steam and water to it. Salts in the superphosphate are solubilized and subsequently reprecipitated in the interstices of the particles to form strong bonds that agglomerate them.

Basic Principles

Fertilizer materials agglomerate into granules onl when conditions are proper for this to occur. Carl Ludwi (1) in a 1954 paper states:

> Think of agglomeration as a progressive gathering of sub-assemblies into a larger interlocked structure. Such action is probable only when the loose bulk can suffer some deformation without fracture and when there is both a tendency for and freedom of the individual particles to find their own equilibrium locations during the packing.
>
> This helpful and important phenomenon is called plasticity. It can be artificially promoted in several ways: (1) by adjusting the screen analysis to get some fluosolid mobility, (2) by adding liquids which make it easier for the fragments to slip into place, (3) by intimate mixing of plasticizers (liquids) with fines to capitalize on liquid to solid surface tensions.
>
> Any liquid medium among the fines will lubricate the particle migration and, because the liquid can be displaced, will also afford a higher freedom of movement to the non-yielding solids. Less obvious, but highly significant in the agglomeration process, these liquid plasticizers, when displaced or sheared, give rise to unsatisfied surface tensions which, seeking equilibrium, help the particles reach their optimum locations.

In the foregoing quotation, Ludwig very lucidly describes the relationships of liquid-to-solids that must exist for agglomeration to occur. Things have not changed in 34 years; it still requires the proper ratio of liquids-to-solids to form an agglomerate.

Surface tension films that develop around the solid particles merge with adjacent surface tension films and these films in their urge to draw together, also pull their captive solid particles together. The rolling action of a drum, pan, or blunger bed promotes intimate contact and thus assists the surface tension forces in consolidating the wetted sub-assemblies into larger assemblies or agglomerates.

The objective of the formulator is to provide just enough liquid to achieve the consolidation of solids into agglomerates of the desired size; not too much liquid, or not too little. Because recycle of solids varies in many processes, it is desirable to have one or two sources of liquid in the formula that can also be varied without upsetting the nutrient content of the formulation. These discretionary liquids can be manipulated by the operator to obtain the product size that is desired. Water and steam fulfill this requirement.

As the various types of granulation processes are described in the following sections of this paper, the vital liquid-to-solids relationship will be characterized.

Granulation of Ammonium Phosphates

This discussion will dwell on those processes that involve the neutralization of phosphoric acid with ammonia to produce an NP compound which, in turn, is the major constituent of the final products. Monoammonium phosphate and diammonium phosphate fall into this category, as do any NPK fertilizers in which the neutralization of phosphoric acid is a major operation in the process.

The liquid required to facilitate agglomeration is largely provided by the partially neutralized acid. As the agglomerates form, the liquid phase becomes progressively less fluid, either because of additional chemical reactions or because of evaporation and removal of water. In most cases, both of these occur simultaneously. The extent of neutralization that has occurred before introduction of the NP liquor to the granulator controls the relative plasticizing ability of this fluid.

The solubility curve for the system NH_3-H_3PO_4-H_2O is familiar to all fertilizer chemists. The preneutralizer is operated at a high solubility mole ratio either 0.6 or 1.45. At 75°C, the solubility at these mole ratios is about triple what it is at a mole ratio of 1.0 or 2.0. Agglomeration is achieved by mixing the high-solubility preneutralizer liquor with the dry solids and then shifting the mole ratio to 1.0 or 2.0 by the addition of either phosphoric acid or ammonia to the granulator. Simultaneously, with the chemical reactions, water vapor is evolved and removed from the process. These factors dramatically reduce the liquid phase.

Concurrently, the amount and characteristics of the recycle fed to the granulator also influence the fluid-to-solids relationship. Dry recycle can vary in many ways – quantity, particle size, temperature, chemical composition, moisture, and surface properties; all of which can affect the agglomeration efficiency of the process. Most modern plants control the rate at which recycle is returned to the granulator, but other factors such as crusher performance or dust collector behavior are not always uniform. A certain amount of operator discretion in the use of water or steam may be needed to overcome minor process upsets.

When the pipe-cross reactor (PCR) is used, either singly or in conjunction with a tank-type preneutralizer, some additional operating factors must be considered. The chief advantage of a PCR is the instantaneous release of water from the reaction slurry (melt). This saves dryer fuel, but only if the liberated steam is removed from the granulator. The melt that is discharged from the PCR remains in a fluid state temporarily, because of its high temperature. However, as it mixes with the materials in the granulator bed, it cools and solidifies rapidly. Its contribution to the liquid phase needed for agglomeration is therefore of short duration.

The fluid phase can be prolonged by adjusting the mole ratio of ammonia to acid fed to the PCR to provide higher solubility of the NP compounds in the melt. For instance, many prefer to operate the PCR at a mole ratio of 0.8 or 1.2 rather than at 1.0.

To control buildup in the PCR caused by impurities in the phosphoric acid, significant amounts of sulfuric acid are introduced. Also some residual sulfuric acid is present in most wet process phosphoric acids. The formulator must calculate the ammonia that will combine at a mole ratio of 2.0 with these sources of sulfuric acid and then deduct that amount of ammonia from the total to arrive at the amount available to combine with the phosphoric acid.

A drum granulator is basically a volumetric feed-through device in which chemical reactions occur at different places throughout its length. The opportunity for agglomeration to occur in any given zone depends upon the liquid-to-solids ratio in that particular section of the bed. An example would be the melt discharge of a PCR onto the rolling bed of solids in the first one-third of a drum. If the PCR is operating at a mole ratio of 1.25, the liquid phase will be almost double what it will be after more acid has been added and the mole ratio decreased to 1.6. If opportunity for agglomeration is to be enhanced, the extra phosphoric acid should be added in the center one-third or perhaps even the final one-third of the granulator.

A similar case would exist if the PCR were operated at a mole ratio of 0.8. Then the location of the drilled sparger through which additional ammonia would be fed is most important. Adding ammonia will almost immediately dry the bed and shorten agglomeration time. Placing the ammonia further downstream will maintain

the higher liquid phase for a longer time and promote more agglomeration.

Granulation With Highly Soluble Salts

In this paper the term "highly soluble salts," refers mainly to ammonium nitrate and urea. Compared with other nitrogen salts, they are vastly more soluble and only a small change in water content or temperature has a very pronounced effect upon the total liquid phase available for agglomeration. In fact this propensity is both a blessing and a curse. The blessing is that granulation can be achieved with very little water. The curse is that the products are so heat-sensitive that the slightest upset in dryer temperature, for example, can result in a rapid change in total liquid phase.

In spite of these difficulties, many plants are operating very successfully with urea as a significant contributor to the nitrogen content of the products. Because urea has become a major source of nitrogen worldwide, there is a strong need to incorporate it in NPK products. Urea is also the best nitrogen source for flooded agriculture, which makes it especially important in southern Asia. The plant engineers, have, of necessity, learned to control the process.

Urea ammonium phosphate plants in India, for instance, limit the suddenness of changes in the liquid phase by operating the granulator at relatively low temperatures of 71°-77°C (2).

To quote from Vasani and Leyshon:

> Drying high-urea-content fertilizers has been a well balanced act requiring close control of temperature. Larger dryer fan capacities than normally required for other DAP/NPK grades have to be used to limit gas temperature in the dryer.

These authors go on to say that larger fans serve two purposes: they prevent over-heating and thus, melting of the fertilizer, and they also permit drying to less than 1% moisture, which is a requirement for the UAP grades.

To continue from this source:

> Urea-DAP formulas require longer dryer detention. This is basically not for the normal sized particle with its thin film of new slurry, these dry very rapidly. The added detention is to cope with lumps and agglomerates which dry very slowly.

Additionally, the authors say that urea NPK grades are much more difficult to dry than urea NP products. This is attributed to the lowering of the critical relative humidity when potassium chloride is incorporated in the product.

To continue from this source:

> Hydrolysis is relatively difficult to avoid, but is minimized by certain process conditions including avoiding the addition of either unneutralized phosphoric acid or sulfuric acid to the granulator.

It has also been pointed out that screening and crushing operations are very difficult because of the high hygroscopicity of NPK grades that contain urea.

Products that contain ammonium nitrate are also difficult to granulate on a controlled basis. Temperature has a pronounced effect upon the overall liquid phase. The temperature of the recycle as well as the recycle ratio must be considered to obtain satisfactory performance. W. F. Sheldrick (3) reported on a 20-10-10 formulation produced by spraying a mixture of ammonium phosphate and ammonium nitrate into a granulator. Ammonium sulfate and potassium chloride were added as solids.

It was determined that as the recycle temperature was lowered, the granulation temperature also dropped, and the recycle ratio required to control liquid phase could also be reduced. In this case, the output of the plant could be increased merely by cooling the recycle.

Sheldrick's paper explained how Fisons, Ltd., was able to predict the granulation parameters for various NPK grades by developing relationship curves based on bench-scale laboratory tests. The curves presented in his paper correlate water content, temperature, particle size of feed and chemical reactions that occur in the process.

Granulation Based on the Ammoniation of Single Superphosphate

Superphosphate is a mixture of many chemicals. The primary constituent is monocalcium phosphate monohydrate. This is a water-soluble source of P_2O_5. When single saperphosphate is properly made and cured, using Florida 72 BPL rock (about 33% P_2O_5), the product will contain about 88% of its total P_2O_5 in this form. About 10.5% will be in the form of dicalcium phosphate, which is soluble in a citrate solution and thus considered to be available to plants. Approximately, 1.5% of the P_2O_5 will remain in the form of tricalcium phosphate. Moisture will makeup about 6% of the product weight. The gypsum will be mostly in the anhydrous form and will represent about 48% of the product weight.

The analysis of a properly made superphosphate will then be: total P_2O_5 19.9%, available P_2O_5 19.6%, water-soluble P_2O_5 17.5%, free acid 2.4%, water 5.9%, CaO 27.1%, SO_3 28.4%, R_2O_3 1.3%, F 1.6% (4).

It should be pointed out that the first rotary drum ammoniator was built for the purpose of continuously adding ammonia to superphosphate. It was found that when this was done under controlled conditions, agglomeration would occur (5).

The next step was to capitalize on this discovery and add acids which would also be reacted with ammonia, generating heat and contributing to liquid phase and thus promoting granulation. The acids and the ammonia were added to the rolling bed in the ammoniator through drilled pipes called spargers. The ammoniator then became an ammoniator granulator.

The drilling of holes in the spargers is designed to promote the ammoniation of superphosphate before the acids are contacted. The sequence of superphosphate ammoniation reactions is:

First, the free acid is neutralized:

$$H_3PO_4 + NH_3 \rightarrow NH_4H_2PO_4 \qquad [1]$$

Second, the monocalcium phosphate becomes involved. This reaction occurs as ammonia is added up to 2-lb per unit (20 lb) of P_2O_5:

$$Ca(H_2PO_4)_2 + NH_3 \rightarrow NH_4H_2PO_4 + CaHPO_4 \qquad [2]$$

Next, a series of secondary reactions take place. These occur more slowly, and at the 2- to 4-lb per unit of P_2O_5 ammoniation level. This shows MAP becoming DAP:

$$NH_4H_2PO_4 + NH_3 \rightarrow (NH_4)_2HPO_4 \qquad [3]$$

These reactions involve products of the first two reactions, and this one shows the involvement of the dicalcium phosphate:

$$3CaHPO_4 + 2NH_3 \rightarrow (NH_4)_2HPO_4 + Ca_3(PO_4)_2 \qquad [4]$$

If gypsum is present, then two more reactions occur at the 4- to 6-lb per unit P_2O_5 ammoniation level. Dicalcium phosphate, ammonia, and gypsum produce tricalcium phosphate and ammonium sulfate:

$$2CaHPO_4 + 2NH_3 + CaSO_4 \rightarrow Ca_3(PO_4)_2 + (NH_4)_2SO_4 \qquad [5]$$

And MAP plus ammonia and gypsum results in dicalcium phosphate and ammonium sulfate:

$$NH_4H_2PO_4 + NH_3 + CaSO_4 \rightarrow CaHPO_4 + (NH_4)_2SO_4 \qquad [6]$$

If ammoniation goes all the way to this 6th reaction, the water solubility is reduced to 25% of the total P_2O_5.

Because the two gypsum reactions (5 and 6) occur slowly, sulfuric acid should not be added too soon because that will intercept the ammonia and prevent the conversion of the gypsum. Of course, if more water solubility is desired, then the acid should be added early.

Logically, ammonia should be added at a uniform rate through a long sparger beginning near the inlet end of the drum. Sulfuric acid should be added stepwise to facilitate the generation of the desired end product.

All of the reactions produce heat. When superphosphate is ammoniated up to 6 lb of ammonia per unit of P_2O_5, 1,480 Btu of heat is released per pound of ammonia.

When this heat is coupled with the heat produced by reactions of ammonia and acids and heat added through steam injected into the bed, the desired granulation temperature of 93°-99°C is attained.

This process is very operator-dependent. The operator's duties include frequent adjustment of water and steam inputs to the bed. He literally "makes" agglomeration occur.

Granulation of Superphosphate

When superphosphate is granulated by itself (without the addition of other materials) the liquid phase necessary for agglomeration is derived primarily from water and steam. The development of strongly structured granules that will withstand handling and storage is desirable; and, as with other granulated fertilizers, this is dependent upon the bonding of the wet granule together with a matrix of dissolved salts. The more salts that are solubilized and then, upon drying, reprecipitated into the interstitial spaces, the stronger the resulting granules will be.

Many excellent papers have been written regarding the variables that affect the granulation efficiency. A 1969 paper by Rao and Hohmann (6) does an excellent job of reviewing the literature and bringing out the key factors involved in this process. One of the most significant findings was the importance of temperature. They showed that as the temperature increased, so did the granulation efficiency and the crushing strength of the resultant granules. They also noted that the salts found in single superphosphate are somewhat slow to dissolve, so that a

certain residence time at the elevated temperature and about 10% added water will produce 20%-30% liquid phase, which is the amount needed for good granulation. Particle size of the feed material is important too because the dissolution rates will be proportional to the amount of exposed surface to be wetted.

At an ISMA conference Magnati et al. (7) reported an interesting relationship between the free acid present in the superphosphate and the amount of water needed for successful granulation. Their formula converted to English units is:

% Free moisture + % free acid = 17 @ 122°F (50°C)
For every 5.4°F over 122°F, subtract 0.1
For every 5.4°F under 122°F, add 0.1
% Free acid is expressed as % P_2O_5 equivalent.

International Minerals and Chemical Corporation's (now IMC Fertilizer, Inc.) experience in the granulation of single superphosphate has verified this concept, and it is now common practice to acidulate rock with a slight excess of sulfuric acid to enhance its granulatability.

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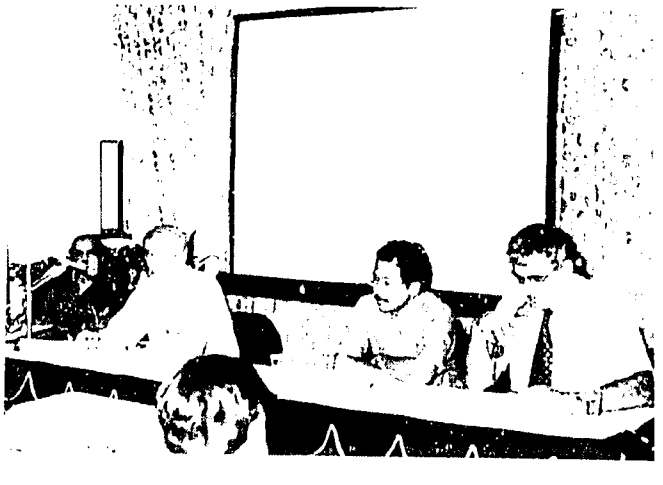


Solid Fertilizer Granulation – An Appropriate Manufacturing Technology

Sanjeev R. Doshi, Director, Fertiplant Engineering Company Pvt., Ltd.

Abstract

Fertiplant Engineering Company Pvt., Ltd. (Fertiplant) has developed a granulation process that uses water (or steam) to agglomerate solids and does not involve chemical reactions or require the use of liquids (other than water or steam) such as ammonia, phosphoric acid, or nitric acid. Solid raw materials such as "off-grade" NPK fertilizers, plant sweepings, diammonium phosphate (DAP), urea, and muriate of potash (MOP) can be converted into strong granules with the desired particle size and chemical composition. The equipment needed is simple – essentially a small bulk-blending plant to which a granulator, dryer, and cooler have been added. The estimated total cost for a 150-mtpd plant is US $1-1.2 million. Fertiplant has built 56 such plants in India and all have operated quite satisfactorily.

Introduction

Solid fertilizer granulation is to be distinguished from chemical reaction granulation. In solid granulation, only solid fertilizers (either in powder, prilled, or granulated form) such as urea, DAP, and MOP are mixed and granulated. There are no chemical reactions, as is typical in ammonium phosphate granulation or nitrophosphate granulation. The process is purely physical in nature.

Logically, this would be the next step in process complexity to bulk blending, that is, after dry mixing and blending the mixture would be granulated. This type of production process is not very widely practiced in the world. People either stop at bulk blending, or straight away set up an ammonium phosphate or nitrophosphate-type granulation plant, where liquids such as ammonia, phosphoric acid, and nitric acid are reacted and granulated. However, in India, there are more than 50 solid fertilizer granulation plants based on solid raw material feeds. This paper deals with the appropriateness and current relevance of this technology and the experience with it in India.

Philosophy

In the 1950s when the Government of India was formulating its fertilizer manufacturing policies, it followed the pattern and the philosophy prevalent in the United States. There was a need for establishing large plants to manufacture basic fertilizers like urea and DAP, but at the same time the need for smaller sized NPK plants for local manufacture and distribution of fertilizer was also emphasized. However, the Indian Government went a step further. It did not stop at bulk blending but insisted that these small mixing plants should also have an attached granulation process. In this way, the advantage of bulk blending could be combined with those of granular fertilizers.

The philosophy, therefore, behind the establishment of smaller capacity solid fertilizer granulation plants can be summed up as:

1. Smaller capacity granulation plants should be built to meet the demands of the local markets.

2. The enormous flexibility of bulk-blending plants should be combined with the advantages of granular fertilizers.

The Deccan Sales Corporation, Ltd. (Deccan), a Fertiplant group company, was the first company to establish such a NPK mixing and granulation plant in Bombay, way back in 1963. The various pieces of equipment were purchased from Fertilizer Equipment and Engineering Co., now known as FEECO International, of Green Bay, Wisconsin, U.S.A. Experience with this technology was so good that the group company, Fertiplant, entered into a licensing contract with FEECO and until this date, has supplied 56 such plants in India. The location of these various plants throughout India is shown in Figure 1. Most of these plants have capacities in the range of 100 to 200 mtpd.

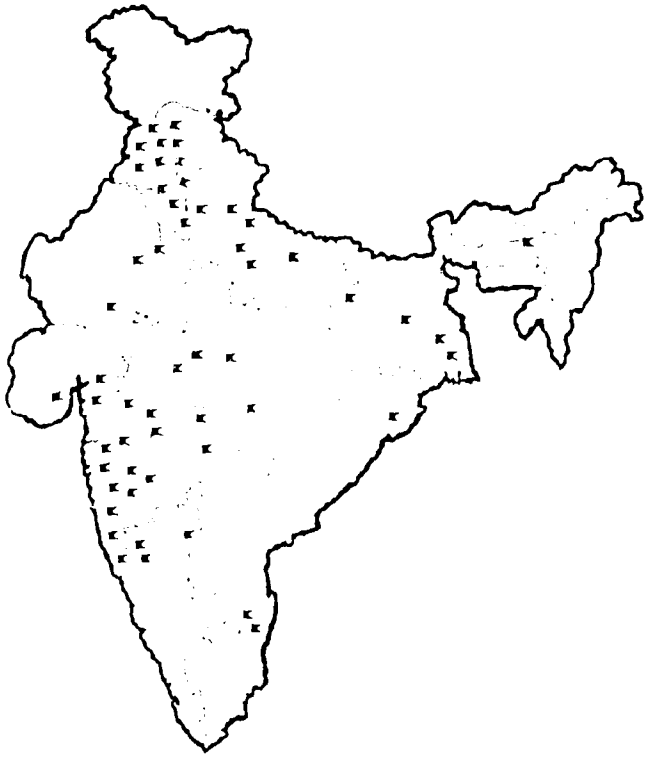


Figure 1. **Location of Fertilizer Granulation Plants Supplied by Fertiplant Engineering Co. Pvt., Ltd.**

Technology and Process

The Fertiplant granulation plant consists of three main sections: (1) mixing and blending, (2) granulation, and (3) screening and recycle.

The measurement of the different ingredients in the correct proportion can either be done by volumetric methods or by gravimetric methods. After the ingredients are measured in the correct proportions to achieve the desired nutrient ratio and blended (mixed) in a double-shaft paddle mixer, the mixture is conveyed to the granulation plant.

From Figure 2, it can be seen that the process flow for the solid granulation plant is almost identical to the process flow of any typical chemical granulation plant. The only difference is that there is no liquid handling or reactions with chemicals like ammonia and phosphoric acid. Also, since no chemical reactions take place, scrubbers are not required. Cyclones are sufficient to remove dust from the gases before they are exhausted to the atmosphere. The wetting medium for the granulation is water. If steam is available, it may be used with an advantage.

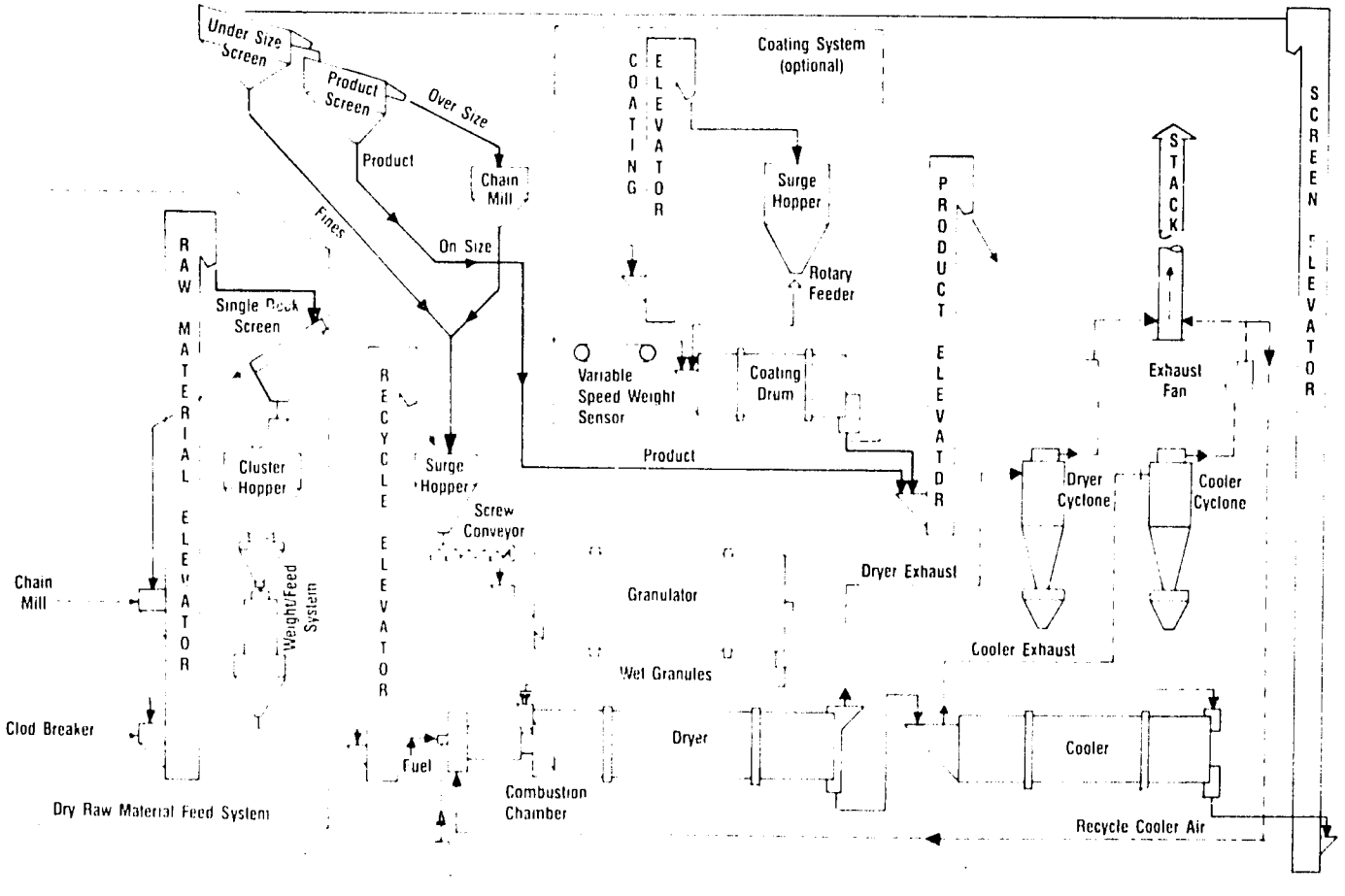


Figure 2. **Flowsheet for Fertiplant's Solid Granulation Plant in Bombay, India.**

Process Description

Blending of Raw Materials

Raw materials like urea, DAP, MOP, single superphosphate (SSP), phosphate rock, and filler are removed from storage in the right amounts, either by a volumetric method which controls the flow of material onto the belt conveyors or by a gravimetric method where the right amounts of the various materials are fed from a cluster hopper into the weigh hopper and a batch of the correct nutrient mix is made.

After the correct quantities have been extracted, the materials are either mixed or blended in a double-shaft paddle mixer (pugmill) or in a ribbon or other type of mixer. Afterward, the blended material is conveyed to the granulator by an elevator.

Granulation

Steam and/or water is added to the material in the rotary drum granulator in the required quantities. The damp material containing about 10% moisture is fed by gravity into the dryer. The dryer is a cocurrent unit equipped with a hot-air generator at one end which delivers hot gases at 500° to 600°C to the inlet of the dryer. The dryer has its exhaust system consisting of a cyclone and fan. The material leaves the dryer at a temperature of 70°C and the gases at about 80°C. The outlet product moisture is maintained around 3%.

From the dryer, the material is then transferred to the cooler by means of a belt conveyor. The cooler is a countercurrent unit, which has its own dedusting system consisting of a cyclone and a fan. Material leaving the cooler has a moisture content around 2%. In a few installations, the exhaust air from the cooler is recycled to the hot-air generator in order to conserve heat.

Screening and Recycling

The cooled granulated material is raised by elevator to the screening section which consists of an undersize screen and an oversize screen. The undersize material falls directly onto the recycle belt conveyor whereas oversize material is fed to the double rotor chain mill, the output of which is conveyed to the same recycle belt conveyor. The accepted size material is in the range 2-4 mm or 2-5 mm, depending on the demands of the marketplace. The product is conveyed to the packing hopper. Coating systems can also be provided.

As previously stated, the equipment and the process flow are similar to those of any chemical granulation plant.

Special Design Features

Solid granulation has its own problems which have to be overcome by proper design of the equipment. In the first place, the granulator has to be longer to allow sufficient time for the granule formation which is basically by physical agglomeration. The first part of the dryer also has to be properly designed since it is here that the urea just begins to attain plasticity. The right amount of plasticity is necessary, which in fact, helps in granulation. Care must be taken not to heat the product too much. The cooler is also extremely useful in the solid granulation process. This is because the material leaving the dryer is sticky and has to be cooled sufficiently to produce round, hard granules. In fact, all three drums help in granulation. From experience, it has been learned that the percentage of the volume in the drums that is filled with material has to be substantially lower than in standard dryers and coolers used in a chemical granulation plant. The peripheral speeds of all three drums are also important and so is the internal flight design. These and many other design features have to be considered while designing and sizing of equipment for solids granulation.

Quality of Granules

Since the solids granulation process is similar to the chemical granulation process, the quality of granules is as good as those produced by chemical granulation. There is uniformity of color; the size distribution is good; and the strength of granules meets the standards required by the Indian Government for granulated fertilizers. The product is stacked 20 bags high as is normal practice in the fertilizer industry. In fact, one cannot differentiate between granules produced by the two processes.

Possible Grades

Almost any of the conventional grades of fertilizer can be made in a solids granulation plant. Even high-urea grades like 18-18-10, which is a very popular grade in India, is easily produced. Table 1 gives a few of the typical grades made by Deccan in Bombay. This table shows that the percentage of urea used can be higher than 40%.

What is more important and advantageous is the ability of such plants to use rejects/off-specification material from large single- or multinutrient plants. In almost all countries in the world, fertilizer quality is governed by law. In large plants, because of disturbances in the manufacturing process or because of some other reasons, many times off-specification or reject products are produced. Such products cannot be marketed to farmers. The only alternative is to reprocess the material. This reprocessing is an expensive and rather troublesome

affair. Large plants usually prefer to sell such material to solid granulation plants, who have the flexibility to use the material and produce a good quality product of a given NPK grade.

Table 1. **Typical Grades and Composition of Solid Granular Fertilizers Manufactured by Deccan Sales Corporation, Limited**

Grades	Ingredients Used	Quantity Used	Nutrient Content in Product N	P_2O_5	K_2O
		(kg/mt)	-------(%)------		
18-18(8)-10[a]	Urea	310	14.40	-	-
	DAP	200	3.60	9	9
	Phosphate rock	320	-	9	-
	Muriate of potash	166	-	-	10
	Filler	4	-	-	-
		1,000	18	18(8)[a]	10
20-0-20	Urea	430	20	-	-
	Muriate of potash	332	-	-	20
	Neem cake	100	0.25	-	-
	Filler	138	-	-	-
		1,000	20	-	20
25-13-0	Urea	468	21.58	-	-
	DAP	190	3.42	11	-
	Superphosphate	125	-	2	-
	Neem cake	60	-	-	-
	SPARTIN (micronutrient)	80	-	-	-
	Filler	77	-	-	-
		1,000	25	13	0
16-12(4)-16[a]	Urea	314	14.43	-	-
	DAP	87	1.57	4	-
	Phosphate rock	267	-	8	-
	Muriate of potash	267	-	-	16
	Neem cake	65	-	-	-
		1,000	16	12(4)[a]	16
14-5-5	Urea	300	13.75	-	-
	Superphosphate	312	-	5	-
	Muriate of potash	83	-	-	5
	Neem cake	100	0.25	-	-
	Filler	205	-	-	-
		1,000	14	5	5

a. The values in parentheses indicate water-soluble P_2O_5 (%) in product.

In fact, many of the solid granulation plants use plant sweeping or off-specification materials. Even materials with a high-moisture content do not pose a problem in granulation (except maybe with the handling and conveying systems). With the use of such materials, at worst, the recycle ratio may increase, but equally good granules can be produced.

Capital Costs

The capital costs for the 150- and 400-tpd plant are shown in Table 2. These costs are based upon the actual order booking done by Fertiplant during the year 1987.

Table 2. **Capital Costs for Fertiplant's Solids Granulation Plant**

	Size of Plant 150 mtpd	400 mtpd
	- (US $ x 1 million) -	
Ex-works cost for battery limits plant (without raw materials handling and packaging section)	0.50	0.95
Additional cost of NPK metering and mixing equipment	-	0.30
Total cost of battery limits plant	0.50	1.25
Additional cost for raw materials storage and handling, packaging section, civil works, interest, erection charges, and miscellaneous items (approximate)	0.50-0.70	1.10-1.25
Total Project Cost	1.00-1.20	2.35-2.50

Notes

1. The cost for the 400-mtpd plant was for an SSP granulation unit and therefore the cost of NPK metering and mixing equipment was added to arrive at the cost for an equivalent NPK plant.
2. The total cost of civil works, raw materials handling, and other items assumes a combined 3-month storage facility for raw materials and finished products and Indian cost estimates for civil and other works.

The cost of the battery limits plant indicated here may seem to be on the low side. However, it must be realized that in a solids granulation plant, the recycle ratio is typically about 60% compared with a chemical granulation plant where the recycle ratio is as high as 600%. Therefore, the equipment sizing is on a lower scale. For example, a 25-mtph chemical granulation plant would be designed for a throughput of 200 mtph. Whereas the same 25-mtph solid granulation plant would be designed for a 50-mtph throughput. That means, for a similar output capacity, one plant is designed to handle 50 mtph throughput, whereas the other handles a 200-mtph throughput. Naturally, the sizing and, therefore, the cost of the equipment are much lower for the solids fertilizer granulation plant.

Also, one must not forget that this process and technology is available from India where the cost, as compared with that in Europe or North America, is much lower.

Outlook for Solid Fertilizer Granulation in the 1990s

The solid fertilizer granulation technology is simple, it produces excellent granules, and it is extremely cost attractive. In India there are many such plants all over the country and the experience has been good. Therefore, the relevance of this technology for the future should be investigated. Some of the points to consider are discussed.

Manufacturing and Local Marketing of the Grades Recommended by Agronomists

Flexibility is the key word in solid fertilizer granulation. Almost any raw material can be used and, therefore, any grades can be manufactured. As the years go by, the agronomists, as well as farmers, are going to be more specific with regard to the formulations required for their particular crop and soil and who can be in a better position than these plants to meet the local demand?

Selection of Most Economical Raw Materials

Since there are many basic fertilizers available throughout the world, many different combinations of raw materials are available for manufacturing any particular grade. These plants, therefore, can have great flexibility in choosing the most economical raw materials. For example, they can minimize the cost per unit of nutrient content of the inputs. This certainly gives an added advantage over chemical granulation processes where standard raw materials have to be used. Market conditions can therefore be taken advantage of by these units.

Use of Plant Sweepings and Off-Specification Materials

As mentioned earlier plant sweepings and off-specification materials, whether they have a lower nutrient content or a higher moisture content, can be used in these solids granulation plants. Everyone is aware of the disproportionate reduction in cost for these off-specification materials. This can be fully exploited by these solids granulation plants and that can make the entire operation extremely profitable.

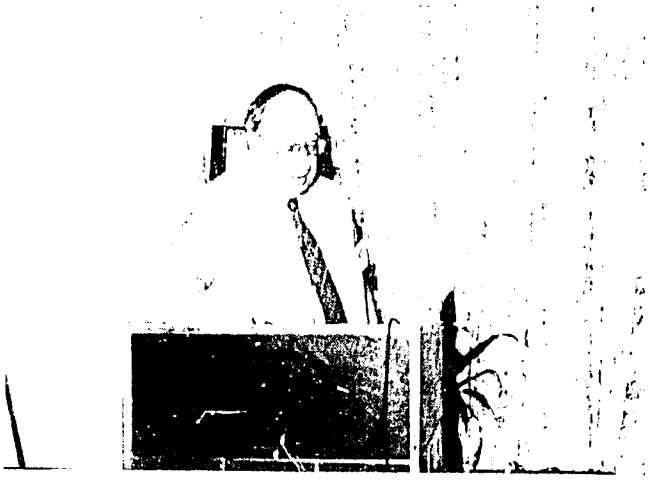
No Liquid Handling

In the solid granulation plants, there are no liquids such as ammonia and phosphoric acid to be handled and this is a great boon especially in those countries where the total fertilizer production is limited and it would be quite uneconomical and impractical to import, store, and handle huge shipments of these liquids. Because no liquid handling or chemical reactions are involved, the process becomes extremely simple and easy to operate and maintain.

Considering the above points, it is apparent that this technology is relevant, not only in the developing nations, but also in the developed nations which can take advantage of the use of offgrade materials and plant sweepings. Therefore, it is obvious that this technology has its own important place among the various technologies available for fertilizer manufacture.

Conclusion

This paper has described briefly the solids granulation technology, the quality of granules, the cost of the equipment, and the relevance of this technology for both the developed and developing nations.



Complex Fertilizer Production – Quality Control Experience of Madras Fertilizers, Ltd.

K. R. Krishnaswami, General Manager, Madras Fertilizers, Ltd.

Abstract

Madras Fertilizers, Ltd., (MFL) operates three NPK granulation trains for manufacturing several complex (NPK) fertilizers. Eighty percent of its production is 17-17-17. Since the process is a continuous one and the production of granules from liquids and solid feed materials is complex, the quality control of the product is difficult to attain because any process correction is accompanied by a time lag before its effects are realized.

Little trouble is encountered in metering the liquid components – phosphoric acid, ammonia, water, and steam. But the proportioning of the solid materials – urea, potash, dust, recycled product, and conditioning agent – involves the use of weigh feeders which operate with less than optimum accuracy because of mechanical malfunctioning and because the flow of solids may be interrupted in bins and chutes.

The screening of hygroscopic materials as well as the conditioning of the product also presents several problems.

MFL has partially alleviated these problems by (1) increasing the frequency of analyzing the product, (2) establishing a program for close monitoring of equipment and operating conditions, (3) improving the mechanical condition and operation of the screening units, (4) calculating the input of raw materials for marginal over formulation, (5) modifying the weigh feeders to improve their reliability and accuracy, (6) arranging pan feeders that more evenly distribute the material over the screens, (7) using smaller size urea to result in a more homogeneous product, (8) using dolomite instead of sand as a filler, and (9) using a fine powdered clay as a conditioner; however, the search for a better conditioning agent continues.

Introduction

Madras Fertilizers, Ltd. (MFL), operates three complex NPK manufacturing units designed and engineered by Dorr Oliver to produce the following grades of NPK based on urea, wet-process phosphoric acid, and potash: 17-17-17, 14-28-14, 11-22-22, 18-46-0, 24-12-12, and 24-24-0.

Of the above grades, based on market demand, MFL has chosen to manufacture 17-17-17, 14-28-14, 24-24-0, and 18-46-0. Again of these, the major share (nearly 80%) goes to 17-17-17.

MFL started regular production of complex NPK fertilizers in two units during the third quarter of 1971. The third unit was added in 1976. The installed capacity is 540,000 mt of NPK complex fertilizer per year. Urea ammonium phosphate-based NPK complexes manufactured by MFL, in spite of their inherent problems in maintaining long-term keeping quality, enjoy a high market share and are very popular among the farmers.

The Process

The manufacturing process includes the receipt, storage, and feeding of all raw material and the key steps can be divided into three sections.

1. Ammonia and Phosphoric Acid Reaction Section: Liquid ammonia and phosphoric acid react to form a slurry in the preneutralizer.

2. Granulation Section: Fresh solid raw materials – urea, potash, filler, and recycled fines – are granulated by adding ammonium phosphate slurry and additional ammonia.

3. Drying/Cooling/Screening/Coating Section: The granules are dried and screened to remove product-size material which is then cooled and coated to enhance its storage quality.

The basic process technology is adopted from TVA granulation techniques. A schematic of the process is given in Figure 1.

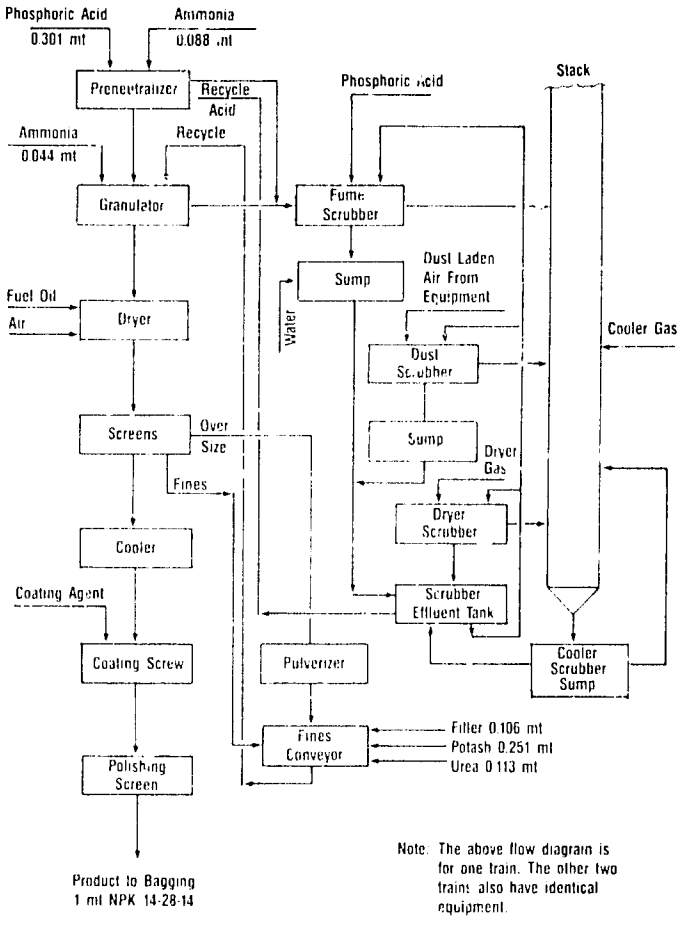


Figure 1. **Flowsheet for the NPK Plant of Madras Fertilizer, Ltd.**

Table 1. **Plant Operating Parameters**

	Operating Ranges
Preneutralizer	
Phosphoric acid strength, % P_2O_5	42
Water content of slurry, %	15-18
N:P mole ratio	1.4
Specific gravity of slurry	1.50-1.54
Temperature, °C	110-120
Steam injection	If required
Scrubber liquor, % P_2O_5	25-28
N:P mole ratio	1.40-1.42 maximum
Granulator	
Slurry temperature, °C	110-120
Product N:P mole ratio	1.78-1.80
Bed temperature, °C	74-75
Moisture content at discharge, %	<3
Recycle-product-ratio	4
General	
Material temperature at the screen inlet, °C	72-73

Problems in Operation and Process Control

The various process parameters maintained at different sections of the plant are shown in Table 1. The problems in maintaining the required parameters are discussed below.

Raw Materials – Feed Control

Liquid Handling

The theory of the phosphoric acid-ammonia reaction is well understood and the operation of the equipment for this reaction is easily controlled. Hence, it is possible to achieve the desired chemical composition of the slurry. This part of the plant presents no significant operating or control problems.

Solids Handling and Granulation

The formation of granules of complex fertilizer in the granulation process is subject to a large number of variables such as the temperature of the slurry, the feed rates of the materials, the size range of the solids, the addition of recycled material, the physical nature of the feed material, and the condition of the equipment. Granulation is still an art, but over the years quite a large amount of experience has been gained and put to practice at MFL. However, the granulation process is not easily controlled because a quick process correction is accompanied by a long time lag before the effect of the change becomes apparent. This poses a problem for the manufacturer with regard to quality control. Another troublesome step in the manufacturing process consists of separating the granules into specified size fractions and returning the material above and below specification limits (oversize and undersize) back to the process. In this step the mechanical condition of the equipment and its performance efficiency determine the nature of the final product manufactured. During the granulation step fresh and recycled solid materials are mixed with liquid slurry to build up large granules. This involves the layering and agglomeration of smaller particles of fresh and/or recycle solids onto a core particle through the adhesion provided by the liquid slurry. The composition of slurry coming into granulator is usually fairly constant and does not vary much from prescribed operating values.

The composition of the solids in the final granule can vary because of the difficulty in accurately feeding these materials. Though the feeding systems have provisions for varying the rate, in practice the variations that can be obtained are not precise. Effective granulation is a problem and any difficulty in the granulation process causes the production capacity to decrease as compared with the total feed into the granulator. This increases the in-process

material inventory in the system, thereby causing a larger quantity of material to be recycled to the granulator. While the liquid (slurry) feed rate to the granulator is kept constant, the composition of the material inside the unit changes. Once there is a change in the composition of material in the granulator, there is a direct effect on the product composition. If the only reaction in the granulator were a chemical one, corrections could be made instantly by changing the reaction itself as is the case when producing ammonia or urea. However, in granulation some chemical reaction is combined with physical blending.

There is always a time lag between the corrective action taken as a result of analysis or data feedback and the results of such action on the operation of the unit. Consequently some off-specification material is produced during the time lag.

Particle Size and Moisture Control – Screening

The moisture levels at various sections of the plant are shown in Table 2.

Particle-size separation at MFL is carried out in a double-deck screening system to separate the granulated material into undersize, oversize, and product size fractions. The screening system poses constant problems due to (1) the quality of locally made screen material and (2) nature of the product being screened. Poor quality of the screen material causes the screens to expand or tear. The hygroscopic nature of the recycled materials and the presence of fines cause the screens to blind. As a consequence, off-specification sizes show up in the product stream. Over the years, MFL has identified better screen manufacturing vendors, introduced better screen vibrating equipment, and reduced screen load by increasing screen area. A third screen has been introduced on two of the granulation units (trains A and B). Maintenance of these systems is accorded high priority.

Maintenance of Product Keeping Quality – Coating of Product

In order to improve the keeping (storage) quality of the product, it is necessary to prevent moisture from coming in contact with the granules. This requires the use of a coating agent to provide an impervious covering for the product. Various coating agents are used by different manufacturers for different products and the selection of the most appropriate one to provide the best storage quality is still an open question. MFL has been carrying out research and development work in this area and has been experimenting with many coating agents. Certain patented materials are very effective but enormously expensive. The fine clay used at MFL is cheap and has effectively prevented materials in storage from caking for a few months. Unfortunately, MFL has a large quantity of bagged products that remain in storage for periods exceeding 3 months. During movement of these bagged materials, the use of hooks on the bags tends to expose the fertilizers to outside moisture. The inherently hygroscopic nature of the product and the long periods of storage tend to cause serious quality deterioration. MFL does not have bulk storage facilities which are weather-controlled (dehumidified). Such a storage would preserve quality of the product but at a higher operating cost. Once again, it is a matter of economics. An optimum period of storage should not exceed 2 months.

Quality Control at the Laboratory

The quality control work at the laboratory consists of analyses of (1) raw materials, (2) in-process materials, (3) final plant products, (4) warehouse products, and (5) bagged material testing.

Table 2. **Particle Size and Moisture Control**

Sample Number	Location	Screen Size	Moisture Level (%)	Remarks
1	Granulator exit	-	1.5-2.5	
2	Dryer exit	-	0.8-1.0	Cocurrent hot air used for drying
3	Cooler exit	-	0.7-0.9	Countercurrent air used for cooling
4	Process screen	Top deck 4 mm Bottom deck 2 mm		
5	Polishing screen	2 mm size	0.7-0.9	

Raw materials are analyzed for the following:

Phosphoric acid	P_2O_5 content and impurities
Potash	K_2O content, impurities, moisture, and size
Urea and filler	Size and moisture

Process analyses are made on an hourly basis at different process points as indicated below:

Preneutralizer	N:P mole ratio and moisture
Granulator	N:P mole ratio and moisture
Dryer	Moisture
Product at NPK plant	Ammoniacal nitrogen, urea, nitrogen, total P_2O_5, and K_2O
Final product at bagging unit	Ammoniacal nitrogen, urea nitrogen, total P_2O_5, K_2O, moisture, and particle size

Product and Fertiliser Control Order (FCO), a Government of India regulation, analyses are carried out on nearly 150 samples per month received from various warehouses. The MFL laboratory is well equipped with modern analytical instruments like the Auto-Analyzer. The Auto-Analyzer at MFL employs a continuous-flow automatic technique and has the capacity to analyze 40 samples per hour with high precision and accuracy. A comparison of the time required for analyses by classical methods and by use of the Auto-Analyzer is given in Table 3. This comparison indicates that the Auto-Analyzer requires only about one-fourth as much time as the classical methods do.

Table 3. **Comparison of the Time Required for Analyses by Classical and Auto-Analyzer Methods**

Nutrients	Time Required for Analysis, Minutes	
	By Classical Method	By Auto-Analyzer Method
Ammoniacal nitrogen and urea nitrogen	100	20
P_2O_5	40	18
K_2O	20	16
Total time required for analysis of a product sample	100	20

Fertilizer Control Order Tolerance Limits and Need for a Change

The FCO stipulates the specification for the NPK products and also the tolerance limits within which variations are permitted. However, it is pertinent to mention here that the FCO standards were fixed at a time when there was very little operating experience of large-size plants that make different formulations of NPK complexes. The tolerance limits fixed are more stringent than those in technologically advanced countries like the United States, the United Kingdom, Australia, or Canada for similar products as can be seen from a comparison of these standards given in Table 4.

The negative tolerance limit of 0.5 unit for each nutrient N, P_2O_5, and K_2O is meant for two distinct sets of constraints:

1. The analytical constraints which vary depending upon the method of analysis and the apparatus used.

2. The process constraints which depend on the production technology and the complex operating parameters.

It is to be stressed that out of the FCO-allowed tolerance of 0.5 unit, a variation in the analysis to the extent of 0.2 to 0.3 unit of nutrient is attributable to the methods of analysis, in spite of the best analytical techniques. Thus, after allowing for the above analytical tolerance, the tolerance meant for production technology and operating field conditions is limited to only 0.2 to 0.3 units. There is thus a great need that the tolerance limits should be changed.

Measures Taken to Improve Product Quality

Some of the measures taken at MFL to improve product quality are discussed below:

1. The normal frequency of analyzing the product is increased immediately if an analysis is found to be off-specification and the increased frequency is continued until the next analysis is acceptable. The time taken for the analysis itself has been considerably reduced by the use of the Auto-Analyzer equipment at the central laboratory.

2. A program of predictive inspection and maintenance involving extensive monitoring and auditing of equipment and operating conditions is carried out with

Table 4. **Tolerance Limits for NP/NPK Fertilizers Followed in Various Countries**

Country	Total N	Maximum Negative Deviation Permitted, in Nutrient Units: Citrate-Soluble P_2O_5	K_2O	Total Nutrients	Remarks
India	0.5	0.5	0.5	1.27	17-17-17 grade
	0.5	0.5	-	1.40	28-28-0 grade
	0.5	0.5	0.5	1.55	10-26-26 grade
United States	0.68	0.70	0.5	a	17-17-17 grade
	0.83	0.74	-	a	28-28-0 grade
	0.58	0.73	1.27	a	10-26-26 grade
United Kingdom	1.7	1.7	1.7	2.55	
Australia	0.75	0.75	0.75	-	
Canada	1.0	2.0	2.0	b	
European Economic Community	1.1	1.1	1.9	1.5	

a. Overall index value is used.
b. No specification for total nutrients. Only for combined nutrient level (CNL).

specific emphasis on maintaining quality, even at the cost of reduced production.

3. Every step is taken to keep up the mechanical condition of the equipment, to maintain efficiency of the screening units, and to reduce the possibilities of producing off-specification material because of plant downtime.

4. Inputs of nutrient raw materials are calculated on the basis of marginal over-formulation as insurance against the nutrient content in the product falling below specification. This is done even at the expense of increased cost of raw materials.

5. The raw material feeders have been modified to improve their reliability and to reduce spillage. This greatly improves control of the chemical composition of the product.

6. An arrangement of pan feeders has been installed to evenly distribute material over the screens. This improves the efficiency of the screening operation, gives better size separation, and also avoids overloading the screens, thus reducing the level of mechanical damage.

7. Smaller size urea is being used for NPK production to avoid urea slipover along with product NPK. A facility to screen the urea plant product into two size ranges – above 2 mm and below 2 mm – has been installed. The undersized urea (below 2 mm) fraction is fed to the NPK plant. This has helped greatly in improving the quality of the NPK product.

8. Earlier, MFL used sand as the filler material because it was cheap and locally available in ample quantities. However, the granulating tendency and cohesive power of this material are poor. Dolomite, which is more crystalline and is available in a smaller size, has been found to be a better granulating medium and therefore it is being used at present as a filler.

9. The low critical relative humidity (CRH) of the urea-based NPK complex fertilizers results in poor long-term storage properties, and this requires conditioning treatment to avoid caking of the product in storage. MFL has been coating its products with fine powdered clay as discussed above. However, this treatment has not been yielding satisfactory results. The practice of coating products with clay has been replaced with the use of fatty amines and other formulations that are proprietary in many of the western countries. MFL has been experimenting with one such proprietary chemical formulation to improve the long-term keeping quality of its products. These plant-scale trials are yielding encouraging results.

Further Measures Planned to Improve Product Quality

Further improvements in product quality are anticipated as a result of the application of the latest technology in research and development and plant experience.

A few of the many improvements now under evaluation for possible implementation are:

1. Introduction of weigh feeders with an electronic frequency control system for solid raw materials; these feeders have an accuracy of ±1%. Already a trial unit has been installed on the basis of the above principle and the performance is being evaluated.

2. Continuous, specific-gravity analyzers with recorders to help operators maintain better control of the slurry.

3. Modification and improvement of the coating screw to give a more effective coating to the product is being studied.

4. Because NPK manufacture involves a number of solid feeds, an uninterrupted flow of solids from the bins through the chutes is essential for consistent operation, which is an important requirement for product quality. In this connection MFL is considering two optional methods of solving this problem (improving solid material flow).

   a. Use of polymer lining for the bins and chutes to permit free flow of material.

   b. Use of an air cannon system to prevent any adherence of solid material to the surfaces of chutes and bins.

   On a trial basis some chutes and bins have been either lined with polymer or provided with an air cannon. The performance of these modifications is being evaluated.

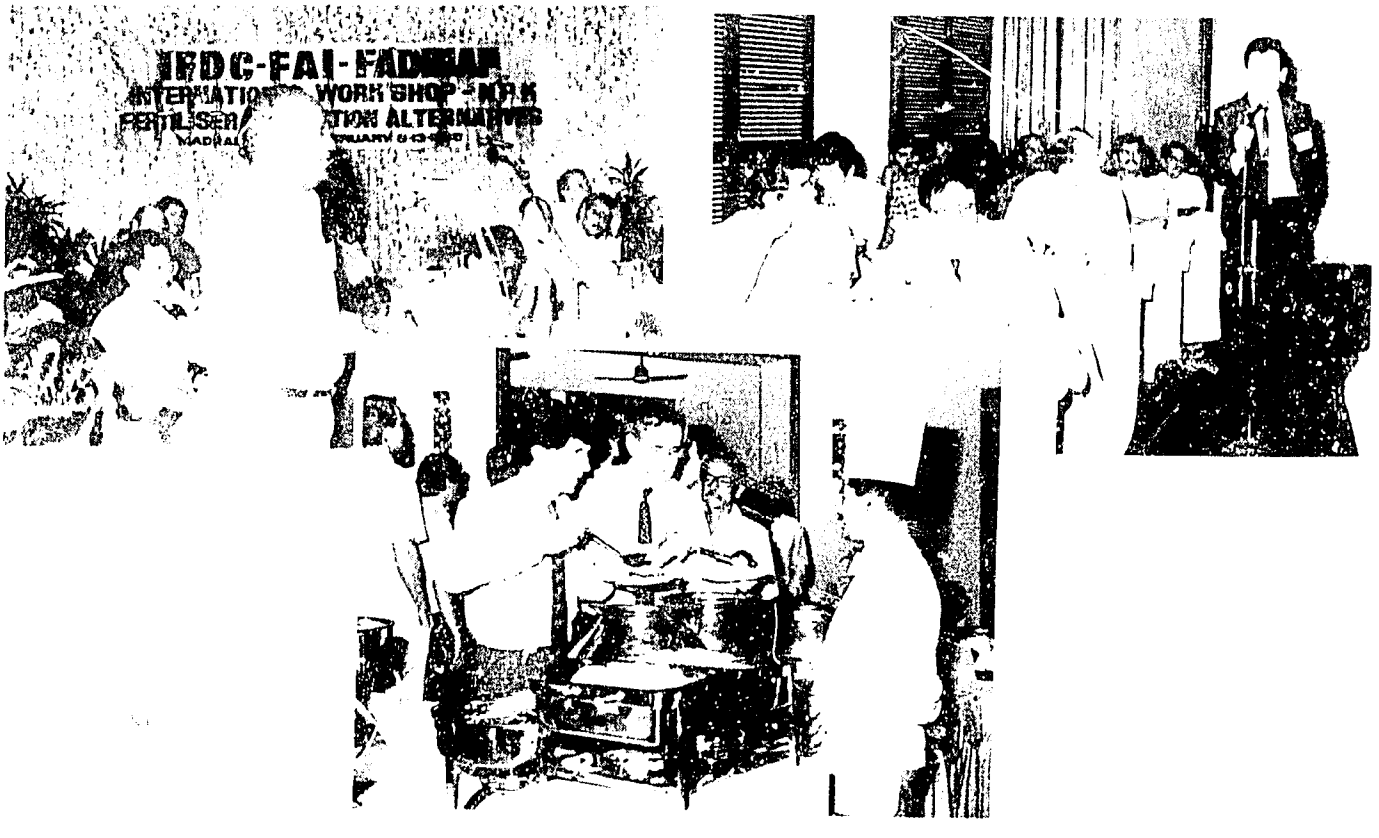
5. In order to keep the final NPK product from containing granules less than 1 mm in size or more than 4 mm in size, certain measures are being taken with regard to the screen opening. These are:

   a. Installation of an additional polishing screen to remove all undersize particles below 1 mm.

   b. A decrease in the screen opening in the product screen on the top deck from the present 4.4 mm to 4.0 mm.

Conclusion

As discussed above, the manufacture of NPKs involves the use of a number of solid raw materials. Some of them are hygroscopic, abrasive, and corrosive in nature. These factors work against the continuity and consistency of the process. Systematic procedures for plant operations, maintenance, and laboratory services are employed at MFL to ensure continuous and smooth flow of materials to obtain effective quality control. There is a need for looking into the stringent quality-control tolerance limits for NPK complex fertilizers stipulated by the FCO considering the difficulty in the manufacturing process and the prevailing practice in other countries.



Urea-Based High Potash Formulations

S. Chander, General Manager, Zuari Agro-Chemicals, Ltd.

Abstract

Zuari Agro-Chemicals, Ltd. (ZAC), operates a compound fertilizer manufacturing complex near Vasco da Gama, Goa, India. The complex includes an ammonia plant, a urea plant, a DAP plant, and a compound fertilizer plant with a capacity of 535 mtpd. Phosphoric acid and potash are imported. NPK production is mostly 19-19-19. Operation of the plant has been quite satisfactory, although some problems have been encountered with foaming in the preneutralizer, deposition of scale in the preneutralizer and scrubber, handling hygroscopic materials in the humid plant location, and pollution and quality control. Methods for coping with and solving these problems have been developed.

Introduction

Zuari Agro-Chemicals, Ltd., is a company jointly sponsored (technical and financial) by the House of Birlas and U.S. Steel Corporation. The factory is located on a 500-ha plot overlooking the Arabian Sea near the town of Vasco da Gama in the state of Goa. The Port of Mormugao is approximately 15 km from the factory. The Toyo Engineering Corporation of Japan was retained to design and construct the plant and its auxiliaries. During the first phase the ammonia and urea plants were constructed with 660-mtpd and 1,140-mtpd capacity, respectively. These units went on stream in 1973. At that time a steam and power generation plant also went on stream. The compound fertilizer (NPK) plant with a capacity of 535 mtpd, constructed at the same time, started commercial production in 1975. The delay was due to the nonavailability of imported phosphoric acid. In the second phase a DAP plant with a 500-mtpd capacity went into production in December 1984. The fertilizers produced are marketed mainly in the states of Andhra Pradesh, Maharashtra, Karnataka, and Goa. The market area has been recently extended to upcountry, particularly for DAP.

The main raw materials used per year are about 220,000 mt of liquid naphtha and 100,000 mt of furnace oil. Besides this, 210,000 mt of phosphoric acid (52.5% P_2O_5) and 51,000 mt of muriate of potash are imported. Naphtha is pumped from the port through an underground pipeline, while furnace oil, phosphoric acid, and muriate of potash are transported by road from the port. With the recent addition of DAP production, anhydrous liquid ammonia is received from Maharashtra by road tankers at a rate of 120 mtpd.

The capacity utilization of the nitrogen fertilizer plants ranged from about 58% to 65% in 1973/74 to about 108% in 1987 while the phosphate fertilizer plants improved from about 40% in 1975/76 to about 110% in 1986.

Compound Fertilizer Plant

The NPK plant at Zuari is designed to produce three formulations, namely 14-35-14, 28-28-0, and 19-19-19. Over the years 19-19-19, known by the brand name SAMPURNA, has gained immense popularity and thus is produced almost throughout the year. The raw materials required for this grade of complex fertilizer are ammonia, urea (both from captive sources), phosphoric acid, and muriate of potash (both from imports).

The proper quality of raw materials in terms of chemical and physical analyses is extremely important in the production of granular fertilizer. Ammonia and urea from the captive source meet the specific quality requirements. The phosphoric acid analysis varies from shipment to shipment, depending on its source. It is thus necessary to have a complete analysis of the acid in order to plan process operations. The impurities like iron and aluminum even in small quantities help in good granulation, while suspended insolubles affect it adversely. Table 1 shows the specification of phosphoric acid suitable for good granulation and the actual analysis of acid usually received by ZAC.

Potash is generally imported from two sources, Canada and East Germany. With potash both the chemical and size analyses are extremely important. The particle size of the potash greatly affects the operational control. Table 2 shows specifications of the potash desired and used by ZAC.

Table 1. **Chemical Analysis of Phosphoric Acids**

Item	Standard Specification	Senegal		Morocco		Phosphate Chemicals	
P_2O_5, %	52.00 minimum	51.65	54.00	53.80	53.95	54.66	54.89
Density	1.75 maximum	1.676	1.708	-	-	-	-
H_2SO_4 (SO_4), %	4.5	4.67	3.92	2.20	2.01	3.34	3.34
Fe_2O_3, %	1.1-1.9	2.79	3.50	0.42		1.14	1.70
				0.23	0.21	2.24	1.14
Al_2O_3, %	0.7-1.6	-	-				
MgO, %	0.4-1.2	-	-	0.96	0.82	0.77	0.71
Suspended solids, %	2.0 maximum	1.04	0.51	0.29	0.69	1.36	2.12
Viscosity cp @ 100°F	80.0	-	-	-	-	90.0	80.0

Table 2. **Screen and Chemical Analyses of Muriate of Potash (KCl)**

Mesh Size	Specification	East German Fine White KCl	Canadian Pink KCl
+10	Nil	0.4	0.3
-10 +30	40	11.0	52.5
-30 +50	40	84.0	45.2
-50 +80	15	4.4	1.5
-80	5	0.2	0.5
K_2O, %	60	60.1	59.3
Moisture, %	0.5-1.0	1.02	0.52

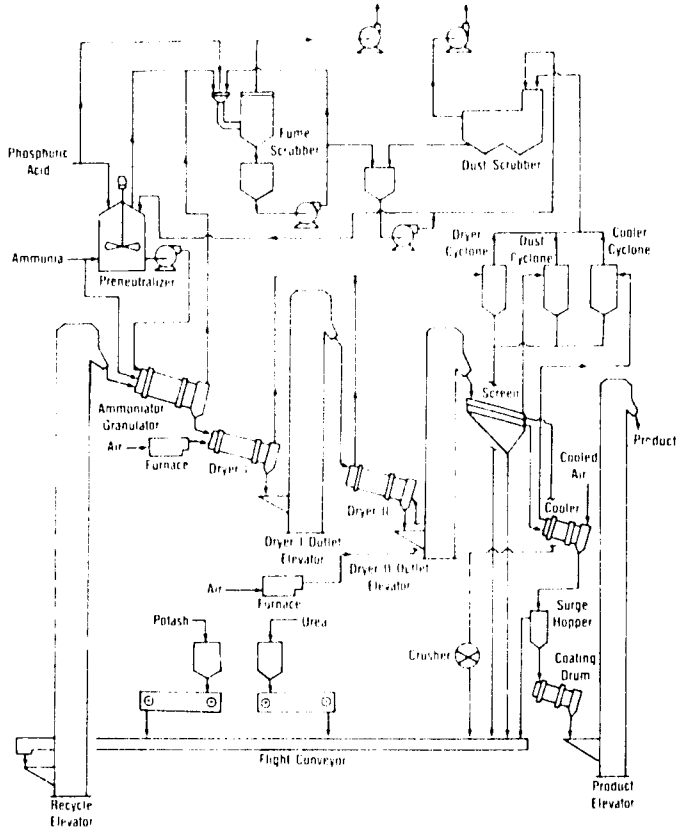


Figure 1. **Flow Diagram of NPK Plant (19-19-19) – 25 Metric Tons per Hour.**

Process Description

The NPK plant is comprised of two sections namely, the dry and wet sections. A flowsheet of the NPK plant is shown in Figure 1. Phosphoric acid is reacted with ammonia in the preneutralizer. Since the reaction is exothermic, water and dilute solution recovered from other parts of the plant are added to control the temperature in the range of 112° to 118°C at a mole ratio of around 1.4. The slurry so produced in the preneutralizer is pumped to the ammoniator-granulator where it is sprayed on o a rolling bed of solid feeds, for example, urea, potash, and recycled solids. Ammonia is also injected at this stage to increase the mole ratio further to achieve the grade of 19-19-19. This granulated, moist material is passed through two dryers arranged in series and the moisture is reduced to less than 1.5%. The dried material is screened. The undersize material along with the crushed oversize material is recycled to the granulator. Part of the product size is also recycled to the granulator. The final product is cooled, coated, and taken to storage bins.

A venturi-type fume scrubber is used to recover the unreacted ammonia gas from granulator and preneutralizer. The scrubbing is done with dilute phosphoric acid. The dilute solution thus formed is pumped to dust scrubbers where dust emitted from the dryers and leaving the cyclones is recovered. The concentrated scrubber solution formed is sent to the preneutralizer.

Performance of Major Pieces of Equipment

The performance of the major pieces of equipment such as the preneutralizer, ammoniator-granulator, bucket

elevators, recycle flight-type conveyers, and vibrating screens has been quite satisfactory with scheduled preventive maintenance. There has been a unique experience of breakdown of the dryers (specifications of the dryers are given in Table 3). On three or four occasions, circumferential cracks, some as long as 7 m, have appeared on the dryer shells. These were repaired by welding. The dryer shells were further strengthened by welding on additional reinforcing rings. On two occasions the drive-end tires have also cracked. Replacement tires were procured from a local source, but they have not been satisfactory. Slight eccentricity of the dryer shell contributed to the above experience. The plant shutdowns, however, for longer periods due to dryer repairs are now avoided by providing facilities to operate the plant with one dryer at a slightly reduced capacity, which is generally 90%-92% of full capacity.

Table 3. **Specifications of Dryers**

	Dryer No. 1	Dryer No. 2
Flow rate, mtph	180	180
Diameter, mm	3,500	3,500
Length, mm	43,000	43,000
Rotating speed, rpm	4	4
Inclination, degrees	4	6
Holdup, %	10	15
Lining	First 10 m with SUS 27	none
Knockers	Provided[a]	none
Motor, kW	280	280

a. Later removed.

Plant Operations

The main objective of plant operations and process control is to produce uniform size granules of NPK within a narrow range of chemical analysis (19-19-19). To begin with, part of the chemical reaction is carried out in the preneutralizer, basically to help increase the production rate and minimize ammonia loss. The chemical reaction is completed in the granulator. The key operating parameters for close control of granulation are the ammonia-to-phosphoric acid mole ratio; the solids content and temperature of the slurry; the temperature, liquid phase, and moisture content of the material in the granulator; and the recycle ratio.

Mole Ratio In the preneutralizer, the mole ratio of ammonia-to-phosphoric acid is maintained close to 1.4. A slight shift has been experienced depending on the quality of the acid used. The moisture content of the slurry is kept at 20% and the temperature at 116° to 118°C. The mole ratio is further increased by ammoniation in the granulator to 1.65-1.7 (see Figure 2).

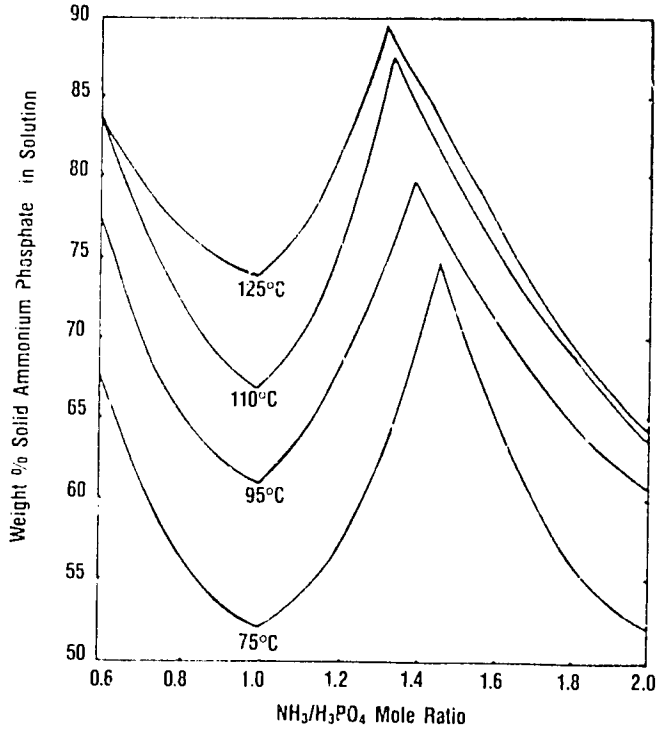


Figure 2. **Solubility for Ammonium Phosphate-Water System.**

Granulation Control—Close control of granulation depends on the design of the granulator and regulation of the process parameters mentioned above. It is generally accepted that granulation occurs when the liquid phase of the mixture reaches proper proportion which is about 20% to 30%. The liquid phase consists of water and dissolved salts. The amount of salts that dissolve in a given amount of water depends on the kind and quantity of the salts and the temperature. In case of feed salts such as urea and potash with ammonium phosphate used to produce a concentrated fertilizer like 19-19-19, many problems occur because this results in a soluble-salt system where the quantity of liquid phase is very sensitive to changes in the temperature and moisture content.

The relationships among the moisture content, temperature, and particle size are briefly described below.

1. The temperature range within which acceptable granulation occurs becomes narrower as the moisture content is decreased (see Figure 3).

2. The finer the product, the higher the granulation temperature required (see Figure 4).

3. The slope of the granulation curve increases significantly as the proportion of highly soluble salts increases; in particular in urea, ammonium phosphate, potash systems, the curves are steep, denoting great

sensitivity of granulation to small changes in the liquid phase (see Figure 5).

4. A lower recycle temperature helps to maintain a lower recycle ratio.

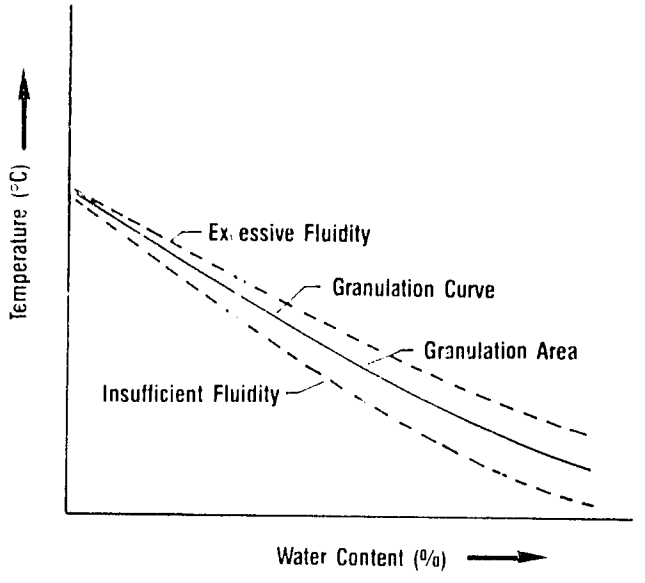


Figure 3. **Temperature-Moisture Relationship for Acceptable Granulation of Urea-Based High-Potash NPK Fertilizers.**

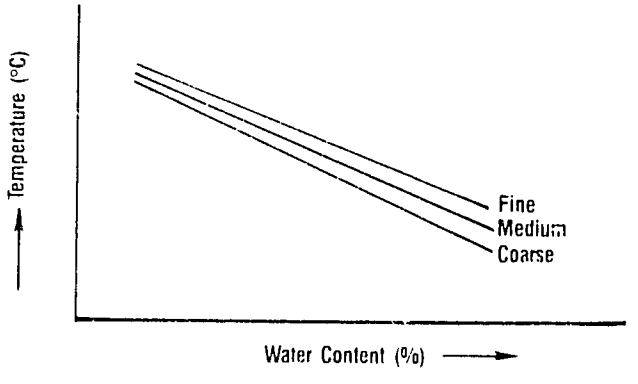


Figure 4. **Effect of Particle Size of Feed on Granulation of NPK Fertilizers.**

The sensitivity of a high urea grade formulation to heat has already been emphasized. A slight increase in temperature causes overgranulation. A further increase in temperature leads to "softening" of the product. This stage must be prevented, since the mass becomes very sticky and chokes the dryer inlet and causes hard deposits on the flights of the dryer. The specifications for the granulator are given in Table 4.

Recycle Ratio—The process is based on the use of recycle material to serve as nuclei for the growth of granules. The use of recycle material at a nearly steady rate and temperature helps in good granulation. It is also important to maintain minimal changes in the feed rates of the slurry, urea, and potash. The control of the temperature at 55° to 60°C and the moisture content at 2.2% to 2.5% at the granulator outlet have been found to be ideal conditions for granulation.

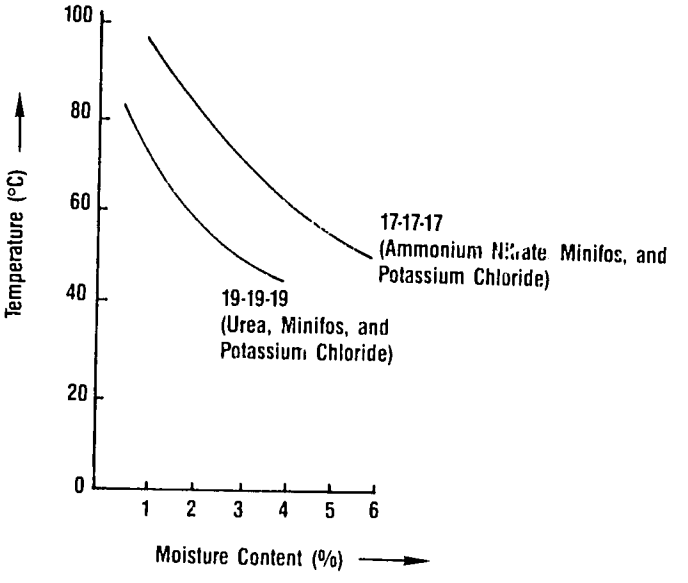


Figure 5. **Granulation Curves for NPK Fertilizers Based on Minifos.**

Table 4. **Specification of Ammoniator-Granulator**

Diameter, mm	3,500
Length, mm	9,000
Retainer (Weir)	At 6,000 mm from feed end
Slurry feed	Spray nozzles
Ammonia feed	Liquid feed through pipe below rolling bed
Motor, kW	132

Particle Size Control—The product particle size in the range of 2- to 4-mm is specified in the Fertilizer Control Order (government imposed regulation). The undersize particles are useful for granule growth as mentioned above. Control of the granulation is necessary to avoid overgranulation. Temperature control in the granulator and drying cycle has an important influence on the control of particle size.

Major Operating Problems Faced

Foaming in Preneutralizer

Dust carried over from the dryer and removed in the dust scrubber is recycled back to the preneutralizer. In

the event the urea nitrogen is high, foaming in the preneutralizer takes place. This leads to changes in slurry flow due to pumping difficulties. Often the preneutralizer overflows. In order to control foaming, regular analytical checks are carried out and the urea nitrogen is maintained below 0.6%. For suppressing foam, generally antifoamers are used. It has been found that lowering of slurry temperature by 2°-3°C by adding small quantities of water for short periods of time helps to reduce foaming, and also improves granulation which consequently reduces dust carryover to the scrubbers. A typical recycled scrubber solution has 0.2%-0.3% nitrogen derived from urea, 0.8% nitrogen derived from ammonia, and 1.0%-1.3% total nitrogen.

Scaling in Dryers

The 19-19-19 is dried at a low temperature and a low drying rate. Any sudden increase in temperature tends to soften the mass of product which results in choking of the inlet to the dryer, as well as causing buildup of material on the flights. In order to achieve proper drying, the deposits built up are pneumatically removed (chiseled) once every 3-4 months. The dryer is not washed with water in order to avoid the creation of liquid effluents.

Humidity Control

The ZAC Plant is located on the sea coast, where high humidity prevails around the year. The critical relative humidity of 19-19-19 is very low, the spillages from various pieces of conveying equipment tend to absorb moisture from the surrounding air within a short time, and this results in the formation of slush (see Figure 6). It is quite difficult to handle such material and it is thus necessary to avoid such a happening. At ZAC a dehumidification unit has been installed, which operates round the clock, and this has helped in recovery of spillage in solid form.

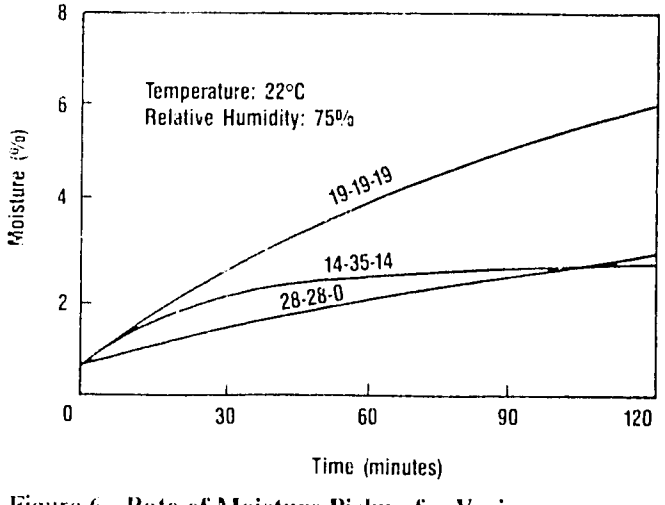


Figure 6. **Rate of Moisture Pickup for Various Fertilizers.**

Raw Material Quality

The desired quality of raw materials has been stressed earlier. Phosphoric acid is obtained from many sources and the amount of insolubles or sludge, as it is commonly called, varies considerably. High sludge contents disturb the granulation control, leading to excessive dust generation and foaming with consequent loss of production. Similarly, if the screen analysis of potash does not meet specifications (see details in Table 2), it also causes granulation problems. The potash received from East Germany tends to separate out as finer particles. Lately, there has been some improvement in the potash supplied from this source by using a mixture of fines and prilled material.

Product Quality Control

Quality control of the product assumes a high priority in plant operations; high-grade NPK products are made from raw materials comprising solids, liquids, and ammonia in gaseous form. It is necessary to have accurate and timely analytical data. The operators carry out instant tests such as the determination of specific gravity and pH measurements. The analysis for nutrients at various stages is carried out in an "Auto-Lab," which is attached to the plant. The Auto-Lab is manned around the clock by chemists. Normally samples of the product are taken and analyzed at intervals of 90 minutes; however, at times this interval is reduced to 45 minutes, which is minimum time for such an analysis. The quality of the product, therefore have fluctuations in nutrient content to some extent. The allowable variation on 19-19-19 is 0.6 for each nutrient. Such variations in other countries are wider. The following tabulation shows a comparison of the variations allowed by the Fertilizer Control Order with the variations allowed in other countries (1).

Allowable Variations in Nutrient Constituents
(19-19-19 Grade – 1:1:1 ratio)

Country	N	P_2O_5	K_2O
India	0.6	0.6	0.6
United Kingdom	1.7	1.7	1.7
United States	0.7	0.7	1.0
Canada	1.0	2.0	2.1

Mention needs also to be made to the sampling method. Improper sampling leads to incorrect analyses and this adversely affects the process control.

Pollution Control

Liquid effluents are generated by spillage of solids which absorb moisture because of their low critical humidity and by liquid leakages from pump glands. The entire plant floor area is covered with concrete and the drains are properly lined to prevent seepage of acid. The ZAC factory is built upon a laterite soil which allows easy seepage. The liquids are collected in a recovery sump tank and recycled to the fume scrubber. The solids are manually recovered. The dehumidified atmosphere helps in this recovery. Some liquid effluent is generated by workers washing in the bagging plant. These washings are segregated and reused in the NPK and DAP plants.

Ammonia is recovered from the preneutralizer and the granulator by scrubbing the offgases with dilute phosphoric acid in an efficient venturi-type fume scrubber. The pH of the dilute acid is maintained at 5.5. Analyses of the offgases from the stack show an ammonia content of less than 100 ppm.

Most of the dust from the dryers is separated in cyclones and the remainder is scrubbed in an efficient tumbler-type scrubber with a dilute solution from the ammonia scrubbing system. Dust from the screens, belt conveyors, various chutes, and elevators is removed by a new dedusting system installed recently. The dust emission from the stacks is hardly noticeable.

Major Changes in Plant

Changes made in plant operation are shown below:

1. Scale in the preneutralizer is now being removed periodically. The walls of the preneutralizer become coated with a thick scale over a period of time. This often peels off and causes slurry pumping problems. Traditionally, the scale is removed by manual scraping. It is now simplified by washing the walls with a heated solution of 50% phosphoric acid and steam. The liquid in the preneutralizer is agitated for a few hours. Such an operation is carried out once every 2 months. Scale in the fume scrubber is removed in a similar manner.

2. In the ammoniator-granulator, the ammonia was previously fed in the gaseous form. Ammonia is now added in a liquid form. This has improved ammoniation in the granulator and reduced ammonia losses.

3. Breakdowns of various blowers in the plant, mainly with the bearings, have been experienced. Failure of the components of blowers is now prevented by using a "trend-analysis" technique made possible by use of vibration-monitoring instruments. This provides a diagnosis of material buildup on the blades of the blowers and consequently dynamic unbalance. The timely cleaning of the blades restores the balance and thereby prevents damage to the equipment. This improvement has not only reduced the maintenance expenses but has helped to improve the on-stream efficiency and promote steady plant operations.

4. Recently a complete "dedusting system" consisting of cyclones, a scrubber, and solution circulation facilities was added to collect dust from the screens, various chutes, conveyers, and other items of equipment.

Conclusion

The fertilizer industry in an effort to produce more concentrated products has taken to adding urea as a source of nitrogen. In recent years this practice has grown rapidly. The economics favor this growth. The technology as well as the critical equipment has improved over the years. It is, however, emphasized that a high degree of skill is required to operate plants such as the one operated by ZAC. The use of raw materials that meet the standard specification on which the design of plant is based will make operational control easier. The quality control as well as the pollution control should not be compromised for any cost. The economics and the ease with which the multinutrient fertilizers can be used should motivate the Indian farmers to improve their per-hectare consumption with fruitful results.

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Optimizing Formulation of Complex Fertilizer Grades

P. K. Ramasubbu, Deputy General Manager (Process) and N. Natarajan, Deputy Chief Engineer (Process),
FACT Engineering and Design Organization

Abstract

This paper highlights the relative advantages and drawbacks of urea-containing grades, especially in plant locations where high humidity prevails, compared to low urea or non-urea-containing complex fertilizers. Different processes by which the NP/NPK complex fertilizers could be produced with special reference to urea-containing ammonium phosphate (UAP) and UAPK processes is explained. A discussion is presented of the FACT Cochin Division experience with grades like 17-17-17 and 28-28-0, the various problems faced, and measures taken to solve them. Grade optimization experience and the need for producing a non-urea, ammonium sulfate-phosphate grade of fertilizer, namely 20-20-0, in the Cochin Division is discussed. The various factors to be taken into consideration for grade optimization, especially with urea-containing grades, are touched upon with special reference to retrofitting of pipe reactor technology in existing plants.

Introduction

Urea, being a single nutrient high-analysis nitrogen fertilizer, plays a major role in the production of NP/NPK complex fertilizers throughout the world. The farmers are well aware of the advantages of high analysis NP/NPK complex fertilizers for augmenting the food production needed for an ever-increasing population. The farmers generally prefer the 1:1:0 or 1:1:1 ratio high-analysis complex fertilizers for the various food crops to obtain balanced nutrition. In spite of a number of giant capacity ammonia/urea complexes being conceived in the Indian fertilizer industry, the demand for nitrogen and also total nutrients are on the increase to meet the challenging needs for increased food production. According to the projections made, the demand at the end of the Government of India Seventh Plan is about 9.3 million mt of nitrogen and 14 million mt of total nutrients as compared with the expected production of 6.56 million mt of nitrogen and 8.75 million mt of all the nutrients put together. Incorporation of urea or other nitrogen fertilizers like ammonium sulfate in the NP/NPK fertilizers forms an important aspect at this juncture for effective improvement in the overall consumption pattern.

Brief Description of the FACT Organization, Production Facilities, Product Pattern, and Capacities

Before going into the subject of optimization of NP/NPK formulation, it seems relevant to mention briefly about our company, Fertilisers and Chemicals. Travancore, Limited Udyogamandal, in Kerala, popularly known as FACT.

Today the Indian fertilizer industry is the fourth largest in the world and FACT has pioneered this industry in India by setting up the first nitrogen fertilizer factory as early as 1944 near the Cochin port. From a single-product fertilizer plant of the 1940s, FACT has, through the years, grown into a large multiproduct, multi-divisional corporation today. FACT's two manufacturing divisions at Udyogamandal and Cochin together have an annual capacity of 270,000 mt of nitrogen and 151,300 mt of P_2O_5 fertilizer nutrients. FACT's marketing division has a well-organized sales network which covers even the remotest villages.

The rich fund of expertise, experience, and skills gained over the years in the manufacturing units of FACT was pooled in 1966 to form two separate divisions, FACT Engineering and Design Organization (FEDO), and FACT Engineering Works (FEW). Today FACT is also implementing a massive expansion program by putting up an ammonium sulfate-caprolactam project which marks the entry of FACT into the field of petrochemicals, too.

Udyogamandal Unit

Starting commercial production in 1947 with a single ammonium sulfate plant having an annual production capacity of 10,000 mt of nitrogen, the Udyogamandal Division today comprises a variety of medium capacity plants using different routes to produce a wide variety of fertilizers and chemicals. The products and capacities are:

	Annual Capacity (mtpy)
Ammonia	112,200
Sulfuric acid	250,800
Phosphoric acid	33,000
Ammonium chloride	24,750
Ammonium sulfate	198,000
Superphosphate	49,500
20-20-0 ammonium phosphate sulfate	148,500

Cochin Division

This unit was set up in the late 1960s at Ambalamedu, Cochin, in two stages. The first stage consisted of an ammonia/urea complex with an annual capacity of 198,000 mt of ammonia and 330,000 mt of urea, while the second stage is an NPK complex plant which was to have an annual capacity of 485,000 mt of various NP/NPK fertilizers along with 330,000 mt of sulfuric acid and 115,000 mt of P_2O_5. At present the complex plant produces mainly two products, namely, ammonium phosphate sulfate (20-20-0) and DAP using imported ammonia.

The actual production at the Udyogamandal and Cochin Division plants during 1986-87 was as follows:

	Capacity Achieved 1986-87 (mtpy)
Udyogamandal Unit	
1. Ammonia	72,400
2. Sulfuric acid	195,000
3. Phosphoric acid	8,100
4. Ammonium chloride	6,600
5. Ammonium sulfate	107,600
6. Superphosphate	13,600
7. 20-20-0 complex	139,800
Cochin Division	
1. Ammonia	114,000
2. Urea	230,100
3. Sulfuric acid	260,200
4. Phosphoric acid	34,400
5. DAP (18-46-0)	36,700
6. 20-20-0 complex	366,000
Total for FACT	
Nitrogen	238,100
P_2O_5	120,200

Need for Urea-Based Fertilizers

In earlier days of development of complex fertilizers, low-analysis formulations were produced by using straight fertilizers like ammonium sulfate and other such sources of nitrogen. However, the use of urea as a source of nitrogen made it possible to produce high analysis grades. The popularity of high-analysis balanced NP and NPK fertilizers increased rapidly because of the fact that higher total plant food content can be achieved. Conditions such as soil characteristics, climatic conditions, and cropping patterns determine the type of formulations required in most cases. The required $N:P_2O_5:K_2O$ ratios in NP and NPK grades are preferably 1:1 and 1:1:1, especially in South India. Based on market demand the high-analysis grades required are 28-28-0, 17-17-17, and 19-19-19.

For the production of such high-nitrogen balanced fertilizers, urea is a necessary ingredient. Any other source of nitrogen such as ammonium sulfate or ammonium nitrate cannot produce these high-analysis grades.

The advantages of urea-containing fertilizers are:

1. Savings in distribution cost.
2. Compared with ammonium nitrate, urea is easier to use because the critical relative humidity of complex fertilizer containing ammonium nitrate is lower than that with urea. The problem of caking with urea is less than that with ammonium nitrate, especially when KCl is present in the NPK complex.
3. Urea is cheaper than other sources of nitrogen such as ammonium sulfate or ammonium nitrate.

However, high-urea-containing grades have certain disadvantages. It can be seen from Figure 1 and Table 1 that the higher the urea content, the lower is the melting point of the product. Even though the critical relative humidity of urea is 75.2% and DAP 82.8%, the mixture of these two as in the case of complex fertilizers results in much lower critical relative humidity on the order of about 62% as shown in Figure 2. Addition of a third component like potassium chloride will reduce the critical relative humidity further. This results in more severe problems of hygroscopicity for urea-containing complex fertilizers. The problem with ammonium nitrate is still greater because its critical relative humidity is only 59.4% compared with ammonium sulfate of 79.2% and urea at 75.2%.

Table 1. **Percentage of Urea Nitrogen and Melting Point of NP/NPK Fertilizers**

NP/NPK Fertilizer Grade	Percentage of Nitrogen Derived From Urea	Melting Point, °C[a]
19-19-19	85.49	137
28-28-0	65.45	137
17-17-17	65.40	137
14-28-14	30.91	52
11-22-22	30.78	152
18-36-0	30.75	152
14-36-14	12.16	>155
10-26-26	9.40	>155
12-32-16	5.35	>155

a. Derived from Figure 1.

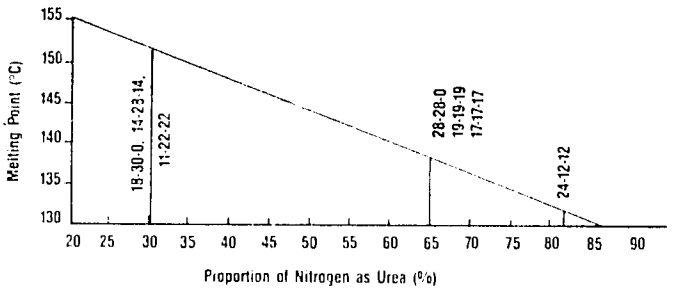

Figure 1. **Effect of Urea on Melting of UAP and UAPK Fertilizers.**

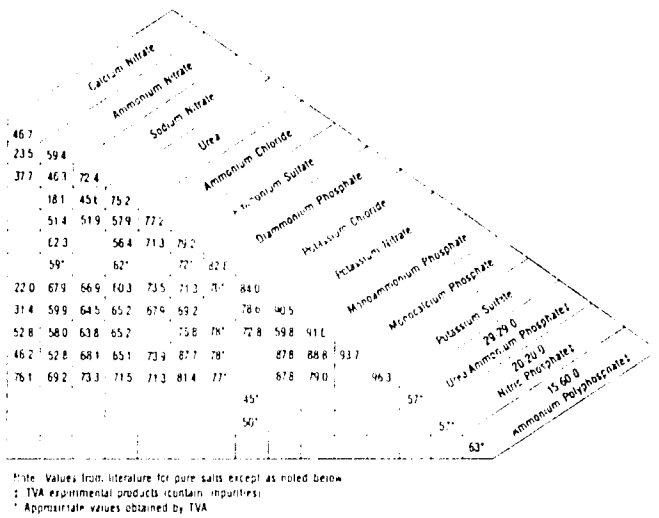

Figure 2. **Critical Humidities of Fertilizer Salts and Mixtures at 30°C (86°F).** (Values are Percent Relative Humidity)

In addition to the hygroscopicity problem the presence of urea causes foaming in the preneutralizer and the scrubbing system of the granulation plant. A low melting point also restricts the drying temperature in the dryer, necessitating a longer retention time for effective drying of the complex fertilizers, especially in the UAPK grade of fertilizers.

Technology of NP/NPK Fertilizers

The NP/NPK fertilizers are generally produced by the following routes:

1. Dry ingredient granulation process using various finished fertilizers.
2. Bulk blending of various finished fertilizers.
3. Nitrophosphate-based NP/NPK fertilizers.
4. NP/NPK fertilizers by conventional slurry ammonium phosphate route.
5. Melt granulation process.

Even though urea is used in all the processes except the nitrophosphate-based process, this paper will discuss briefly the slurry ammonium phosphate process and a melt granulation process because they are increasingly incorporated in the latest generation of fertilizer plants. The non-urea NP/NPK process will also be elaborated on.

Conventional Slurry Ammonium Phosphate Process (UAP and UAPK)

Almost all UAP or UAPK fertilizer plants in the world use this conventional slurry granulation process. Wet process phosphoric acid (48%-54% P_2O_5) is reacted with ammonia in the preneutralizer to a mole ratio of about 1.3-1.4 to achieve a slurry containing about 15% water.

The reacted slurry is then granulated by evenly distributing it over the recycle material in the TVA-type rotary granulator or in a pugmill-type blunger. The granulated product is dried in the rotary cocurrent dryer and screened to separate product from the oversize and fines. The separated fines and crushed oversize materials are recycled to the granulator or blunger along with a weighed quantity of fresh feed of urea and potash.

The screened product is cooled and given a coating of china clay or kaolin along with an anticaking agent to preserve the quality of the product before it is bagged and dispatched.

A scrubbing system is provided both to prevent atmospheric pollution and also to recover unreacted ammonia vapor from the preneutralizer/granulator as well as to remove dust particles entrapped with the gases from the dryer, cooler, and equipment vent system. Scrubbing is achieved by the intimate contact of the ammonia and dust-laden air with a circulating solution of weak phosphoric acid in a venturi-type scrubber and afterward the solution is fed back to the reactor. The general arrangement of this process is shown as a block diagram in Figure 3.

The various UAP/UAPK grades commonly manufactured are 19-19-19, 28-28-0, 17-17-17, 14-28-14, 11-22-22, 16-36-0, 14-35-14, 10-26-26, and 12-32-16.

Melt Granulation Process

The melt granulation process uses the latest technology of the pipe reactor system. This process was used by TVA to make UAP. It is a new development in that it effectively utilizes the heat of reaction between ammonia and phosphoric acid to avoid or minimize the drying step. A simple but highly efficient pipe reactor is the key piece of equipment in this process. A typical arrangement of this process is shown in Figure 4.

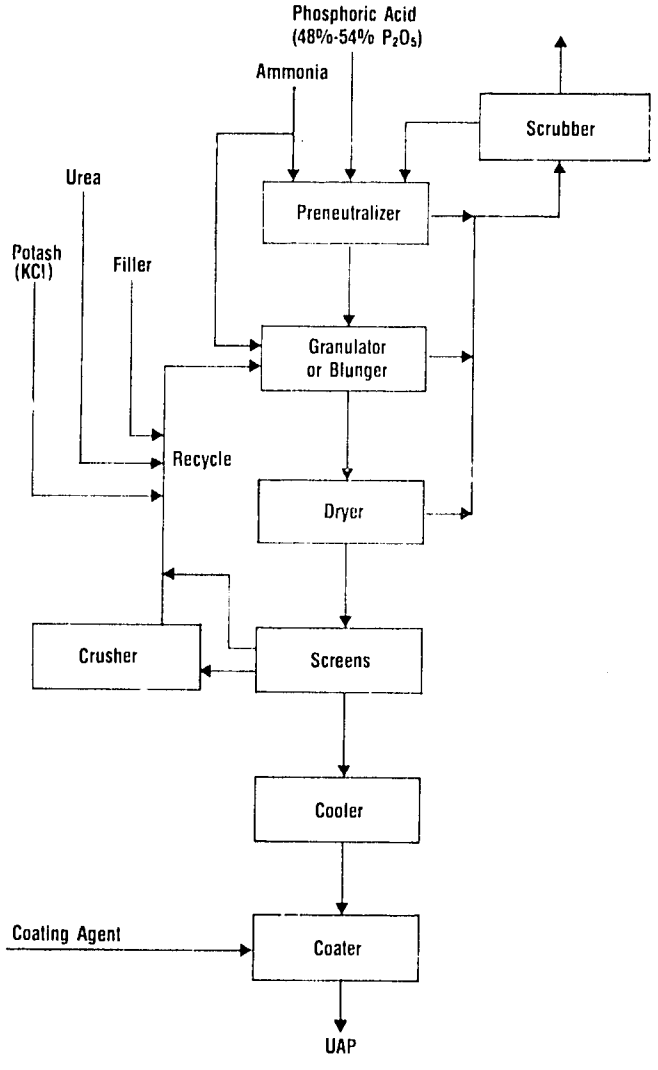

Figure 3. **Flowsheet for Production of Urea Ammonium Phosphate by Conventional Slurry Granulation Process.**

Wet-process phosphoric acid (52%-54% P_2O_5) is metered to a spray scrubber, where excess ammonia from the pipe reactor is recovered. Phosphoric acid that has partially reacted in the absorber is recycled to the absorber and a slip stream from the recycle is taken to the pipe reactor (normally 15 cm diameter and 3 m long). Phosphoric acid enters the pipe reactor through a side inlet, while anhydrous gaseous ammonia enters through the main inlet at a measured rate. The slurry goes to the vapor disengager where free water and some combined water are evolved together with unreacted ammonia which is recovered in the spray scrubber. The slurry in the form of melt is mixed by the helical blades of the vapor disengager and the compacted liquid mass is fed to the double-shaft pugmill. Granules from the pugmill are cooled and screened, and the product sent to storage, while the oversize and undersize particles are recycled. Typical grades of UAP made in this process are 28-28-0 and 11-55-0. In each grade 15%-25% of the phosphate is in the polyphosphate form. The presence of polyphosphate in the complex helps in improving storage quality.

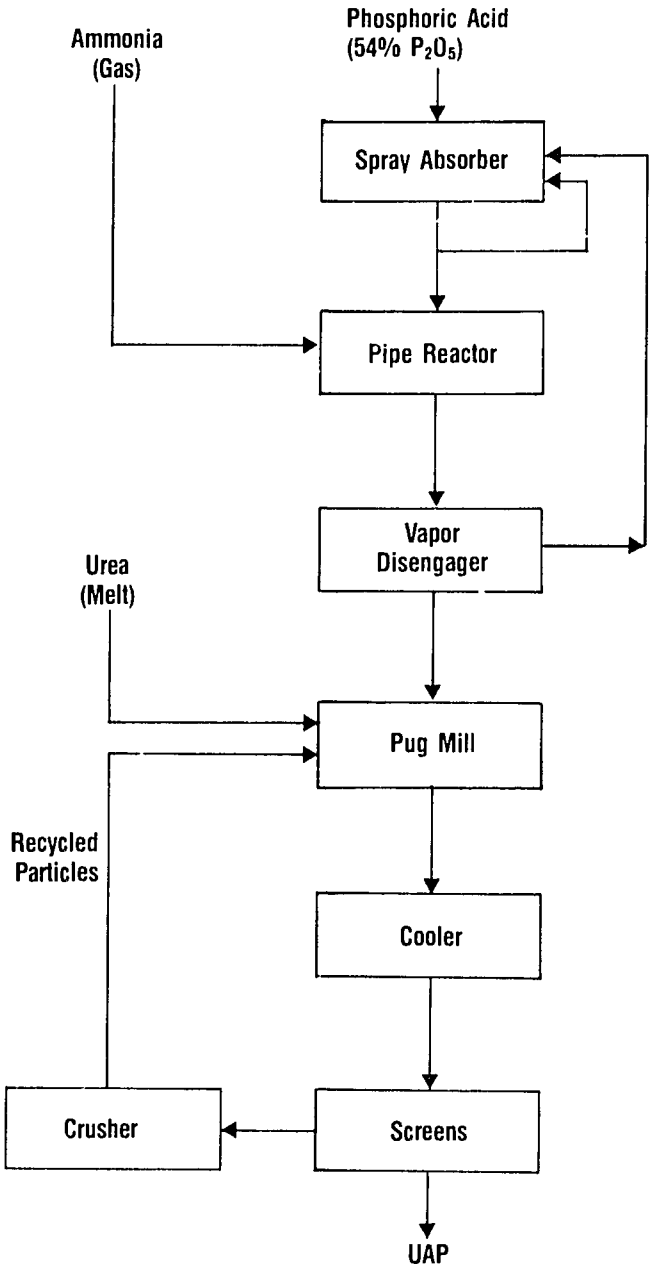

Figure 4. **Flowsheet for Production of Urea Ammonium Phosphate by a Melt Process.**

Design and Performance of FACT NP/NPK Plants

Design Basis Philosophy

The FACT Cochin Division NPK complex fertilizer plant situated at Ambalamedu, Kerala was designed along with the 1,000-mtpd sulfuric acid and 360 mtpd P_2O_5 phosphoric acid plants as part of its second stage of expansion.

It is laid out in two identical trains. Similar to most other plants in India, it is based on conventional slurry granulation process using a TVA-type granulator. The plant was designed, engineered, and installed on the basis of the know-how supplied by Wellman Lord of the United States (who has now become part of the Davy McKee Group).

Different NP/NPK complex fertilizers such as 17-17-17, 14-28-14, 28-28-0, 18-36-0, 24-12-12, and 11-22-22 were contemplated in the design with an hourly capacity of 40-46 mtph per stream and a total installed capacity of 485,000 mtpy of product from both streams. When ammonia is not available, the plant was designed to produce TSP at a capacity of 30 mtph for each stream.

The original scheme of the NPK plant consisted of:

1. A two-stage system for neutralizing 37% P_2O_5 phosphoric acid with gaseous ammonia and recovering the vapors from the first stage in a barometric condenser using saline water to control the water balance in the entire system.

2. A TVA-type granulator with a mechanical scraper arrangement.

3. A recycle system consisting of a rotary dryer, a double-deck screen unit, a recycle conveyor, elevators, and a venturi gas scrubbing system.

4. A conditioning system for coating the product.

Originally, 37% P_2O_5 phosphoric acid was adopted in the design along with the use of gaseous ammonia for the ammoniation reaction with a view to reducing the load in the concentration section of the phosphoric acid plant. However, in actual practice this system failed and a higher P_2O_5 concentration was necessary.

Raw Materials Used and Processes Adopted

The NPK plant was designed on the basis of importing ammonia for the entire NP/NPK complex. Phosphoric acid was to be obtained from a captive source, urea from the adjoining stage 1 urea plant, and potash from imported sources. Adequate infrastructure facilities were incorporated for storing and feeding the various raw materials as required using weigh feeders for solid raw materials and flow meters for the liquid raw materials. The process adopted is the same as that used in the conventional slurry granulation NP/NPK complex plants.

Operational Bottlenecks and Equipment Problems With 17-17-17 and 28-28-0 Production

Right from the commissioning period in 1976 a number of design and operational bottlenecks were encountered in the production of the complex grades like 17-17-17 and 28-28-0 for which there was demand in the southern region. The main problems experienced were operational difficulties due to congested layout, poor performance of the screens and crushers, poor granulation, and equipment failures. There were frequent chokings of the granulator chute, malfunctions of the mechanical scraper in the granulator, and failure of the Rhewum magnetic-type double-deck screens for product separation. Because of poor granulation, the dust content in the product was high and this caused choking of the chutes and ducts. Other operating problems such as overflow of slurry from the preneutralizer launder and upsets in the mole ratio of the slurry resulted in choking of scrubber circulation and slurry discharge lines. Spillage of materials at different points also affected the continuity of production.

To achieve a quality product it is necessary to maintain a steady feed rate of the raw materials, an optimum N:P mole ratio (1.35-1.45), a minimum of moisture in the reactor slurry, effective distribution of the slurry in the granulator, and a uniform quantity of recycle. In addition to these conditions, the effective and continuous performance of various pieces of equipment, especially the screens, crushers, and the recycle equipment are also important factors.

To achieve the above objectives, the following improvements were made in the operating procedures and the equipment.

1. The concentration of the feed acid was increased to 45%-50% instead of 37% P_2O_5.

2. The N:P mole ratio in the scrubber system was maintained at 1.20-1.25 instead of below 0.4 by adjusting the feed of phosphoric acid to the scrubbing system.

3. A single-tank reactor with better slurry pumps was provided instead of a two-stage reactor system.

4. A rubber paneling arrangement was installed inside the granulator instead of a scraper mechanism to overcome buildup and lump formations.

5. The Rhewum double-deck screen unit was modified to increase the gap between the screen decks and to replace the electromagnetic vibrators with a motor vibrator arrangement. Subsequently single-deck, Derric screens were installed.

6. An Auto-Analyzer was used instead of conventional laboratory analysis for quicker analysis of nutrients. This provided effective feedback for control of nutrients in the product.

In spite of all these improvements the severe humidity conditions in the Cochin area and the high hygroscopicity of 17-17-17 and 28-28-0 urea-containing grades posed problems in achieving continuity of operation and this resulted in low stream efficiency.

One of the major problems faced till recently was the poor performance and frequent failures of the scrubbing system wherein ammonia fumes and dust containing gases are scrubbed. Similar problems were encountered with the granulator and cooler scrubber having an internal venturi (Figure 5). Frequent chokings of the venturi were experienced and there was no easy way to clean the unit. A new scrubbing system with an external venturi for better and easier cleaning was recently installed for removing the fumes and dust. A typical arrangement of this new system is shown in Figure 6. The flowsheet of the Cochin Division plant as it exists now with single-tank preneutralizer and the new scrubber system in shown in Figure 7.

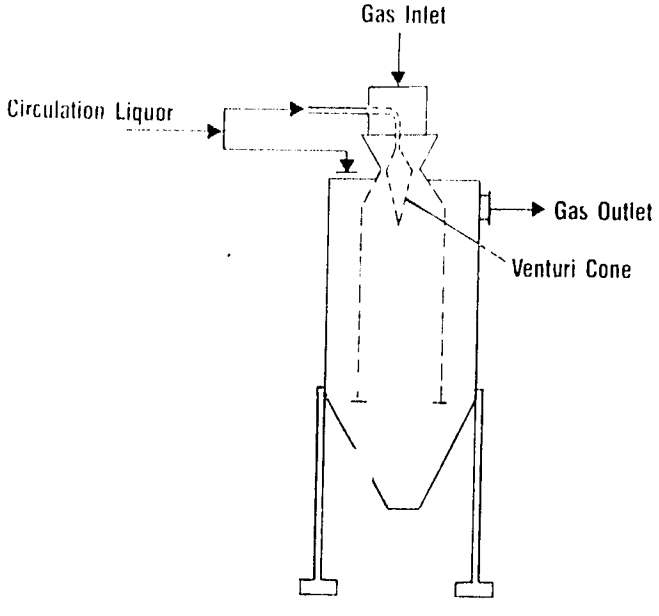

Figure 5. **Arrangement of Previous Venturi Scrubber.**

Grade Optimization and FACT/FEDO Experience With 20-20-0 (Non-Urea) Grade Ammonium Phosphate Sulfate Production

TVA has carried out many studies on maintaining the quality of urea- or ammonium nitrate-containing fertilizers. One of these studies (1) concluded that the critical relative humidity of urea ammonium phosphate (30-30-0) is 63%, which is less than the CRH of urea (75.2%) or MAP/DAP. When potash is also added to the mixture, the critical relative humidity decreases from 63% to 45%.

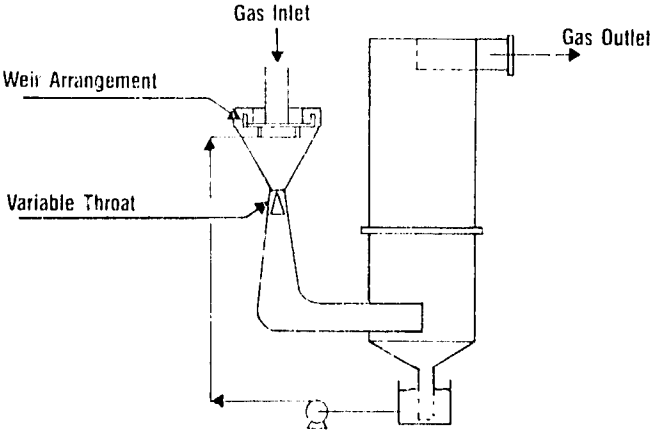

Figure 6. **Arrangement of New Venturi Scrubber.**

It will be necessary to maintain a very low humidity in the production and storage facilities used for urea-containing UAP or UAPK grades, as contemplated for the FACT Cochin Division NPK plant in order to maintain the product quality. Due to the fact that the Cochin area has a very high relative humidity (about 90%-100% for 5-6 months each year), it has become difficult to maintain such a low relative humidity even though dehumidified air is supplied to the unit. The problem is severe, especially

Table 2. **Annual Production of NP/NPK Fertilizers at FACT's Cochin Division Plant**

Before Product Changeover

	1978/79	1979/80	1980/81	1981/82	1982/83
Production, mtpy	103,690	99,406	198,414	151,869	179,233

After Product Changeover

	1983/84	1984/85	1985/86[a]	1986/87	1987/88 Through December 1987[b]
Production, mtpy	214,700	333,262	323,979	402,700	315,700

a. Some production lost because of the decommissioning of 10,000-mt capacity ammonia storage at Wellington Island, Cochin, and also 5,000-mt capacity at FACT Cochin Division site during this year.
b. Data for last half of 1987/88 accounting year not available.

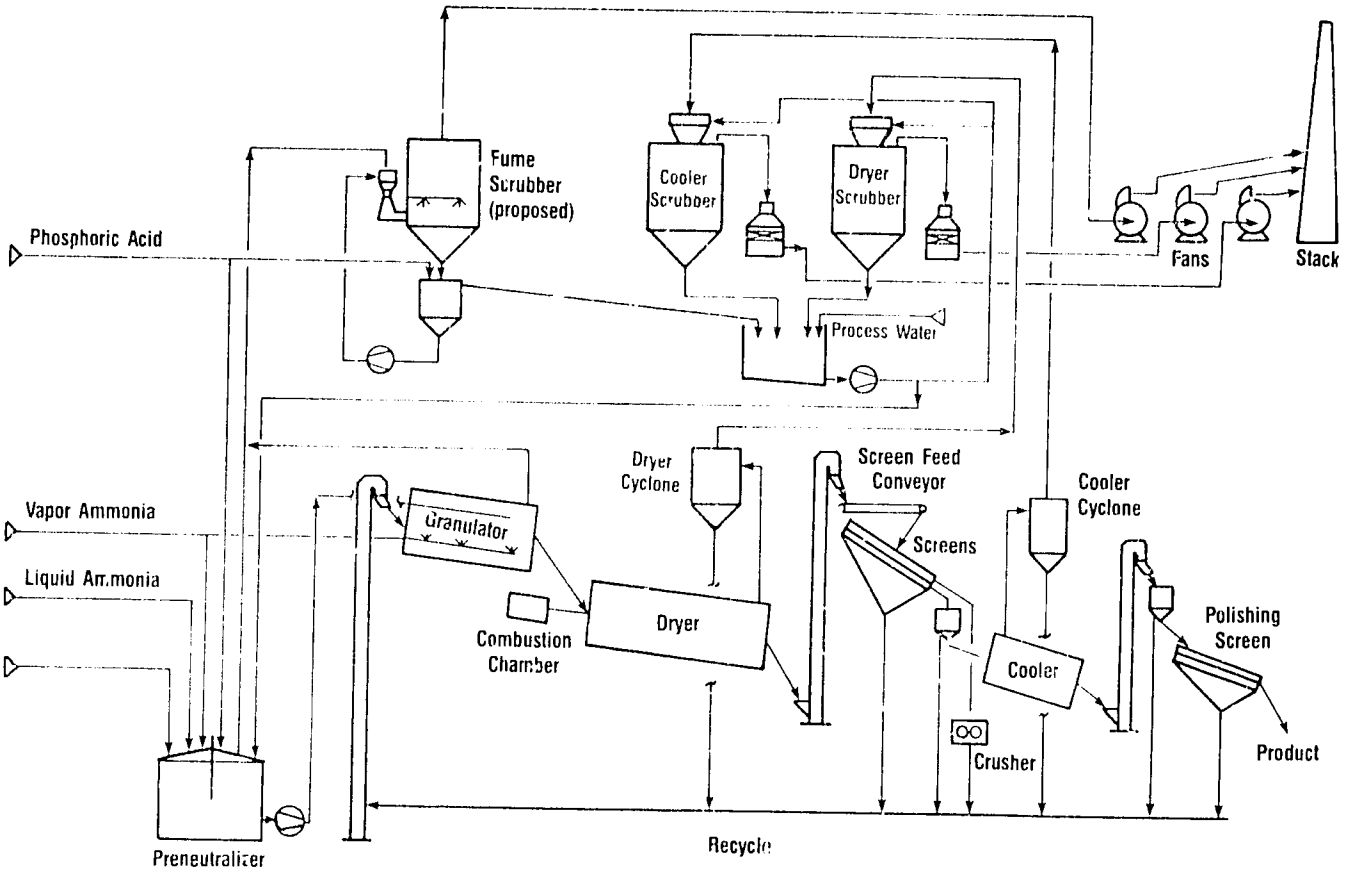

Figure 7. **Flow Diagram of Existing DAP and 20-20-0 Plant at FACT Cochin Division.**

during the rainy season, and maintaining continuity of UAP or UAPK production becomes difficult. The product quality also cannot be maintained especially when stored in bulk.

To overcome the humidity problem prevailing in the Cochin area and to achieve reliable performance, the kinds of product made were changed in 1982/83 to less hygroscopic grades like DAP and 20-20-0. This has resulted in higher plant utilization. The annual production achieved before and after the product changeover is given in Table 2.

Maintaining quality of the new products, namely DAP (18-46-0) and 20-20-0, has not posed much of a problem even when they are put in bulk storage. Continuous monitoring of product analysis with the Auto-Analyzer has helped to effectively control nutrient variation within the tolerance limits stipulated by the Government's Fertilizer Control Order.

As already explained, there are various advantages to the manufacture of urea-containing, high-nutrient NP/NPK fertilizer grades. However, the drawbacks of the high humidity problems prevailing in the area of Cochin plant cannot be ignored if effective utilization of plant capacity and satisfactory performance are to be attained. Since the presence of urea limits the drying temperature it also becomes necessary to provide a larger dryer with adequate retention time. Considering the various aspects it will be worthwhile to go in for low-urea grades for plant installations located under conditions of high humidity. Otherwise, it will be necessary to provide elaborate dehumidification facilities for the production, bagging, and bulk storage areas.

It is reported in literature that the presence of polyphosphates improves the storage qualities of urea-containing fertilizers. Also low moisture content in the product minimizes the caking tendency. This is due to the fact that the initial moisture present in the fertilizer forms solutions in the presence of easily soluble salts like urea and forms crystals. These crystals grow with the cycling of temperature and cause bonding which is known as caking. This effect will be less with smaller amounts of moisture in the product (2, 3).

FACT/FEDO Experience in Granulation Plant Design, Operation, and Quality Control

The experience gained by FACT over the years in the various aspects of the design, operation, and quality control in its granulation plants is given below. The following factors contribute to the good performance of complex fertilizer manufacturing plants.

1. Proper selection of the product.
2. Proper layout of equipment and chutes.
3. Proper design and selection of equipment.
4. Sufficient analytical facilities for maintaining the product quality.

Design Aspects

Unlike most of the straight nitrogen fertilizer plants, the complex fertilizer manufacturing plant has to handle mixtures of solid materials and hence is susceptible to variations during processing, especially in the recycle system. To achieve the expected onstream efficiency, it is necessary to design the system with adequate surge capacity to have more flexibility during operation. The layout of the plant should provide adequate space and should have properly sized ducts and chutes to avoid any choking problems. The following items are most critical.

Equipment Selection – The equipment chosen should be of proven design with a record of reliable performance. The critical equipment items in the granulation plant are the preneutralizer, screens, granulator, oversize crushers, dryer, and the recycle equipment. The continued performance of the plant depends mainly upon these pieces of equipment.

Preneutralizer – In case of a conventional granulation process it becomes necessary to use the preneutralizer to increase the N:P mole ratio of feed phosphoric acid to 1.35 to 1.45. Depending on the formulation chosen and capacity required, it is necessary to carefully size the cross sectional area and height of the preneutralizer, taking into account the amount of water vaporization from the preneutralizer; otherwise surges and upsets will occur.

Granulator – It has been found from experience that the rotary-drum granulators are increasingly used with a length-to-diameter ratio of 2.00 to 2.25 and an optimum speed between 38% and 42% of the critical speed to achieve effective rolling and tumbling action which results in good granulation.

Screens – It is preferable to have adequately sized conventional type long, narrow-width double-deck screens with an adequate gap between the screen decks and an effective means of vibration. Motor vibrators are generally preferred for maintaining adequate and effective vibration throughout the width and length of the screen cloths.

Oversize Crushers – The oversize crushers should be sized to take care of any sudden upsets in the granulation process with consequent increased amount of oversize in the dried product. It is preferable to design the capacity of the crushers to handle 40%-50% of the recycle capacity depending upon the grade manufactured.

Other Pieces of Equipment – Selection and reliability of other pieces of equipment, especially the scrubbing system, are very important for achieving good operating efficiency.

Plant Operation and Quality Control

The main operational controls are the N:P mole ratio of the reactor and scrubber slurry and the product analysis. When different grades of NP/NPK fertilizers are to be produced with the addition of urea and potash in the recycle system, it becomes necessary to have accurate control of these solid raw materials. Quick and timely feedback of product analysis is essential for taking corrective action to minimize the variation in product specification. The Auto-Analyzer facility enables a quick feedback of nutrient analysis to operating personnel. Hence this facility is essential, especially for urea containing NP/NPK formulations.

Improving Productivity of NP/NPK Complex Fertilizer Plants

All complex fertilizer plants in India employ the conventional slurry granulation process to produce various grades of NP/NPK fertilizers. The Government of India Seventh 5-Year Plan has been formulated keeping in perspective the development targets up to the year 2000. If the goals set for 2000 are to be achieved, the fertilizer industry has to undergo substantial expansion. The projected demand for the fertilizer nutrients in 2000 is around 20 million mt. The production in 2000 is projected to reach about 15 million mt of nutrients as compared with the present production of 7.4 million mt. The P_2O_5 production itself is expected to reach about 4 million mtpy from the present level of about 2 million mtpy. Since the fertilizer industry is capital intensive, the projected expansion by 2000 warrants substantial investment.

Considerable developments have taken place in the complex fertilizer manufacture during the last decade, mainly in Europe, Australia, and Japan. Perhaps the most outstanding developments that have taken place in recent years is the adoption of various pipe reactor systems to augment production and to reduce energy consumption in the plant by lowering the recycle requirement. Innova-

tions have been made in the pipe-reactor technology by many process licensers like S.A. Cros of Spain, CdF Chimie-AZF of France, Uhde GmbH of West Germany, ERT-Espindesa of Spain, and Incitec of Australia. The use of these innovations in the various NP/NPK and DAP plants abroad have shown that this improved technology is a boon for augmenting the production of NP/NPK plants in India.

The pipe reactor is a simple piece of equipment which can be easily retrofitted in the existing plants having suitable connected facilities at little cost and with substantial benefits. The main advantages of the pipe reactor processes are:

1. They require low investment and reduce operating cost because of their lower recycle ratio.

2. They are highly efficient and easily adapted to various feedstocks and different grades of phosphoric acid.

3. They have higher operating flexibility with better control of granulation.

In view of the various advantages mentioned above, it will be worthwhile to retrofit many of the existing plants in India with pipe reactors.

Conclusion

Considering the various aspects of fertilizer manufacture discussed in this paper, apparently it will be advantageous to utilize urea for high analysis NP/NPK fertilizers provided the plant is located in a low-humidity area. Otherwise an elaborate dehumidification system has to be provided for production, bagging, and storage areas in order to maintain product quality and continuity of production.

Alternatively, it may be preferable to produce low urea-containing grades or non-urea NP/NPK complex fertilizers in order to have sustained quality production of fertilizers. Reduction of the product moisture to the order of 0.5%-0.6% instead of 1.0% is expected to help in improving the product quality. The pipe reactor system, in addition to augmenting production, can give a better quality product. Hence the existing plants can be retrofitted to reap the benefits.

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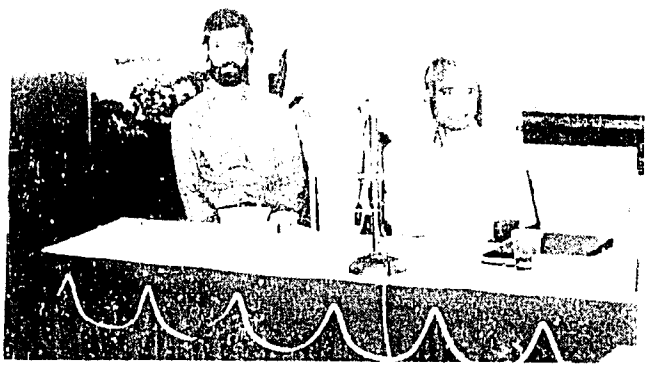


DAP/NPK Performance Improvement by Retrofitting

K. Govindarajan, Executive Director, Southern Petrochemical Industries Corporation, Ltd.

Abstract

Existing DAP/NPK plants have the capacity to expand their production facilities by retrofitting them with a new pipe reactor process. The new GESA "double-gun" process being employed for the first time in India, offers improvement in operating efficiency without any discharge of liquid effluent, with operational flexibility, increased reliability, less maintenance, and energy saving. A considerable increase in production capacity is expected to be achieved at a quite low investment cost. This paper describes the conventional process and its drawbacks and the retrofitting of the Southern Petrochemical Industries Corporation, Ltd. (SPIC) DAP-I plant with the GESA "double-gun" process.

Introduction

The growth in the fertilizer industry in response to the increased use of chemical fertilizers has been phenomenal in the last two decades. Nevertheless, India imports sizable quantities of fertilizers to bridge the increasing demand-supply gap. Consequently, substantial new capacity is planned over the coming years.

Any attempt to augment fertilizer production needs a close scrutiny as to constructing a new plant or revamping or modifying the existing plant. The cost of production is quite high in the case of new plants owing to high investment cost and rising cost of raw materials. The fertilizer industry is moving towards lower investment per unit of output in the last few years. Recent developments in fertilizer technology can be employed advantageously to retrofit existing old plants with the necessary modifications. Revamping results in improved energy efficiency and lower production costs.

SPIC Fertilizer Complex at Tuticorin

Southern Petrochemical Industries Corporation, Ltd. (SPIC), has its fertilizer division located at Tuticorin with the following production facilities:

Liquid ammonia	1,100 mtpd
Urea	1,600 mtpd
Sulfuric acid	470 mtpd
Phosphoric acid	165 mtpd
DAP – Train I	500 mtpd
DAP – Train II	500 mtpd

In addition to the above production facilities, there is a captive power plant with a capacity to produce a maximum of 18.4 megawatts and shore terminal facilities to import ammonia and phosphoric acid.

The DAP/NPK Plant-I installed in 1976 is based on the process improved by Tennessee Valley Authority and Nissan-HZ. Later a second unit with a similar capacity and the same process "know-how" was commissioned and commercial production was started in the beginning of 1983. The product mix has been restricted to mainly DAP to satisfy the agricultural requirements. However, urea ammonium phosphate 28-28-0 has also been produced in Plant-I for a short time.

Augmentation of Production

In accordance with the national goal of maximizing productivity, SPIC undertook a thorough study on the potential capacities of its plant equipment for possible augmentation in production.

Production can be augmented by introducing new processes and/or replacing/modifying certain pieces of the plant equipment to attain higher production, reduced downtime, lower maintenance cost, and better operating efficiency.

An analysis of the conventional process, with its limitations and drawbacks, is useful before examining the various technologies that are available for consideration.

Conventional Process

The manufacture of ammonium phosphate is achieved by neutralizing phosphoric acid with ammonia. Depending on the quantity of ammonia used, it is possible to produce monoammonium phosphate (MAP).

$$NH_3 + H_3PO_4 \rightarrow NH_4H_2PO_4$$

or, by further reaction, diammonium phosphate (DAP):

$$NH_3 + NH_4H_2PO_4 \rightarrow (NH_4)_2HPO_4$$

DAP is most commonly produced in granular form, typically in a slurry process using an ammoniator-granulator and a preneutralizer (Figure 1).

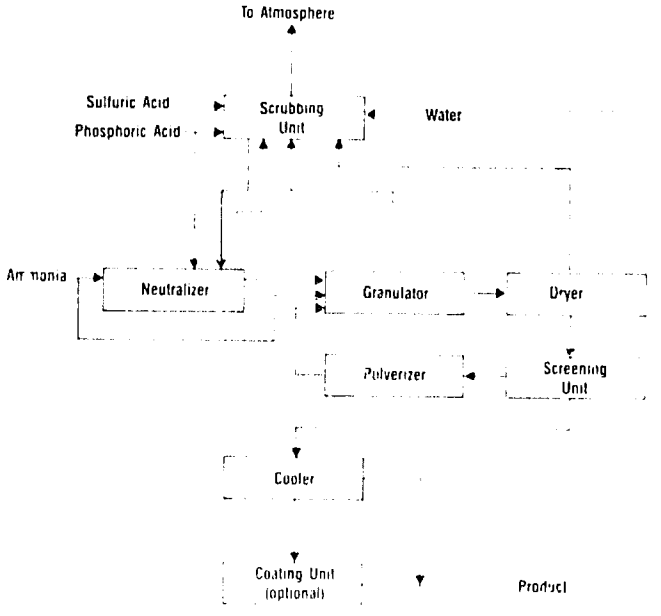


Figure 1. **Flowsheet for Production of DAP/NPK Fertilizers by Conventional Process.**

The solubility of the slurry in the neutralizer decreases with increase in N:P mole ratio up to a ratio of 1 and again increases between the ratios of 1.0 and 1.4. Hence, for fertilizers with higher nitrogen, a mole ratio of 1.4 is maintained in the neutralizer and for lower nitrogen grades it is maintained between 0.6 and 0.7. The solubility of ammonium phosphate slurry is shown in Figure 2. A small portion of the phosphoric acid fed to the plant is used to scrub exhaust gases from the granulator and dryer. The scrubber liquor is then fed, together with the main phosphoric acid stream, to the preneutralizer to which ammonia and, if necessary, water are added.

From the preneutralizer, the partially reacted material, which is now a slurry, is pumped to the granulator and sprayed onto recycled solid material which contains fines, crushed oversize, and product. Further ammoniation takes place in the granulator through spargers to bring the N:P mole of ratio to about 1.8 (in the case of DAP). The reaction is exothermic, as in the preneutralizer, with evaporation of water.

Wet product leaving the granulator with moisture content of about 2% to 3% is then dried, screened, and cooled before being sent to storage. Oversize particles are crushed; the fines together with a portion of the product is recycled to the granulator. Exhaust gases from the preneutralizer, granulator, and dryer are passed through scrubbers to recover the ammonia.

Drawbacks to the Process

The slurry-granulation process is not without its problems. The slurry needs a minimum water content in order to be pumpable, whereas moisture in the product in the granulator has to be maintained within narrow limits, because a product that is too dry or too damp can lead to unsatisfactory granulation. If the material in the granulator is too moist, a high solids recycle ratio is necessary to absorb the excess moisture in order to obtain suitable granulation. A high recycle ratio increases investment and operating cost (power consumption) since the size of the main equipment varies almost directly with the recycle ratio. With a high recycle rate a rather high fuel consumption is also required for drying the granulated product to a specified moisture content.

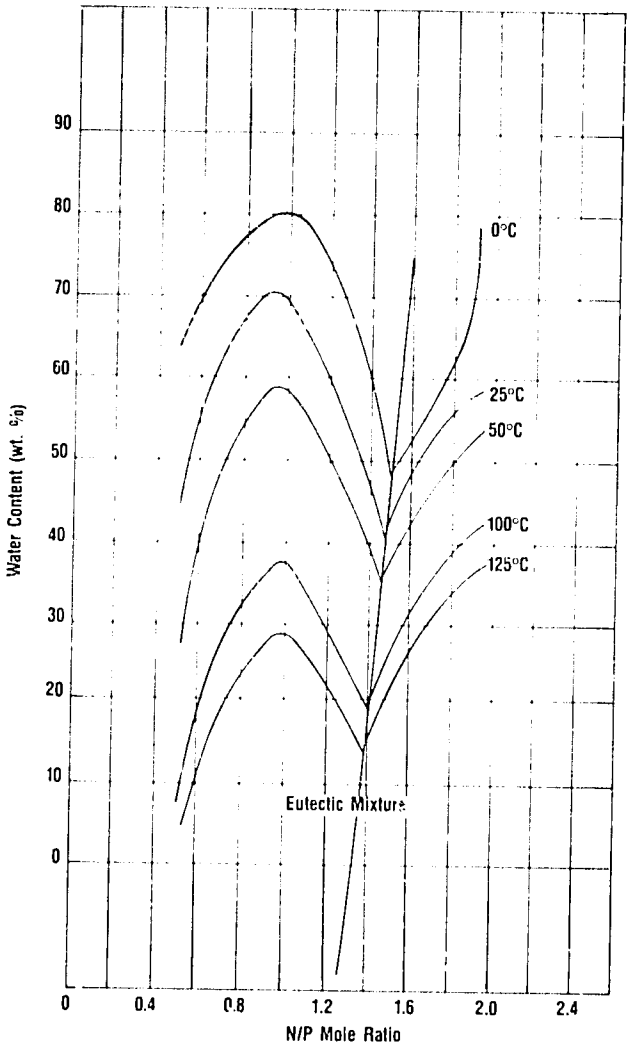


Figure 2. **Solubility Diagram of Ammonium Phosphate Slurry.**

An analysis of the conventional process as given above reveals that the bulk of the energy is consumed in recycling the solid material and in drying the granulated product. Efforts have been made to reduce the energy requirement for these operations and to develop more energy-efficient processes.

The recycle ratio depends on the ratio of liquid-phase-to-solid-phase in the granulator, which itself depends on the water balance and the heat of crystallization. So long as the desired recycle ratio is determined by the quantity of liquid phase in the granulator and not by the granulation yield, it is conceivable that a reduction in the recycle ratio could be achieved by decreasing the water content of the slurry or by cooling the recycle and/or using a solid salt.

The survey of the various DAP processes indicates that on an average 59,000 to 100,000 kcal/mt product is used as fuel to dry the granulated product. The heat of reaction evolved per metric ton of product is about 250,000 kcal. The available heat is greater when more concentrated grades of phosphoric acid are used. Hence, if a process could be designed to utilize the heat evolved in the process itself, it could be made autothermic and substantial fuel savings would be effected.

The considerable increase in the cost of energy and high investment costs have led to the invention of new technologies to achieve the overall reduction in energy consumption and hence sizable decreases in investment and operating costs.

New Technologies

Pressure Reactor

In the Norsk Hydro process, the neutralization is carried out at a pressure of approximately 1 kg/cm^2, gauge. This elevates the boiling point of the reaction mixture and the resultant slurry has a lower moisture content. This allows the plant to be operated at a recycle ratio of about 4:1 as compared with 6:1 required for conventional processes operating at atmospheric pressure. The reactor is installed at an elevation above the granulator and the slurry flows to the granulator under pressure, thus avoiding the need for slurry pumps. Retrofitting an existing plant can result in significant cost and energy savings.

Pipe-Reactor Technology

SA Cros Process—A mixed process that uses both a pipe reactor and a preneutralizer has been developed by SA Cros. Depending on the product and the capacity, the pipe reactor and preneutralizer are used together or individually. For DAP production, 60%-65% of the slurry is made in the preneutralizer and the rest in the pipe reactor (recycle ratio 3:1). For NPK products, only the pipe reactor is used (recycle ratio 2:1).

UHDE Process—Two pipe reactors are placed at the granulator, each capable of producing 25%-60% of the total load. The recycle ratio is 3-4. There is only one elevator in the granulation loop (no recycle conveyor) and the fluidized-bed cooler is used for product cooling. This process can be adopted for DAP and a wide variety of NPK products.

ERT-Espindesa Process—The main feature of this process is that the conversion of ammonia and acid to MAP or DAP is completed within the pipe reactor and thus further ammoniation is not necessary. By this process, powdered MAP or DAP can be produced by spraying the melt from the top of a tower. Alternatively, granular product can also be made by spraying the slurry inside the granulator. Recycle ratios of 2.5-3.0 are achieved.

One of the innovations that revolutionized the manufacture of NP/NPK fertilizer is the pipe-reactor technology. This technology makes use of almost all equipment in the recycle loop of the conventional plant except the preneutralizer and hence offers an opportunity for retrofitting existing plants to derive the maximum benefits of this new invention.

A pipe reactor or a reaction gun, as it may be called by some process licensers, is a long pipe of suitable diameter made of special alloys (like Uranus B6, Jessup 700, or SS 316L) with suitable provisions for the addition of ammonia, phosphoric acid, and sulfuric acid/scrubber liquor. This pipe reactor does the function of the preneutralizer in a conventional process. That is, it combines the ammonia and phosphoric acid in a confined space of the pipe; resulting in intimate mixing and a complete neutralization of the phosphoric acid.

The heat of the chemical reaction instantaneously dries the product as the neutralized product is sprayed onto a rolling bed of solid materials having the required moisture content. Because of the lesser moisture brought into the granulator, the recycle ratio can be reduced considerably from the usual 6-8 to about 3.

The chief advantages of this pipe reactor technology are:

1. For the same capacity plant, the dryer, cooler, material handling equipment, and scrubbing systems can be smaller than the comparable units in a conventional plant.

2. Saving in fuel consumption can be attained by effectively using the chemical heat of reaction.

However, single-pipe reactor technologies pose the following major problems.

1. The entire heat of reaction is released in the granulator which may result in overheating of the product with consequent overgranulation.

2. A very high quantity of water vapor is released in the granulator, and this necessitates a larger sized venting and scrubbing system.

In order to obviate the above disadvantages and derive the maximum benefit, it becomes necessary to distribut the heat of reaction in more than one piece of equipment. That is the excess heat should be diverted into another unit of the recycle loop, say, the dryer, where the crystallization of the salts and evolution of the steam can take place almost instantaneously.

Such a process has been developed by CdF Chimie AZF (formerly GESA - Generale des Engrais SA) of France. This process is called the GESA "double-gun" process.

The main features of this pipe-reactor process are:

1. The investment cost is low.
   a. No preneutralizer is required.
   b. The recycle ratio is low.

2. The operating cost is low.
   a. The operation is autothermal (no heating energy is needed).
   b. The electric power consumption is low.
   c. The loss of citrate-insoluble P_2O_5 is small.
   d. The efficiency of ammonia consumption is high.

3. The process is highly adaptable to various feedstocks.
   a. The process is suitable for phosphoric acids from various sources.

4. Operating flexibility and stability are high.
   a. The scrubbing system is well proven.
   b. Control of granulation conditions is effective.

5. A wide variety of products can be formulated.
   a. MAP, DAP, and various types of NPK can be made.

6. The environmental impact is low.
   a. Emission values are low and comply with EPA standards.

Description of the GESA Double-Gun Process

This process utilizes a traditional granulation system except that the neutralization of phosphoric acid with ammonia takes place in two pipe reactors, one in the dryer and the other in the granulator (Figure 3). The gas-scrubbing unit for this process is shown in Figure 4.

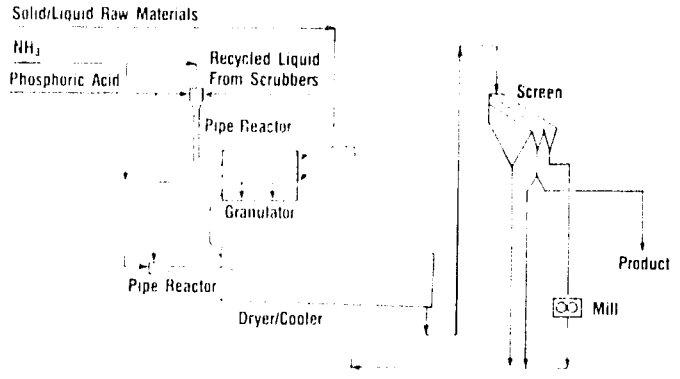


Figure 3. **Granulation Loop for DAP/NPK Fertilizer Production Using Two Pipe Reactors.**

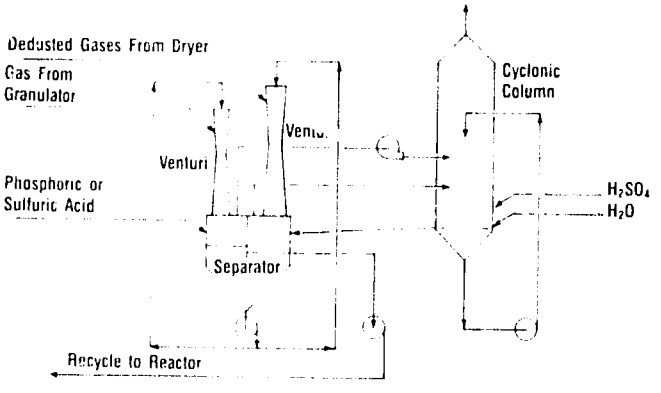


Figure 4. **Gas-Scrubbing System.**

The process envisages distribution of the process heat at two different locations. That is, the heat is divided between the granulator and the dryer in such a way that enough heat is available for drying in the dryer and the product does not get overheated at the granulator. This effects a reduction in the recycle ratio and in smaller losses of ammonia.

Reaction Section – In the pipe reactor installed in the dryer, about 50% of total phosphoric acid is neutralized with ammonia and fixed at a N:P mole ratio of 1.0 to 1.05. Very fast crystallization occurs in the gas stream and hence the product from the granulator is not coated with MAP.

MAP formed at the dryer pipe reactor is easily separated in the vibrating screens (70%-90%) and in the dust cyclones (10%-30%) the particle size being:

80% greater than 50 μm
50% greater than 100 μm

A typical mole ratio measured at different points of the circuit is given in Figure 5 and in the following tabulation.

	Granulator Outlet	Final Product	Fines After Screening	Dust Particles From the Cyclone
N:P mole ratio	1.90	1.87	1.60	1.30

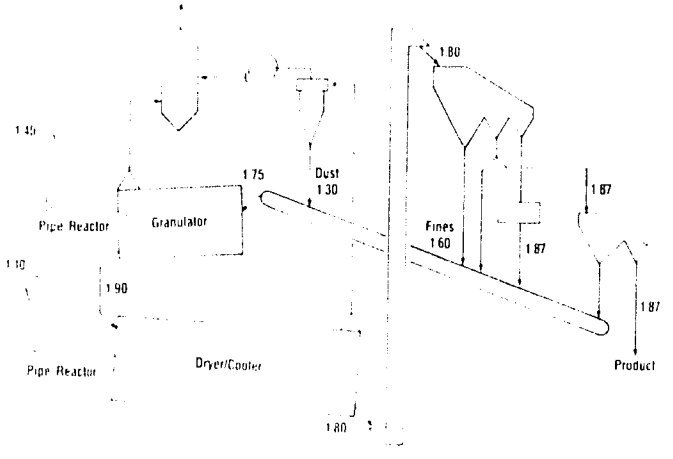


Figure 5. **N:P Mole Ratio at Various Points in Process.**

The finely divided state of MAP is eminently suited to the complementary absorption of ammonia in the granulator up to a mole ratio of 1.90-1.95.

In the second pipe reactor setup in the granulator, the balance of the phosphoric acid is neutralized by ammonia. Washing liquor from the scrubbing system is also fed to this pipe reactor. This pipe reactor is operated at a mole ratio of about 1.4. Additional ammonia is injected into the granulator bed of material through special spargers to bring the N:P mole ratio up to the required value.

The following tabulation shows the operating conditions (distribution of acid and ammonia) for the manufacture of DAP.

	Pipe Reactor in Dryer	Pipe Reactor in Granulator	Granulator Sparger	Scrubber
Phosphoric acid	50%	37%	-	13%
Ammonia	28%	29%	43%	18%[a]

a. The 18% value represents the maximum evolution of ammonia occurring mainly from the granulator.

Scrubbing System – The scrubbing system treats the off-gases and acts itself as a reactor in which about 12% to 18% of ammonia not already fixed is neutralized with phosphoric acid. The efficiency of the scrubbing operation is maximized by using two stages of scrubbing.

In the first stage, efficient contact between off-gases and scrubbing solution in the venturi section ensures that the ammonia is absorbed and neutralized to a pH of about 4 and the fluorine in the scrubbing solution is fixed. Sulfuric acid is added in the final tower (second stage) to recover the ammonia that escaped from the first stage, thus ensuring a high recovery. The scrubbing liquor is recirculated and fed entirely to the pipe reactor in the granulator, thus ensuring a zero discharge of liquid effluent.

Dust recovery is carried out as in a conventional system. The product cooler alone is vented separately to maintain the product temperature at acceptable levels. For this purpose, a battery of cyclones and an exhaust fan are used. The dust free air is vented to the atmosphere either directly or through the fume stack.

Advantages of the Double-Gun Process

The GESA double-gun process offers many advantages over single-pipe reactor processes as well as the conventional slurry granulation process; they are:

1. **Fuel Saving** – Less water has to be removed in the dryer than in the preneutralization process. The heat of reaction between ammonia and phosphoric acid is better used. In fact for DAP, the process becomes autothermal when the average P_2O_5 content of the phosphoric acid is at least 45%.

2. **Power Saving** – Drastic reduction of the solid recycle ratio and the uniform distribution of heat between the dryer and granulator reduces the size requirement of the recycle equipment, thereby reducing the power consumption.

3. **Steam Saving** – For many formulations like DAP, liquid ammonia is used directly, thereby eliminating the requirement of steam for vaporizing ammonia.

4. **Lower Investment Cost** – The reduced size of the equipment in the recycle loop and also in the venting and scrubbing system decrease the investment cost.

5. **Flexibility of Operation** – Excellent control of the distribution of P_2O_5 feed rates between the dryer and the granulator results in accurate control of the solid-to-liquid phase ratio in the granulator as well as accurate adjustment of the temperature of the rolling bed of product in the granulator. This makes the operation easier. Moreover, it is very easy to change the formula-

tion of the product as the hold-up volume of the pipe reactor is very small.

6. **Improvement of Efficiency**—The excellent ammonia/acid contact obtained in pipe reactors aids the reaction to go to completion and reduces ammonia losses. Moreover, the MAP produced in the dryer is very reactive and easily ammoniated when recycled to the granulator, thereby reducing the ammonia losses.

7. **Improvement of Environmental Control**—The total gas flow rate is smaller compared with the conventional as well as single-pipe reactor processes. This is because there is no preneutralizer to be vented and the heat is distributed partly in the dryer (as steam) and partly in the granulator (as an ammonia-vapor mix), thereby reducing the size of the scrubbing system and improving the efficiency. All the scrubbing solutions are recycled to the granulator pipe reactor, thereby avoiding the discharge of liquid pollutants.

In addition to the advantages mentioned above, there are others such as less maintenance cost, greater availability of the plant and hence increased production, better quality product of precise grade and low moisture content, and a reduction in the required number of operating personnel.

Retrofitting of Existing Plants

The double-gun process is well developed and there are, for the time being, 21 GESA pipe reactor plants operating or under construction all over the world.

Since the recycle ratio is drastically less in the double-gun process (3.0 to 3.5) than in the conventional process (greater than 6), the size of the equipment that is already installed for the existing production capacity would afford a considerable increase in the production level by installing the pipe reactors in both the dryer and granulator. It has been estimated by GESA that the production levels can be increased by 70% or more by installing the pipe reactors including their control instruments, and only minimum modifications to the screening, product cooling, and dedusting equipment would be required. Furthermore, the retrofitting needs considerably less time for mechanical completion of all modifications, say about 2 months when all materials are readily available at the site, as compared with 6-8 months for the installation of a conventional process (for erection of equipment and piping). The most important advantage of retrofitting existing plants with the double-gun process is the investment itself. It has been estimated that the capital outlay for an expansion in production capacity of about 70% would only be approximately one-fourth to one-third of that required for installing a conventional plant of the required size.

Retrofitting SPIC's DAP-I Plant

The DAP-I plant at SPIC has been retrofitted with the GESA double-gun process for increasing the production level to 850 mtpd from the present level of 500 mtpd. The modification was done at a total cost of about US $3.5 million (Rs. 451 lakhs) which includes a foreign exchange component of about US $1.0 million (Rs. 140 lakhs).

The modifications that were carried out for augmenting the production capacity are shown in Figure 6 and listed below.

1. **Granulator**
   a. Addition of a reaction gun (Uranus B6 or equivalent)
   b. Addition of a new liquid ammonia distributor consisting of five spargers (316L stainless steel).
   c. Addition of new slurry sprayer (316L stainless steel).
   d. Replacement of outlet (discharge) threshold (316L stainless steel).

2. **Dryer**
   a. Addition of a reaction gun (Uranus B6 or equivalent).

3. **Screens**
   a. Changeover from electromagnetic to unbalanced motor-vibrating system with control cubicles for operation of the motor-vibrating system.

4. **Cooler**
   a. Modification of air exit hood.

5. **Product Elevator**
   a. Replacement of drive unit for handling higher production rate.

6. **Product Conveyor**
   a. Modification of the unit to handle increased production capacity.

7. **New Equipment**
   a. Addition of a set of four cyclones and cooler air fan to meet the increased load on the cooler.
   b. Addition of pumps for feeding strong phosphoric acid at required pressure to reaction guns.
   c. Addition of scrubber liquor pump to transfer washing liquor from preneutralizer to reaction gun in granulator.

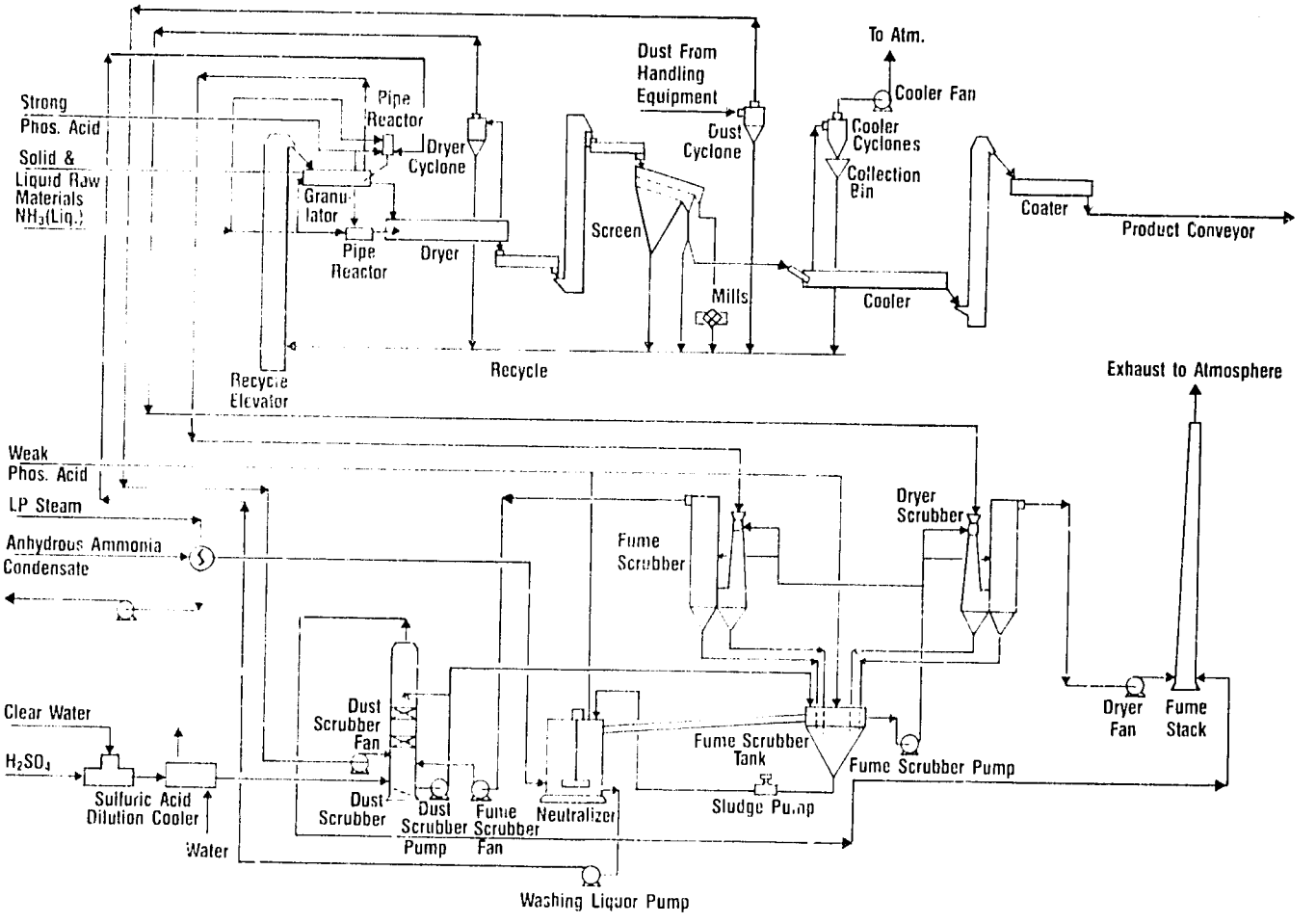


Figure 6. **Flowsheet for SPIC DAP/NPK Plant Retrofitted With GESA's "Double-Gun" Pipe Reactors.**

d. Addition of a sulfuric acid dilution cooler for preparing diluted sulfuric acid for feed to dust scrubber.
e. Addition of sulfuric acid pump, cooling water pump, and a cooling tower.

8. **Ducts**
   a. Replacement of gas duct from granulator to fume scrubber.
   b. Modification of air duct from cooler to new cyclones and from cyclones to new cooler air fan.
   c. Modification of venting ducts from handling equipment, wherever necessary.
9. **Piping and Valving**
   a. Addition of piping and valves to feed raw materials and wash liquor to reaction guns and to feed required utilities.
10. **Control Systems**
   Addition of instrumentation system including:
   a. Magnetic flowmeters and controllers in the acid and ammonia lines to pipe reactors for accurate control of the mole ratio.
   b. Emergency trip valves.
   c. pH and density controllers for scrubbing system.

Benefits Anticipated

The retrofitted plant will produce the following anticipated benefits:

1. Production of an additional 350 mtpd of DAP. This is achieved at a total project cost of about US $3.5 million (Rs. 451 lakhs). A new plant in addition to a higher investment cost would also need a longer construction schedule.

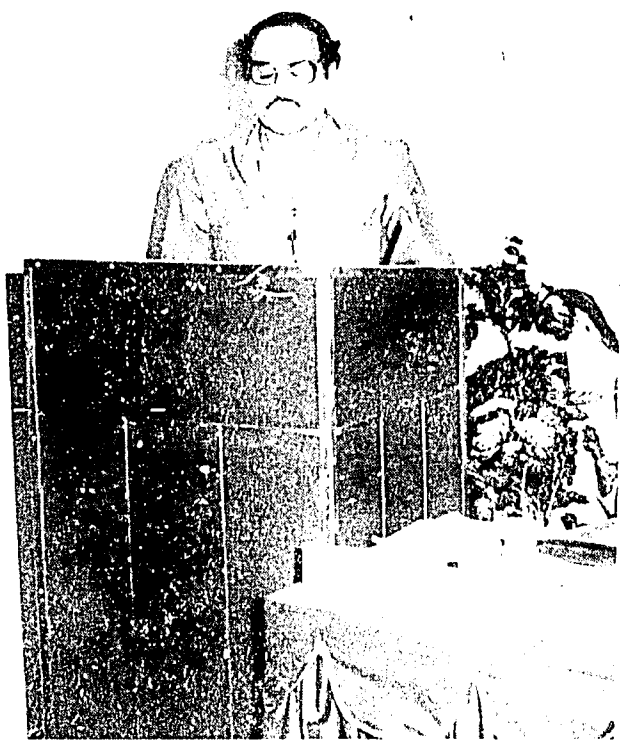
2. Improved recovery efficiencies of the raw materials (ammonia and P_2O_5) are realized by efficient two-stage scrubbing and by recycling the entire scrubbing liquor. This will greatly reduce the pollution, thus keeping the environment clean. Also, the cost of production will be reduced because of the improved raw material recovery.

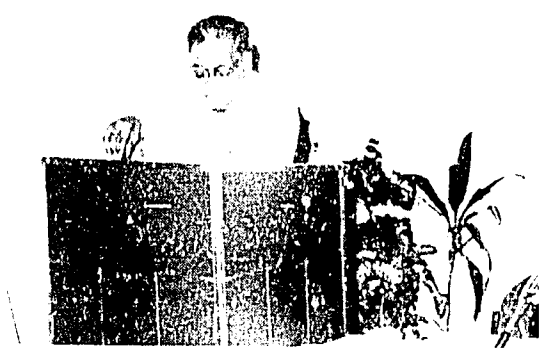
3. A saving of 30% or more is expected in fuel consumption by more complete recovery of the heat of reaction in the process.

4. A saving in power consumption of 30%-35% is expected. This was achieved because the electrical drives were kept practically the same except for a few additions despite the increased production.

Conclusions

Additions to installed capacity of fertilizer plants have, so far, been based on setting up large-scale plants that incorporate the latest technology. However, when there is a potential need for quickly increasing the fertilizer producing capacity, retrofitting may avoid the additional cost of the large infrastructure required for new facilities and save some of the capital costs as well. In such cases the options clearly point toward utilizing the latent capacities of the existing facilities, taking full advantages of the technological developments that have been recently developed in the fertilizer industry.





Impact of Raw Materials and Formulations on NPK Plant Design and Operation

Glen H. Wesenberg, Vice President (Process Engineering), FEECO International, Inc.

Abstract

This paper explains the impact of raw materials and formulations on the design and operation of NPK fertilizer plants. It lists the principal factors that must be considered before the actual design is begun. These factors include the fertilizer requirements of the market area, the availability of raw materials, and a number of equipment design and layout factors. Examples are given of the equipment systems used and the procedures normally followed in designing new plants or modifying existing plants.

Introduction

This presentation will attempt to explain the impact of raw materials and formulations on NPK design and operation.

Figure 1 shows typical fertilizer plant functions for an NPK granulation plant. Block diagrams, such as this, showing desired plant functions and simplified flow of materials become very useful in conceptual determination of complex plant designs.

In determining the requirements for an NPK granulation plant, we should first determine the needs in the market area to fully appreciate the various reasons for having an extensive variety of formulations and raw materials. In determining these formulations and raw material requirements, three basic studies and evaluations should be made:

1. The product requirements of the market area.
2. The availability of materials.
3. The overall economics of the production facility.

In determining the product requirements of the market area (Item 1 above), the following considerations should be evaluated:

a. Crop requirements for plant food and micronutrients.

b. Rate of release of the plant food desired to the respective crops.

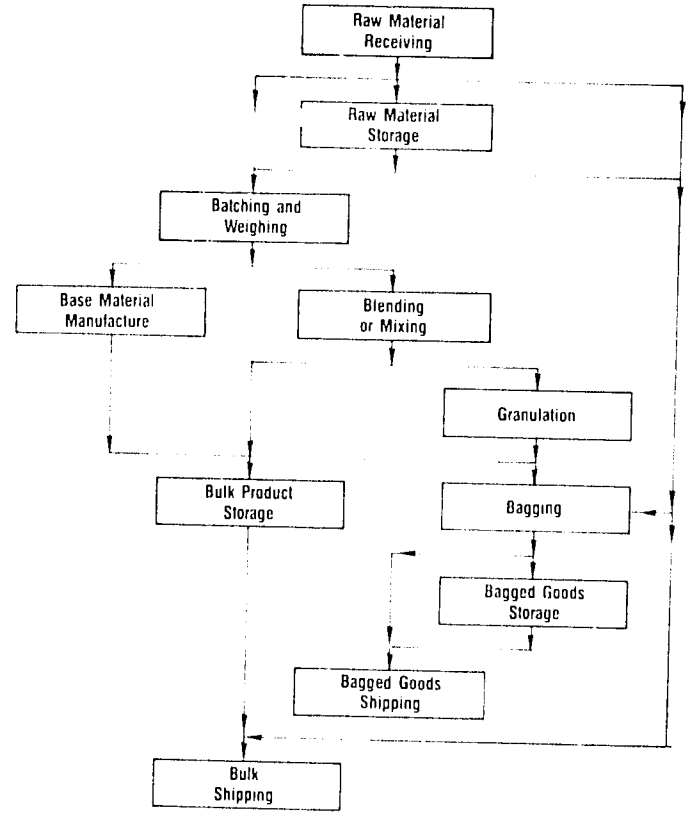


Figure 1. **Typical Fertilizer Plant Functions.**

c. Requirement for uniformity of plant feeding.

d. Type of application equipment. Particle size becomes important in spreading applications where uniformity of distribution is required using mechanical spreaders to uniformly apply the proper amount in a given area. The physical nature of the product becomes very important for this purpose.

e. The type and size of product desired may vary based on the land conditions. The product desired in sandy soils will generally consist of slower released materials. These may also be required in swamplands. Particle size may also be an important factor for specific conditions.

f. If waste materials or byproduct materials having plant food value are used, equipment requirements and formulations may vary considerably.

Table 1. **Plant Food Ingredients Commonly Used in Granular Fertilizer Formulations**

Sources of Nitrogen (N)	Sources of Phosphate (P_2O_5)	Sources of Potash (K_2O)
Anhydrous ammonia (gas or liquid)	Triple superphosphate (dry)	Potassium chloride (standard of coarse)
Nitrogen solutions (NH_4NO_3, NH_3, H_2O)	Normal superphosphate (dry)	Potassium sulfate
Ammonium nitrate-urea solutions	Enriched or concentrated superphosphate (TSP + NSP)	Monopotassium phosphate
Urea (dry, melt, coated)	Phosphoric acid	Dipotassium phosphate
Ammonium nitrate (dry, melt, solution)	Superphosphoric acid	Sul-Po-Mag (potassium magnesium sulfate)
Ammonium sulfate (dry)	Diammonium phosphate	
Nitric acid (liquid)	Monoammonium phosphate	
Diammonium phosphate (dry)	Ammonium phosphate-nitrate	
Monoammonium phosphate (dry)	Ammonium polyphosphate	
Nitrophosphates	Magnesium phosphate	
Ammonium phosphate-nitrate	Calcium metaphosphate	
Ammonium polyphosphate	Nitrophosphates	
Sodium nitrate		
Calcium nitrate		
Calcium ammonium nitrate		

Note: In addition to these listed materials, a variety of waste materials having plant food values are also used. Many formulations contain fillers, micronutrients, and soil conditioners. Some formulations contain combinations of base reaction materials plus pregranulated materials.

g. Addition of conditioning materials may also be desired or required.

h. Homogeneous products will be required where potential segregation problems exist, especially where the distance of transportation and type of transportation equipment vary widely.

i. Government regulations may be restrictive to assure the user that the product delivered and distributed to the crops is suitable and meets guaranteed values.

j. Storageability, especially in highly humid areas, may require additional specialized equipment and use of materials.

k. Soil pH (acidity or alkalinity) may vary requirements for addition of neutralizers, such as limestone.

Another important consideration is the availability of materials (Item 2 above). Various grade requirements can be satisfied by utilizing different materials in formulation to provide proper NPK ratios.

Overall economics (Item 3 above) must be considered in determining the raw material requirements, equipment requirements, and plant design. Items such as raw material costs, system investment costs, production costs and rates, and product volume requirements are the prime considerations in determining the size of the facility, variations and flexibility in equipment requirements, and the raw materials used.

The Granulation Process

Table 1 lists the variety of plant food ingredients commonly used in fertilizer granulation formulations. Some of these ingredients are preprocessed products; however, if prime raw materials are readily available, and/or the demand is sufficient, the manufacture of one or more of these products may be economical and desirable to be incorporated with a typical NPK granulation plant. A discussion of the impact of raw materials on the granulation process follows.

Ammonia Heat of Reactions

Table 2 lists the approximate heat of reactions of ammonia with various materials that are commonly used in formulating. Ammonia does not react without the presence of moisture; this is a very important consideration in designing equipment where reactions occur, especially in the ammoniators-granulators. Experience has shown that a heat of reaction of about 180,000 Btu/short ton (st) is most favorable for granulation – the minimum and maximum range is about 160,000-200,000 Btu/st. If the heat of reaction is above 200,000 Btu/st, then some type of prereaction is recommended. If below 160,000 Btu/st some steam or melt is usually required to obtain good granulation.

Granule Formation

Following is a list of various factors that influence granule formation, stability in processing, and equipment requirements.

Table 2. **Heat of Reaction Between Ammonia and Various Fertilizer Materials at 25°C (77°F)**

Material	Ammoniation Level, lb NH_3/20 lb P_2O_5	Btu/lb NH_3 in form of:[a] Gas	Liquid	Solution[b]
Phosphoric acid (75%)	4.8	3,101	2,511	2,687
Phosphoric acid (75%)	7.2	2,714	2,124	2,300
Phosphoric acid (75%)	9.6	2,520	1,930	2,106
MAP to DAP	4.8	1,939	1,349	1,526
Single superphosphate	5.8	2,018	1,428	1,604
Triple superphosphate	3.8	2,233	1,643	1,819
Sulfuric acid	0.347 lb NH_3/lb, 100% H_2SO_4			
Sulfuric acid (98%)		3,430	2,928	3,016
Sulfuric acid (93.2%)		3,299	2,797	2,885
Sulfuric acid (77.6%)		3,016	2,514	2,602

a. All products in solid phase.
b. Based on solution containing 25% ammonia, 69% ammonium nitrate, and 6% water.

1. Conditions under which the materials decompose.
2. Control and dissipation of heat.
3. Temperature.
4. Moisture.
5. Solubility of salts.
6. Water of hydration.
7. Thermal shock.
8. Complex interreactions.
9. Sequence of reactions and material additions.
10. Combination of materials that retard, buffer, or accelerate reactions.
11. Physical activity during granule formation.
12. Size and porosity of raw materials.

In general, as the ratio of dry raw materials to fluid raw materials decreases in the formulation, the heat of reaction will increase accordingly. The product will also become more homogeneous.

Equipment Sizing and Design

The following is a list of the factors influencing equipment sizing and design requirements.

1. Number and range of quantities of various dry raw materials.

2. Number and range of quantities of various fluid materials.

3. Type of utilities available (for example, fuel, power, and water).

4. Ambient conditions in area.
   a. High humidity.
   b. Temperature range.
   c. Plant subterrain conditions.
   d. Potential storm and/or earthquake zone.

The previous discussion outlined the factors and considerations that are used in formulating NPK grades. Unless these procedures are followed, one cannot determine the most suitable process system and equipment sizes. However, once the plant requirements and formulations are determined, the number and range of quantities of various dry raw materials and fluid raw materials become known. Then equipment can be properly sized.

Utilities

The utilities available influence the size, type, and auxiliary equipment requirements. Typical considerations are package boiler systems for steam granulation, substations for power requirements, water treatment systems, and fuel supply and storage facilities.

Ambient Conditions

Ambient conditions in the area of the plant will determine the necessity for dehumidification equipment, heating or cooling equipment, the extent of enclosures required, and requirements for special supports such as piling, fill, and spread footings.

Critical Relative Humidity and Solubility

Table 3 shows the critical relative humidity of various materials. The critical relative humidity of various salts and combination of materials become a very important consideration in drying systems design and operation, material storage conditions, requirements for insulation, and requirements for coating materials and systems. It is also very important to consider the incompatibility of raw materials in determining the equipment requirements.

Materials such as urea and ammonium nitrate or urea and normal superphosphate in contact with each other, even in the presence of very low humidity, will result in extreme stickiness, buildup, and plugging of equipment.

Figure 2 shows the solubility of pure fertilizer salts in water and the percent salt in solution at various temperatures. In formulations containing comparatively high quantities of dry solid materials, the more soluble salts promote granulation more than the less soluble salts. In general, the higher the quantity of high solubility salts in the formulation, the more hygroscopic the product materials will be. They will normally require the use of coating agents.

Granulation Plant Equipment Systems

Now let us review the basic system loops and variations that may be used in an NPK granulation plant. Various types of equipment may be used to accomplish a specific phase of processing. After the raw materials, grade requirements, and formulations are known, the equipment sizes and types can be selected and the plant can be designed. As these requirements vary, the type of system loop and equipment will also vary. The following discussion will describe some of the variations in system loops and equipment commonly used.

Closed Loop Air Handling

Figure 3 shows a typical Closed Loop Air-Dust Handling System. This system results in considerable savings in energy and simplifies requirements for emission control. However, a complete review of the existing facilities, or proposed new plant, should be made to determine the system feasibility for each specific plant. The closed loop system operates in the following sequence. Ambient air combined with air used to purge fugitive dust from various locations is drawn through the cooler and then passes through a cyclonic separator, or bag-type collector. The air is then drawn through a fan and is used for drying. This air is fed to a specially designed combustion chamber where the air is uniformly blended with the combustion gases and excess air introduced through the burner system. Supplemental ambient air may also be introduced with the air fed to the combustion chamber. The blended, heated air, leaving the combustion chamber, passes through a rotary dryer and then through an insulated bag-type dust collector. This filtered air is then drawn through an exhaust fan having a discharge control damper. The clean air exits to the atmosphere through a stack. The combustion chamber must be designed to not only uniformly mix the blended air and combustion gases, but the orifices, ducting, and transitions must be designed to provide proper air velocities at all locations. It is also important to have the system designed to provide a negative

Table 3. **Critical Relative Humidity of Various Materials**

Materials Absorb Moisture When The Humidity of the Air Exceeds These Values:

Material	Relative Humidity of Air at 86°F (30°C) (%)
Urea and ammonium nitrate (mixture)	18.1
Ammonium nitrate and straight monocalcium phosphate (mixture)	38.6
Urea and nitrate of soda (mixture)	45.6
Calcium nitrate (alone)	46.7
Urea and sulfate of ammonia (mixture)	56.4
Ammonium nitrate (alone)	59.4
Urea and muriate of potash (mixture)	60.3
Ammonium nitrate and sulfate of ammonia (mixture)	62.3
Urea and straight monocalcium phosphate (mixture)	65.1
Ammonium nitrate and muriate of potash (mixture)	66.9
Nitrate of soda and common salt as found in manure salts (mixture)	67.6
Nitrate of soda (alone)	72.4
Urea (alone)	72.5
Sulfate of ammonia (alone)	79.2
Muriate of potash (alone)	84.0
Ammonium phosphate (alone)	91.6
Monocalcium phosphate (the pure compound, entirely free of acid)	93.7
Dicalcium phosphate, gypsum, limestone, sand, and other insoluble materials	100.0

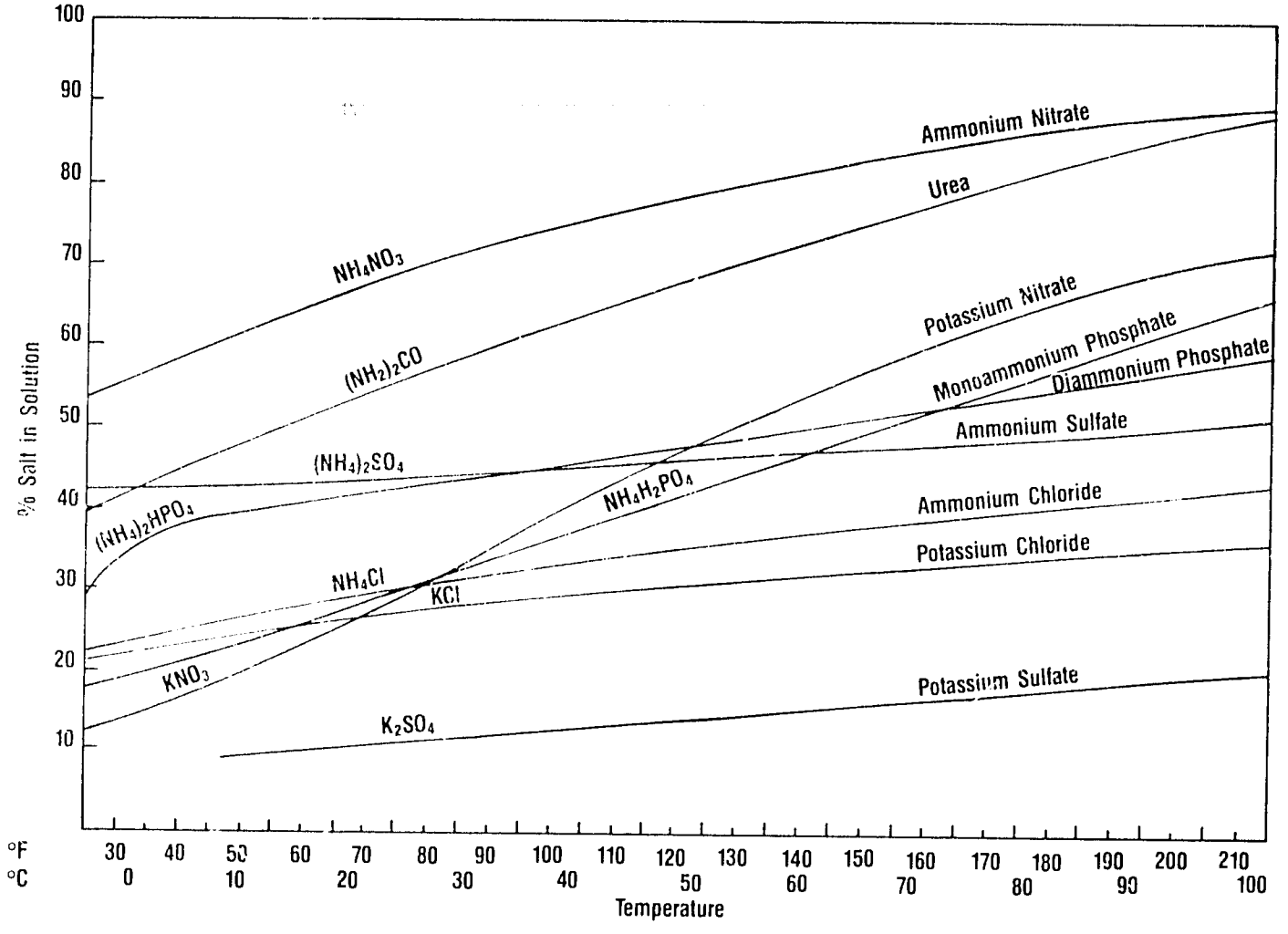


Figure 2. **Solubility of Pure Fertilizer Salts in Water.**

pressure (suction) on the combustion chamber at all times to prevent any dust from accumulating in the combustion chamber. This system recovers the majority of the heat removed from the material in the cooling system. By reusing the air, a lesser quantity is emitted to the atmosphere and less equipment is required for cleaning the air emitted to the atmosphere.

Dry Raw Materials Feed

Figure 4 shows a typical dry raw material feed and weigh system. This system incorporates a lump breaker (clod breaker) in an elevator feed hopper to break up clusters and lumps in the raw materials. The elevator discharges to a single deck scalping-type screen. The oversize materials can be fed to an oversize crushing mill such as a chain mill, roller mill, or cage mill and returned to the elevator for recycle back to the screen. The most commonly used mill for this purpose would be a chain hammer-type mill. The material going through the screen is fed through a simple remote-controlled swivel spout, so each type of dry raw material can be fed to its respective bin of a cluster hopper. It is good practice to design the

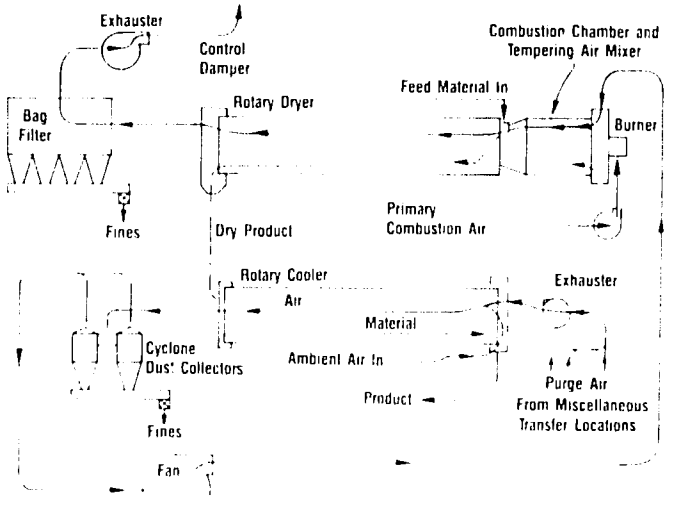


Figure 3. **Closed Loop Air/Dust Handling System.**

cluster hopper to provide one or two extra compartments. If a high proportion of a given material is used with respect to the other materials, two or more compartments may be used for that particular material. The remote

operation of the swivel can be accomplished through a simple mechanical arrangement for manual operation by the front-end loader operator observing an indexed positioning pointer. To minimize dust emitting to the atmosphere when filling the cluster hoppers, a simple enclosure can be built over the entire cluster hopper having the height extending above the swivel spout to a stationary segment. By installing grating over the top of the bins, the enclosed portion can be made very accessible. The cluster hopper discharge gates can be operated through mechanical linkages, pneumatically operated, or pneumatically operated with an automatic batching-type system to proportion the proper amounts of materials into a weigh hopper positioned under the cluster hopper. If the fully automatic system is used, a lever-type scale and sensing system is recommended. By providing this type of system, the batching can be done manually if any failure results in the automated batching system. In the United States this type of system has been used very successfully for a number of years.

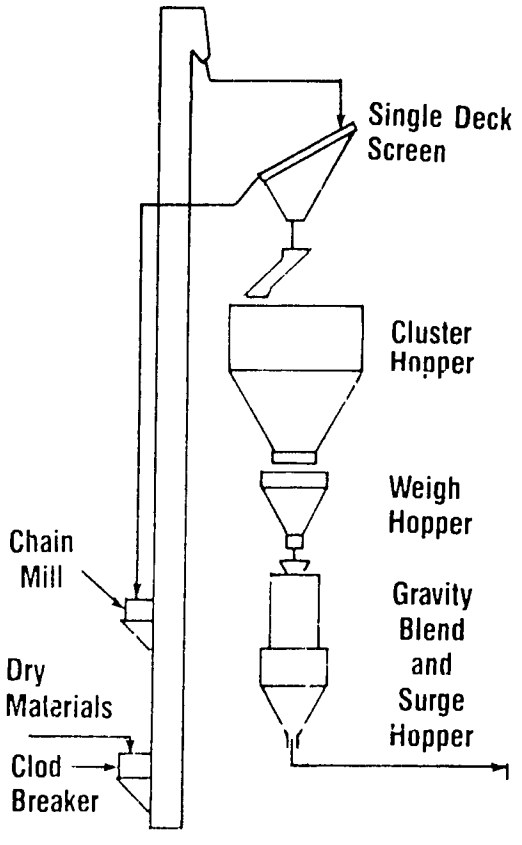


Figure 4. **Dry Raw Material Feed System.**

The material discharged from the batch-type weigh hopper can be passed through any one of a number of types of dry material blenders. However, most plants feel that the material handling equipment through the system and the granulator provide adequate mixing without this requirement. The material from the batch weighing system is normally collected in a surge hopper that is provided with a volumetric-type feeder to provide continuous flow to the granulating system. The material is usually fed to an elevator feeding the granulator. The recycle materials are commonly fed to the same elevator. This provides a comparatively uniform mixing of the new raw material feed and the recycle material before entering the granulator. This raw material feed system is comparatively simple and very functional; however, if the raw materials are not compatible for premixing in the dry state such as urea with ammonium nitrate or urea with normal superphosphate, separate material feed systems may be used as an alternate. Gravimetric-type feeders are recommended if independent feed systems are used for each raw material.

It is desirable to have raw material particle sizes smaller than the granular product size, or at least having the maximum size particles not larger than the smaller half of the product size range so finished product particles are comparatively homogeneous.

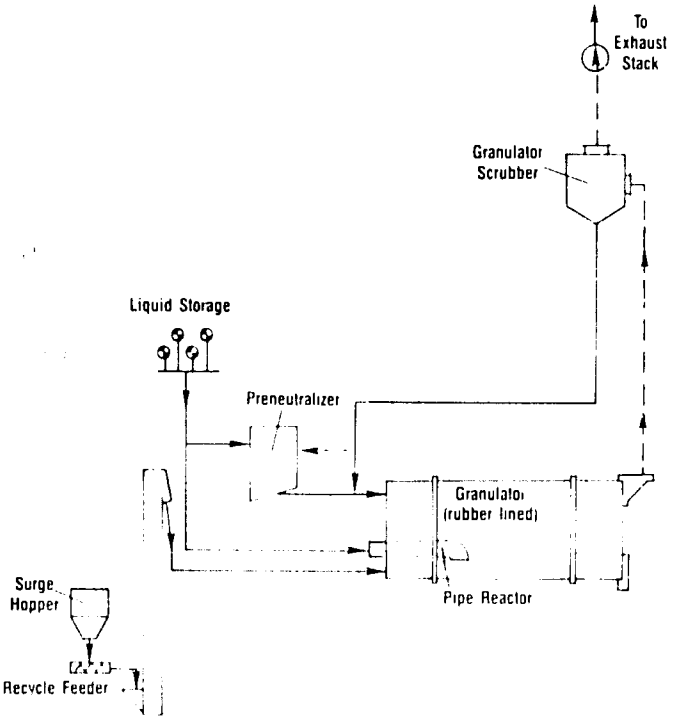


Figure 5. **Fluid Feed System for Ammoniation and Granulation.**

Fluids Feed, Ammoniation, and Granulation

Figure 5 shows fluid feed systems for ammoniation and granulation. It has been previously pointed out that the need for prereacting materials or the benefits of using a pipe reactor will depend upon the formulations and the reactions of the raw materials used. The primary reactions that take place are between ammonia and various acidic materials. The requirements or benefits for either

of these systems should be determined by a thorough survey of existing facilities followed by material balances, heat balances, and specific water balances for the entire system proposed. In feeding fluids to any of the system reactors, either the prereactor tanks, pipe reactors, or granulator, the use of automatic control valves rather than manual control valves is recommended. Precise control is required when a pipe reactor system is used. For metering fluids that have sufficient conductivity, it is recommended that a magnetic-type meter be used which has remote controls located on a panel in a control room. The magnetic meters should always be mounted in a vertical position regardless of the material handled. It is also very important to follow the supplier's installation instructions with respect to pipe sizes and straight portions to and from the meters and proper grounding to avoid electrical interferences. Although our company has tried various type meters to meter anhydrous ammonia, such as turbine, vortex meters, orifice plates, and positive displacement pumps, we recommend using the armored-type rotometer for NPK granulation plants. An ammonia precooler must be used if the ammonia is measured as a liquid. For simplicity of operation and maintenance, separate recorders and controllers for each fluid material are recommended. This simplifies operation for the operators and for maintenance.

Additional auxiliary equipment will be required if molten materials such as urea or ammonium nitrate are used or if steam-water granulation is required. Package boiler systems are commonly used to provide steam where raw material reactions are not adequate for good granulation and a steam source is not already available.

It is important to note that moisture is required for anhydrous ammonia to react with other raw materials. Therefore, proper positioning of equipment in which materials are fed to the granulators is required to minimize ammonia loss.

When prereactors are used, a variety of miscellaneous auxiliary equipment may be required to measure the mole ratio, pH, various temperatures, and pressures.

Although the TVA rotary-type granulator is most commonly used for production of NPK grades, other types of granulators such as double shaft paddle mixers, pan granulators, and pin-type granulators may be required for special variations in raw materials, especially if micronutrients are processed in combination with NPK grades.

After reactions and granulation are completed, most NPK materials must be dried, cooled, and sized.

Drying

Inasmuch as most NPK fertilizer materials are heat sensitive and contain bound moisture, rotary dryers having concurrent hot air and material flow as shown in Figure 8 are most commonly used. Fuel combustion chambers should be designed to adequately mix combustion gases and air so the air temperature entering the dryer does not become excessive. The material feed chute should be designed to avoid high heat impringement, to provide easy access for cleaning, and to have enough slope for material flow into the granulator (preferably 70° from horizontal). Because some of the material may be changing from a liquid to a solid phase as it flows down this chute, it normally becomes the most critical for functional design. Manufacturers are involved in properly designing the dryer to provide sufficient air, good air material contact, and adequate retention time to effectively and efficiently dry a variety of materials. Although, the control of heat to the system is predominantly controlled by the air discharging from the dryer, it is good practice to also sense the air temperature entering the dryer and the product material discharging from the dryer. If either of these becomes excessive, they should override the primary control center or at least give an alarm or indication of the abnormal condition.

Cooling

Rotary coolers having countercurrent air to material flow, as shown in Figure 6, are most commonly used for cooling fertilizer materials. Fluid-bed coolers are also used in limited applications or as supplemental equipment when only the screened product is cooled. Rotary coolers have more flexibility in cooling different rates of material throughput and materials having a range of particle sizes. Fluid-bed coolers are normally more efficient if the throughput rate is constant and the particle size is uniform. Ambient air is normally used for cooling; however, if the ambient temperatures are very high it is advisable to consider the use of a chiller. Chillers may also be advisable, or required, when cooling materials having comparatively low critical relative humidities.

Sizing

Screening of material can either be after drying and before cooling or after cooling. Here again, the nature of the raw materials used and the grade produced must be considered in determining the best locations for screening. If the materials granulate well and are not very humidity sensitive, screening can be done effectively as the material discharges from the dryer. Hot recycle can be returned to the granulator and the cooler size can be smaller. Additional screening may be required after cooling to provide a clean, refined product. If no screening is done between the drying and cooling, all of the material must be cooled.

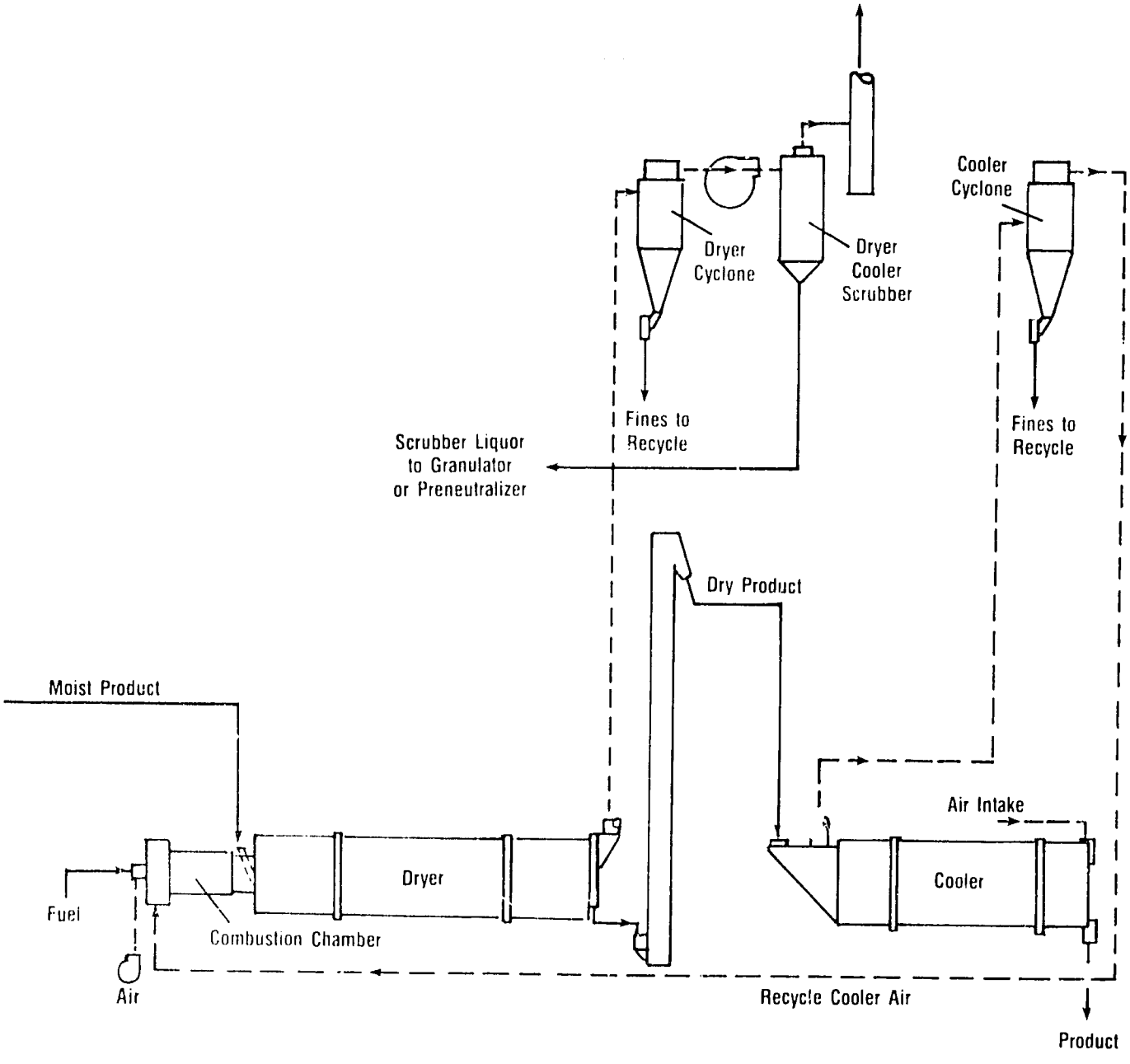


Figure 6. **Drying and Cooling Equipment.**

Some drying is normally done in the cooler; therefore, if oversize particles are large at times, soft wet material is minimized thus improving the crushing or grinding of oversized material. As some evaporation in the cooler takes place, it supplements the effective cooling.

Although the raw materials and grades produced should be reviewed in determining the best screening equipment and procedures, in most applications we have found it most favorable to use single-deck screens having reasonably fine cloths, located between the dryer and cooler so the majority of the fine material can be recycled as hot fines to the granulator and the product size and oversize material will pass through the cooler. After the cooler double-deck product screens will then have a lighter load and do more efficient screening, the cooler size does not have to be as large as all of the material passes through it, and the oversize material will have more retention time for drying prior to crushing.

A variety of screens will provide good screening efficiency provided they are not excessively loaded and are easily maintained. We have found the latest design Tyler Hummer screens to be most effective for screening raw materials and many of the product-type materials. For screening straight materials such as ammonium nitrate, or

urea, or if grades contain high quantities of either of these materials, the Rotex-type oscillating screens have been very serviceable and efficient.

Coating

Rotating drum-type equipment, as shown in Figure 7, is most commonly used for coating. The design and size may vary depending on the material being coated. Ribbon blenders are sometimes used for coating materials; however, attrition of material may be greater because of the increased friction areas. Number 2 diesel oil, aniline oil, diatomaceous earth, and sulfur have been the most commonly used coating agents. Inasmuch as the quantities of coating materials with respect to the product are generally very small, it is important that the coating equipment be well designed for maximum efficiency in providing very uniform distribution.

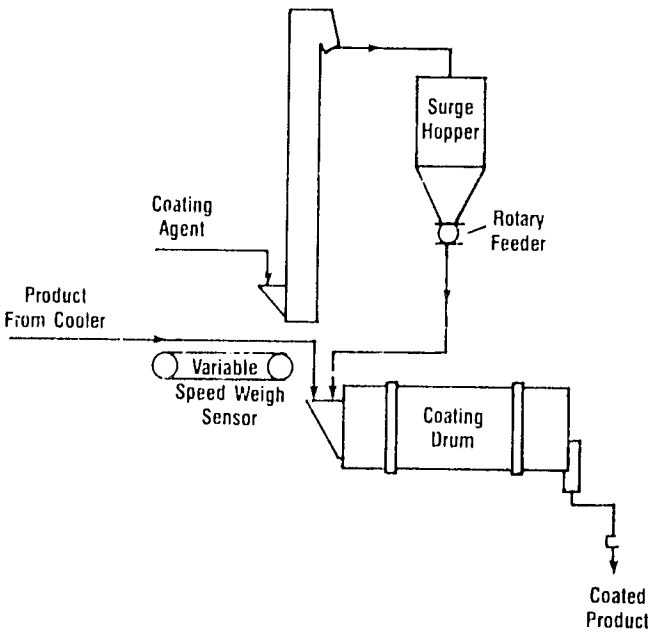
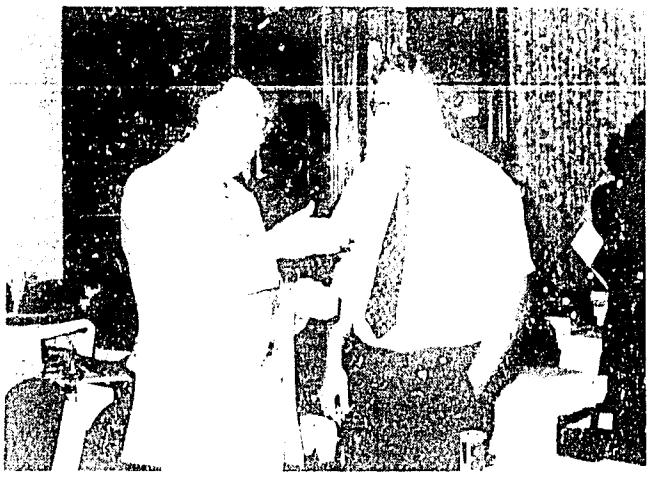


Figure 7. **System for Coating Granules.**

NPK Plant System

After all of the basic requirements of the plant are determined, it is recommended that the plant be designed with considerable flexibility, consideration for potential expansion, and potential addition of auxiliary equipment. As you can see, with the variety of complex considerations, it is strongly recommended that a thorough study be made by qualified and experienced consultants, or advisors, to determine the most appropriate changes and/or plant design selected.



Design of Granulators, Dryers, and Coolers

David Ivell, Senior Chemical Engineer, Norsk Hydro Licensing

Abstract

Two of the more important factors that affect the design of rotary drum granulators are the rotational speed and the product retention time. The speed should be fast enough to attain a good cascading action, yet below the "critical" speed at which the centrifugal force prevents any relative movement of the bed. The diameter, length, and slope affect the throughput and the retention time. Placement of the preneutralizer sprays and the ammonia spargers are also important. A formula that expresses the interrelation among these variables is given.

Design parameters for determining the size of the dryer required are: (1) residence time of the solids in the dryer, (2) percentage of dryer volume occupied by the solids, (3) air velocity, (4) rotational speed of the dryer, and (5) slope of the dryer. An equation that shows the relationship among these factors is given in this paper.

Normally, fertilizer products leave the dryer at temperatures of 75°-120°C. If the material is bagged or sent to storage at these temperatures caking will occur. This tendency to cake varies from grade to grade and with the type of raw materials used in the product. Usually, the product is cooled in flighted rotary drums designed very much like dryers.

Introduction

The bulk of the world's fertilizer is manufactured in the form of solid spherical granules generally having a size distribution of 1.5-4 mm. In the manufacturing process, powdered intermediates, melts, solutions, and slurries are converted into granules with physical properties which afford easy storage, distribution, and application.

Rotary drum granulation is an important process for the formation and shaping of these granules. This paper gives first a review of the techniques employed by Norsk Hydro Licensing (NHL) for the design of new rotary drum granulators.

The material discharged from the granulator is wet and soft and both drying and cooling are necessary to furnish a product of acceptable quality. Therefore, it is necessary to have a look in detail at these two unit operations.

The dryer reduces the moisture content of the granular fertilizer to a level which will allow storage of the product without significant caking. So the mechanism of drying will be examined and the important design parameters for rotary-drum-type dryers will be identified.

The requirements for cooling fertilizer will be investigated and the reasons why overcooling should be avoided will be explained. Rotary-drum and fluidized-bed units are two options for effecting the cooling. The similarities and differences between rotary coolers and rotary dryers are elaborated on and surging, a potential problem with rotary coolers, is discussed. The two types of fluidized-bed units are described and the relative performance reviewed.

Granulator Design

The granulator is a most critical item in the fertilizer manufacturing process. The mechanism of granulation is complex and the design work or granulators has proceeded largely through practical development work, although considerable rationalization of process design has occurred.

Design Parameters

Early development work established that operating speed and material retention time in a rotary granulator were important parameters in determining the granulation efficiency. These criteria are not only to obtain a good rolling action but, more important still, an ideal cascading motion. At very low speeds the bed of material slides from side to side and there is no opportunity for mixing (particularly of liquid feeds). Neither is there any opportunity for granule growth. As speed is increased a rolling bed is formed and conditions are very good for granule growth.

A further increase in speed produces a cascading plus rolling action. This produces an extremely turbulent zone where granulation takes place and sufficient shearing action is produced to break down oversize particles as they are formed. This does not occur until the operating speed reaches about 40% of the critical speed. The critical

speed is defined as the rotational speed at which the centrifugal force equals or exceeds the gravitational force and the material in the bed no longer rolls or slides. The effect of rotational speed is illustrated in Figure 1.

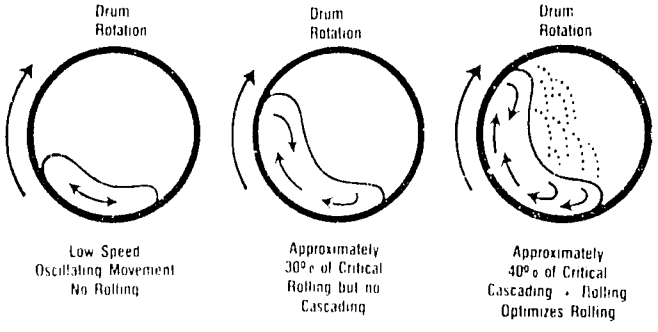


Figure 1. **Effect of Drum Rotational Speed on Granulation.**

When the rotational speed is optimum excellent distribution of the liquid phase is also obtained, especially if a fairly shallow bed is used. However, for grades that require fairly heavy ammoniation, such as urea-ammonium phosphate mixtures, a compromise has to be reached in order to minimize ammonia loss and an outlet weir is installed to create a deep bed.

There are three zones in the granulator:

1. Mixing region.
2. Wetting and partial granulation region.
3. Granulation and shaping region.

The mixing zone is short, typically about 1,200 mm, with the length being dictated primarily by the length of the internal pipework.

The wetting zone is that area in which the liquid phase is formed and a small amount of granulation occurs. The length of this zone is determined by the amount of liquid phase added that can be evenly distributed on the solids. In the NHL process for urea-ammonium phosphate (UAP), small quantities of sulfuric acid, ammonia, and steam are added as granulation aids. For this type of process the wetting region is typically 3 m long for a 1,250-mtpd plant.

Particle rolling distance is the most important variable that can be identified in determining the length of the granulation zone. At a fixed drum loading and speed, rolling distance is proportional to residence time. Residence time in the drum is principally fixed by kiln action which, with suitable adjustment for the effect of the outlet weir, can be represented by the equation:

$$t = \frac{L\,(X + 23)}{NDS}$$

Where L = Length
X = Angle of repose
N = Speed
D = Diameter
S = Slope

Having specified the rotating speed and required residence time in the granulator, there are a number of possible, though restricted, length and diameter relationships which can be used to give the required conveying capacity. The approach is largely dictated by practical experience. The plant throughput determines the diameter and this is used to calculate the drum length and slope.

For high recycle plants where most of the raw materials are fed to the granulator in the form of solutions or slurries, an exhaust fan is necessary.

In such plants large amounts of heat are added to the granulator (for example, hot fines, slurry, and chemical heat of reaction). This heat is utilized in two ways; part of it goes to heating the cooler materials and part to evaporating moisture.

In order to remove the evaporated moisture and also the unreacted ammonia, air is drawn through the granulator and an ammonia recovery system. Within limits, increasing the airflow will increase evaporation and thus reduce the recycle ratio. In practice the velocity of air through the granulator is generally limited to around 1.5 m/s to limit the amount of dust entrained in the airstream.

For low recycle solids-based plants, such as the NHL UAP process, ammonia loss and moisture evaporation are very low, so the granulator can simply be vented by natural convection eliminating the need for an exhaust fan.

Granulator Internals

The relative positioning of sparger pipes is extremely important; the optimum positions have been determined by practice and are indicated on Figure 2.

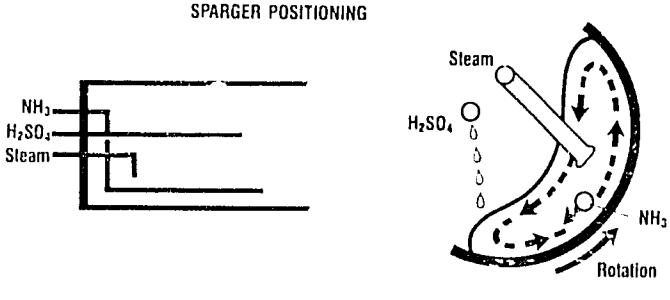


Figure 2. **Location of Granulator Internals.**

For ammonia addition NHL uses a drilled pipe sparger placed beneath the bed of solids within the granulator. The sparger is positioned so that the holes face the oncoming stream of solids for minimum ammonia loss.

The ammonia sparger is normally slightly longer than the sulfuric acid addition zone (and the slurry zone, where applicable) to allow adequate ammoniation time. It has been found in practice that the pipe diameter and thickness (schedule) are determined by mechanical strength requirements rather than any other factor.

Sulfuric acid is also added through a drilled pipe sparger although in this case the sparger is suspended above the rolling bed.

Steam is added through a steam "shoe" which normally consists of an armored rubber hose with the flattened end extending just beneath the bed of solids.

An important consideration in the design of the granulator is the avoidance of and/or removal of buildup. In this respect the sparger support structure is very important because it is a potential buildup point. Hence, the number and size of supports is a compromise between the mechanical strength required and the potential for material buildup.

There are three methods by which buildup in the granulator can be controlled:

1. Scrapers.
2. External hammers.
3. Rubber paneling.

Scrapers can be of the fixed, reciprocating, or rotary type. NHL experience with these devices has been poor and their use has been discontinued. The major problem is one of mechanical reliability although they can cause process problems because their position within the drum encourages buildup.

Pneumatic and mechanical hammers offer a practical alternative but suffer from the disadvantage of noise and a relatively high maintenance requirement.

NHL current practice is to install rubber paneling for cleaning purposes. The principle of operation is that each panel flexes during rotation thus releasing any attached buildup. The quality of the rubber, in terms both of flexing properties and chemical and thermal resistance, is of great importance. Over the last 10 years the use of this method has proved to be very effective.

Summary

The diameter of the granulator is fixed empirically and depends on throughput. A speed of 40% of the critical speed is used to give a good cascading/rolling action. Material movement is by kiln action and the length and slope are determined by the required rolling distance. The size of the exhaust fan for high recycle grades is determined by the required rate of moisture evaporation.

Positioning of sprays and spargers is important. From a practical point of view, buildup inside the granulator is a problem and so the sparger support and the cleaning mechanism are also important.

Design of Rotary Dryers

The dryer is the largest single cost item in a granulation plant and it is therefore the designer's intention to minimize the cost without prejudicing its performance. The present NHL method for design is based upon known performance of existing equipment together with certain empirical/theoretical relationships.

The main object in the drying operation is obviously to obtain a product having a final moisture content that does not exceed a specified maximum. The basic design is therefore a problem in the simultaneous transfer of heat and mass.

Mechanism of Drying

There are two types of drying:

1. Constant-rate drying.
2. Falling-rate drying.

Constant-rate drying occurs when there is a film of water present. Here the rate of evaporation from the surface depends on the temperature and the moisture content of the air in contact with it. For constant air conditions therefore, the drying rate is constant.

Falling-rate drying occurs when there is no water film present and moisture has to diffuse from inside the solid, through the pores, to the surface. As the solids get drier the moisture has to come from deeper within the granule hence the drying rate falls.

With soluble fertilizer salts an additional barrier is present; the pores through which the moisture diffuses become blocked with crystal deposits, thus slowing down the drying rate even further.

The drying of UAP fertilizer produced by the low recycle solids route occurs mainly in the falling-rate period. While some surface moisture does exist on the material discharged from the granulator, it is removed so rapidly that it need not be considered in this discussion.

Thus, the drying rate can be expressed by an equation of the form:

$$\frac{d\,(H_2O)}{dt} = K\,(H_2O)^x\,(T)^y$$

Where t = Time
T = Solids temperature
K,x,y = Constants

Naturally, in order to reduce the residence time required it is desirable to operate with as high a solids temperature as is practical. Fertilizer containing high quantities of urea, particularly where potash is present, has a very low melting point and the drying temperature is therefore restricted to avoid buildup of solids in the dryer. Close control of dryer air temperature is therefore necessary so that the temperature can be maintained as high as possible while at the same time avoiding temperatures in the melting region. In practice, solids temperatures in the range 70°-80°C are generally used in UAP dryers.

The drying curves represented by the equation above are determined experimentally in the NHL research laboratories. The derived expression can be used to determine the required residence time for each grade. Typically residence times required for a low-recycle UAP grade would be in the range of 10-20 minutes.

Design Parameters

The design parameters used to obtain the major dryer dimensions are:

1. Residence time of solids in the dryer.
2. Holdup; that is the percentage of the dryer volume occupied by solids.
3. Air velocity.
4. Speed of rotation.
5. Slope of the dryer.

The parameter which determines the dryer diameter is the air flowrate, which can be obtained from a heat and material balance. Too great an airflow would result in too great a carryover of solid material. The maximum permissible air velocity is fixed at 4 m/s and usually falls in the range 2-4 m/s.

Having fixed the diameter of the dryer the determination of the length depends on the residence time required.

Dryers are designed for a relatively high holdup of 18% to minimize the size of the dryer. The flights are designed for 15% to give a small rolling bed. At this level, the flight carrying capacity is considered a maximum. A higher holdup would necessitate over-large flights that would occupy too much of the drum cross sectional area and leave insufficient area available for cascading.

The single most important factor affecting the rate of drying is the granule temperature. It is therefore highly desirable to heat the granules up quickly to their drying temperature and keep them there. In order to do this each granule should have as much of its total surface area exposed as possible, for as long as possible, to the hot air. This is achieved by having a high cascading rate. The cascade rate is maximized by careful flight design and the correct choice of the drum diameter, speed, and slope.

For optimum cascading the speed of rotation should be in the range 15%-25% of the critical speed, though careful flight design allows speeds as low as 10% of the critical to give a nearly perfect curtain.

The slope of the dryer is determined by the required conveying capacity. There are two mechanisms whereby material moves along the dryer - flight action and kiln action.

With flight action the material is lifted in the flight and in so doing is moved forward, the extent depending upon the slope of the dryer. When it is discharged the airflow deflects it further forward again. The magnitude of this deflection depends on air velocity.

The equation put forward by Seaman and Mitchell holds sufficiently well for design purposes:

$$T = \frac{L}{f(H)\,ND\,(S + MV)}$$

Where T = Residence time, min
L = Length, m
N = Speed, rpm
D = Diameter, m
S = Slope, m/m
V = Air velocity, m/sec
f(H) = Factor based on drum holdup
M = Constant sec/m

The equation shows that transport due to the slope of the drum and the air velocity are independent variables.

As the drier temperature controls work by altering airflow, it is good practice to ensure that the term due to air velocity is not too much greater than the term due to the slope. This is to prevent surging.

Because the flights are sized for a slightly smaller holdup of material than the dryer is actually sized for, there is also a certain amount of movement by kiln action as a small rolling bed is formed. The kiln equation mentioned in the design parameters for granulators adequately predicts that movement.

Dryer Internals

The ideal shape for a flight, one that will give a completely uniform distribution of material across the drum, is semicircular. However, this flight profile is difficult to manufacture and in practice is difficult to keep clean. The best compromise is that having a straight radial section and lip length set at an angle, as illustrated in Figure 3.

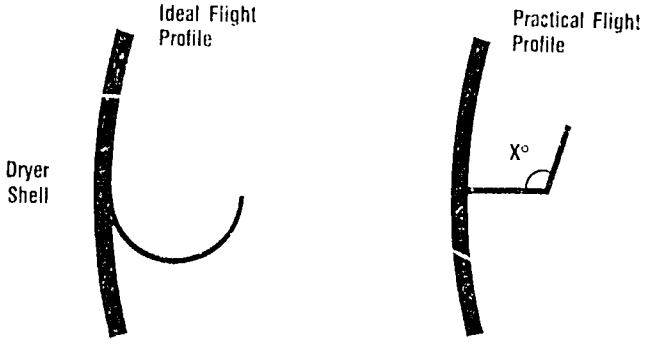


Figure 3. **Profiles of Drier Flights.**

The number of flights, the sizing of the radial and lip sections, as well as the angle between them must be carefully determined if good cascading is to be achieved. NHL uses small-scale laboratory experiments to ensure that the optimum flight design is achieved for the required drum holdup and speed.

To minimize material buildup on the flights while the granules are in the "plastic" region, NHL practice is to specify only half as many flights in the first half of the dryer as in the second half.

It is also important that all feed material get well into the dryer to prevent backspill. The inlet chute is a potential source of blockage so both the slope and cleaning facilities should be properly designed. The scrolls at the inlet of the dryer are considered an extension of the chute and material slides down the scrolls as they rotate throwing material well into the drum.

Summary

The dryer is the most expensive item in a granulation plant and it is therefore very important that the design be optimized. Drying curves can be determined experimentally and residence times predicted. The diameter is determined by the airflow required. The speed of rotation fixes the cascade pattern. Material movement is mainly by flight action. The slope and length of the drum are therefore determined from the required residence time. It is very important to get good cascading action in order to obtain good contact between the hot air and the solids.

Design and Selection of Cooling Equipment

Before detailing the design of coolers, it seems appropriate to ask the question, "Why is it necessary to cool?"

After the drying stage, granule temperatures typically range from 75° to 120°C (75°-80°C for UAP grades). If the product was sent to storage at these temperatures, there would almost certainly be caking problems due to "heat set." The causes of "heat set" can be attributed to the following:

1. At the high temperatures in question, the granules are quite plastic. When subjected to the pressures encountered in fertilizer heaps, the granules tend to flatten slightly allowing a greater area of surface contact. Caking results.

2. As fertilizer is cooled, its solubility decreases. Crystallization occurs in some of the residual moisture. If this takes place in the heap, crystal bridges between granules are formed and again caking results.

3. If fertilizer is put in storage hot, drying will continue; the granules will "sweat." As the granules cool, the humidity of the air trapped in the heap will increase until condensation takes place at the granule surface, and again caking results.

The degree to which these tendencies are exhibited varies from grade to grade. For instance, granular MAP and granular TSP suffer less from these problems than urea-based grades.

With ammonium nitrate/superphosphate based grades, safety is also a major consideration. Self heating is possible in heaps of fertilizer. The main cause is the oxidizing action of the nitrate on the organic matter present in the superphosphate. In acidic conditions this reaction will proceed. The tendency for this reaction to proceed is affected quite appreciably by temperature.

Care must be taken, however, not to over-cool the fertilizer. Although problems of heat set (and safety in ammonium nitrate grades) decrease as the temperature decreases, the moisture pickup tendency increases.

At a given temperature and moisture content the fertilizer will have a particular water vapor pressure. Similarly, at a given temperature and relative humidity,

the atmosphere will have a particular water vapor pressure. If the vapor pressure of the fertilizer is less than that of the atmosphere, the fertilizer will pick up moisture in an attempt to reach equilibrium. A fertilizer put in storage at temperatures very close to ambient temperature will soon reach equilibrium. A fertilizer stored at relatively high temperatures may, in practice, never reach equilibrium before being bagged.

It is recommended that the heap temperature should be kept at least 10°-15°C above ambient temperature. Therefore, the temperature of the product sent to storage is a compromise. Deviation too far either way from the optimum for any particular grade can result in caking problems.

If it is planned to store the product in bulk for a long period of time, the normal practice would be to minimize the air changes within the storage building and cover the heap with plastic sheeting to prevent contact with the surrounding air. The alternative is air conditioning which is expensive.

Traditionally, cooling has been carried out in flighted rotary drums with a countercurrent flow of air. The design of these drums follows the dryer design very closely. Fluidized bed coolers have begun to gain in popularity as an alternative means of cooling and these will also be discussed.

Design of Rotary Coolers

Design Parameters–Again the parameter which determines the drum diameter is the airflow rate, which can be obtained from a heat and material balance. The maximum airflow acceptable is dependent upon the slope of the drum. Since the cooler is countercurrent the material moves along the drum as a net result of the forward action of the slope and the retarding action of the airflow. The same equation for material movement in dryers applies to coolers except that the airflow retards the movement of particles as represented by the modified Saemen and Mitchell equation described earlier:

$$T = \frac{L}{f(H)\ ND\ (S\text{-}MV)}$$

Too great an air velocity therefore will result in the excessive carryover of fine particles and necessitate very large slopes in order to keep the material holdup down to reasonable values. As with dryers, the cooler is designed for an 18% holdup with the flights designed for 15%.

Several factors affect the choice of rotational speed. Within limits, as the speed increases, so also does the cascade rate which in turn determines the overall heat-transfer coefficient. This therefore affects the cooling efficiency, and the length of cooler required decreases according to the equation:

$$Q = U_a\ \Delta T_{lm}\ L$$

Where Q = Heat removed from the solids
U_a = Overall heat-transfer coefficient
ΔT_{lm} = Log mean temperature difference
L = Length of the cooler

However, high speeds lead to shallow slopes in order to maintain the required holdup. As explained previously shallow slopes lead to low air velocities which means large diameter coolers. In practice, slopes of less than 2 degrees and more than 4 degrees are avoided.

Another consideration is the ratio of granule cooling time to "soaking" time. During each cascade the surface of the granules cools to a temperature below that of the bulk material. During the time the granule resides in the flights between each cascade, heat flows outwards from the center to redistribute the temperature throughout the granule. It is clearly important therefore to allow the granules the optimum time to complete this redistribution of heat. Because the temperature difference between solids and air changes along the drum length, the optimum retention time will also vary. However, on average it has been found that a rotational speed of about 18% of the critical speed is the best compromise.

Cooler Internals–The same principle in flight design used for dryers is applied to coolers. The aim is still to maximize the number of curtains across the drum cross section; this is achieved by maximizing the number of flights. There is though a practical limit placed on the gap between adjacent flights; this should be a minimum of 80-100 mm to allow lumps to leave the flights. The actual flight profile employed is shown in Figure 4.

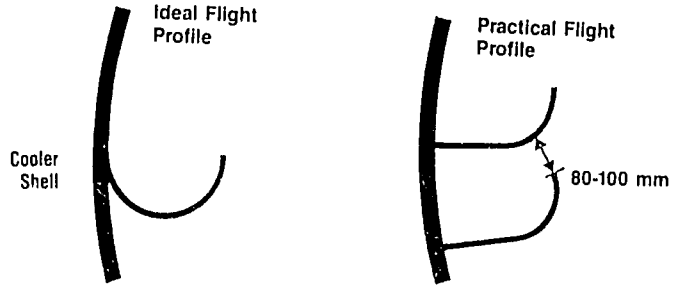


Figure 4. **Profiles of Cooler Flights.**

The solids handling duty is much less severe in the cooler than in the drier; buildup is also much less of a problem since the material is dry and free flowing. The flight profile can therefore approach the ideal semicircular shape. However, this is expensive to fabricate and a practical compromise is made.

Because the cooler must be designed for a range of ambient temperatures and a range of different products, lower-than-design airflows are sometimes used to prevent overcooling.

Low airflows lead to low holdups and if the flights are not full, surging may occur. The following techniques are used by NHL to reduce this problem:

1. The cooling load is never overstated.

2. The flights are designed for 15% holdup while the drum is designed for 18% fill under design conditions.

3. Intermediate weir rings are provided.

Summary—The cooler design is quite similar to that of the dryer except that the airflow is countercurrent. The diameter is determined by the airflow. There is an optimum rotational speed at which the granule temperature gradients have time to even out and good cascading can be obtained. The heat-transfer coefficient is proportional to speed and this determines the length of the cooler. Material movement is mainly by flight action and the slope determines the percentage fill of the drum.

Flight design is as important for coolers as for dryers but can approach the ideal more closely because the material in the cooler is free flowing. Surging can be a problem because of the range of operating conditions but intermediate weirs, correct flight design, and close adherence to the design duty can minimize this problem.

Fluidized-Bed Coolers

Fluidized-bed coolers, as an alternative to rotary coolers, have been growing in popularity. This is mainly due to their small physical size and lower capital cost.

Principle of Operation—Blowing air up through a granular product causes it to lift. When a certain velocity has been reached, the product begins to behave as a liquid. This velocity is known as the fluidization velocity and the relationship is shown in Figure 5.

As the velocity is gradually increased the product will eventually start to "bubble" or "boil."

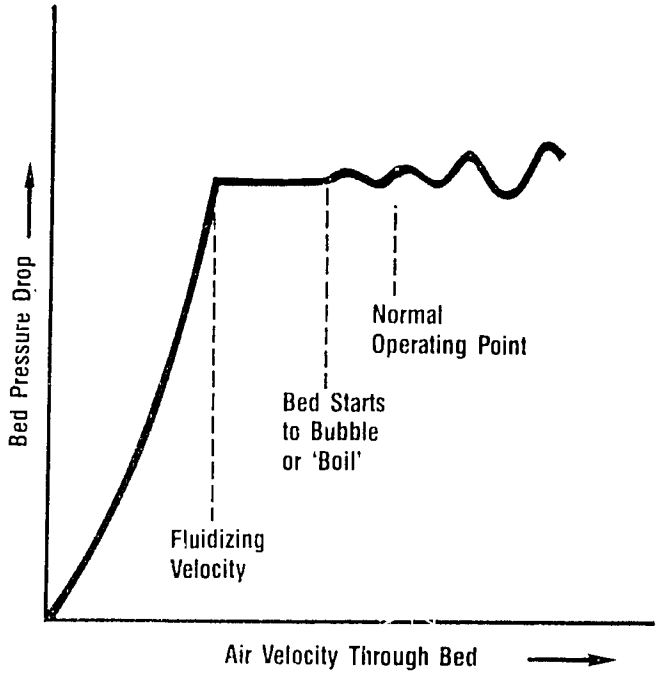


Figure 5. **Relationship Between Air Velocity, Pressure Drop, and Suspension of Particles in a Fluidized-Bed Cooler.**

When the fluidized state is reached, particularly in this boiling region, there is an excellent air-to-product contact, each particle being supported individually in the air stream. The fluid bed thus provides an almost ideal heat exchange between air and product.

Equipment Types—Fluidized bed coolers can be divided into two categories:

1. Static deck machines.
2. Vibrating deck machines.

The static deck cooler relies purely on the fluidizing air to transport the material along the cooler. Vibrating deck coolers can, however, transport the material with negligible airflow. The latter arrangement obviously has a much greater flexibility and turn down, and is more easily able to avoid overcooling.

With grades containing high proportions of urea overcooling can present difficulties because of moisture pickup. Several other techniques are available to prevent overcooling:

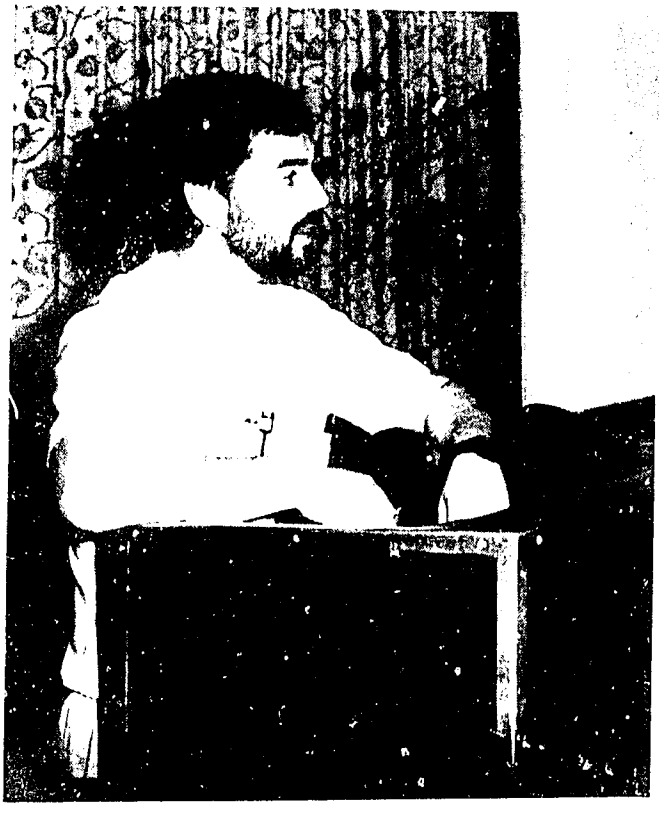
1. Installing a heater in the air inlet stream.
2. Recycling either the heat from the exhaust stream or the exhaust stream itself.

A small heater is generally provided to keep the material warm in case of plant shutdown.

The main disadvantage that fluidized beds have, compared with rotary coolers, is the restricted size range of material that can be handled. Fluidization velocity is, of course, related to particle size. For example, the air velocity required to fluidize a 3-mm particle would entrain a 0.5-mm particle in the air stream.

In general, therefore, the use of fluidized beds is restricted to handling product-sized material only. By careful design, however, it is possible to extend their use to combined oversize and product streams provided the larger lumps are removed.

Summary–Fluidized-bed coolers can offer an attractive alternative to rotary coolers for certain duties. In the fluidized state, heat transfer is very efficient. Static deck and vibrating deck machines are available; the latter is more flexible. Care has to be taken to prevent overcooling especially with high urea grades. Use of fluidized beds is generally restricted to a fairly narrow size range of material.



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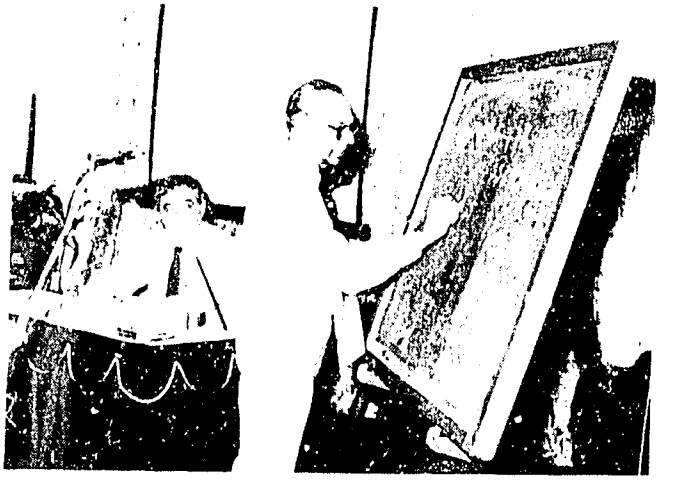


Design Considerations for Nigeria's New Urea-Based NPK Plant

D. W. Leyshon, Technical Director, Jacobs Engineering Group, Inc.

Abstract

The Jacobs Engineering Group of Lakeland, Florida, designed an "ultra high-analysis" granular NPK fertilizer plant based on the use of urea and DAP. A 1,000-tpd plant using this technology began operation in February 1988 at Port Harcourt, Nigeria. The process uses DAP, urea, and potash to produce the highest nutrient grades of NPK possible without involving polyphosphates. The equipment used is essentially a combination of the conventional preneutralizer and a TVA drum granulator. DAP and 15-15-15 have been successfully produced, but the plant is also designed for 19-19-19, 35-17-0, and 28-28-0 as well as several other grades including MAP-based products.

Introduction

The Jacobs Engineering process, as installed in Nigeria, is a modified DAP process of relatively conventional configuration. Typical flowsheets for the process are given as Figures 1 through 4. The plant can make DAP or NPK grades in the conventional preneutralizer-TVA drum granulation mode or by using a pipe reactor. Operating conditions are modified to produce urea NPK grades, which have a very low melting point and are highly hygroscopic, having critical relative humidities in the 45% to 50% range.

Process Description

The raw materials handling system is shown in Figure 1. The raw materials bulk storage area should be located so that it is convenient to the granulation plant. This minimizes the size of hoppers required in the granulation building itself where space is limited and where extraction problems should be avoided.

In the NAFCON project, imported 52%-54% P_2O_5 merchant-grade acid is used. The K_2O is obtained from standard grade potash. Because a market in Nigeria had already been established for 15-15-15, the need for this

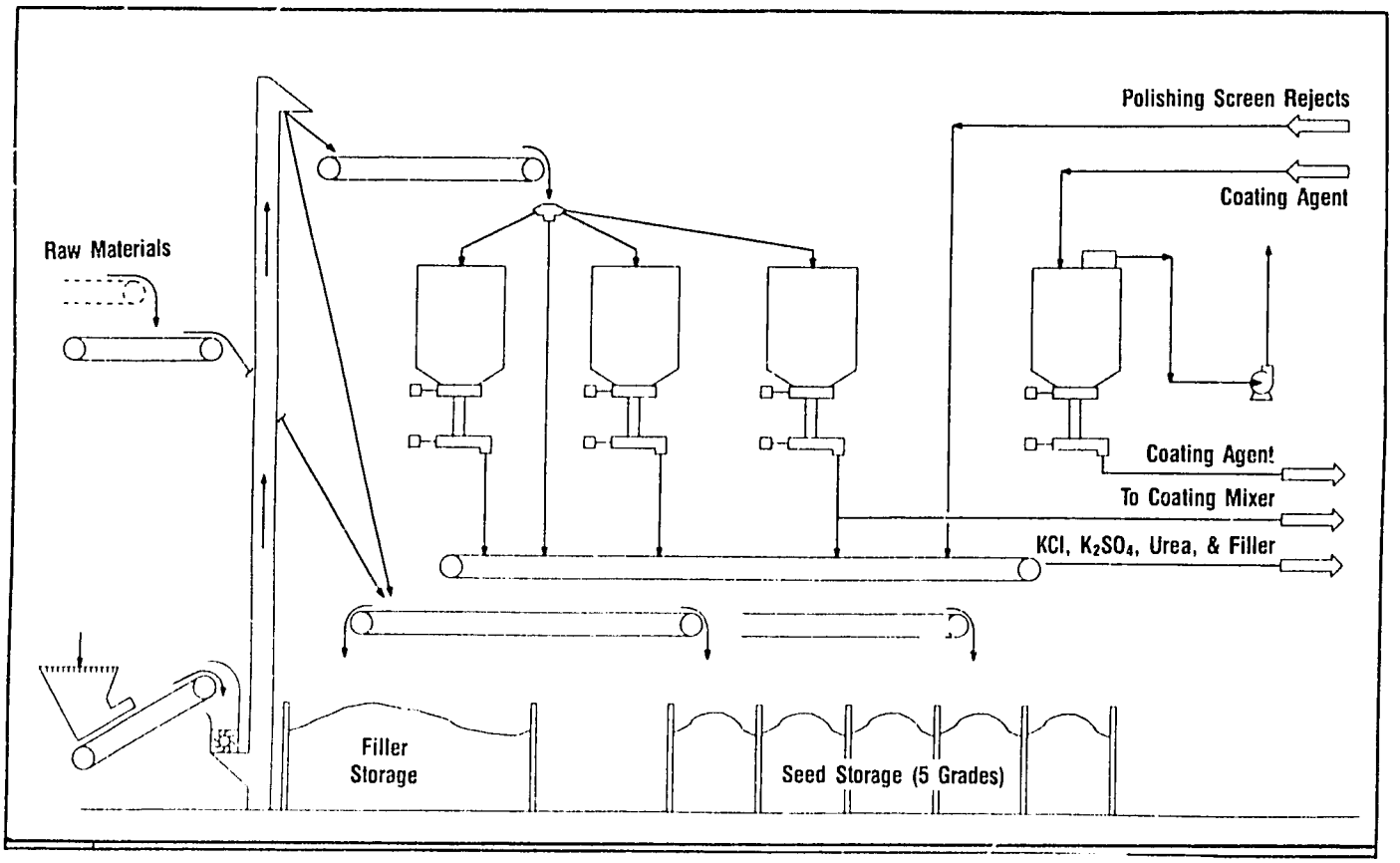


Figure 1. Typical Jacobs Raw Materials Handling – Ultra-High Urea/NPK Grades.

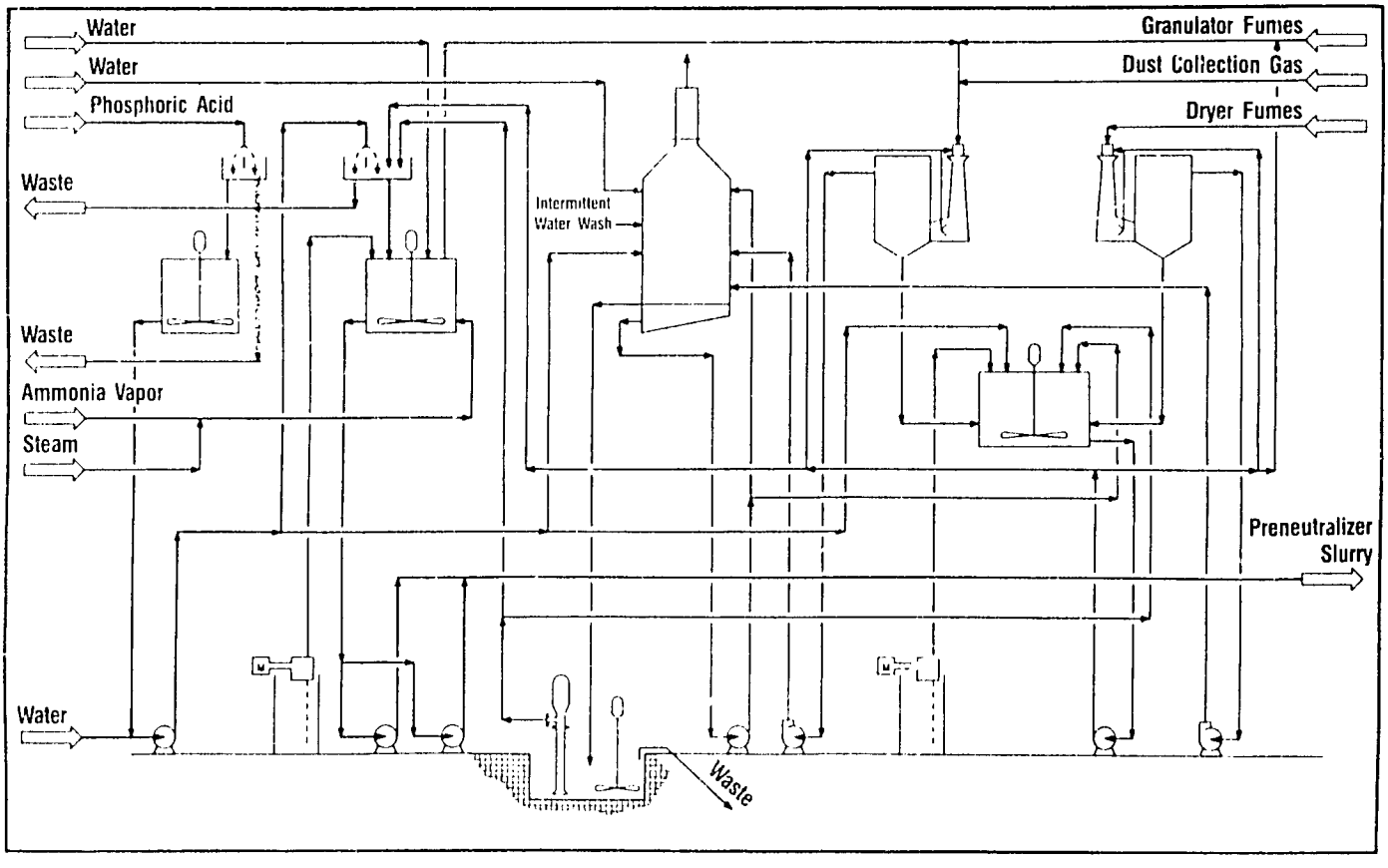


Figure 2. **Typical Jacobs Wet Section – Ultra-High Urea/NPK Grades.**

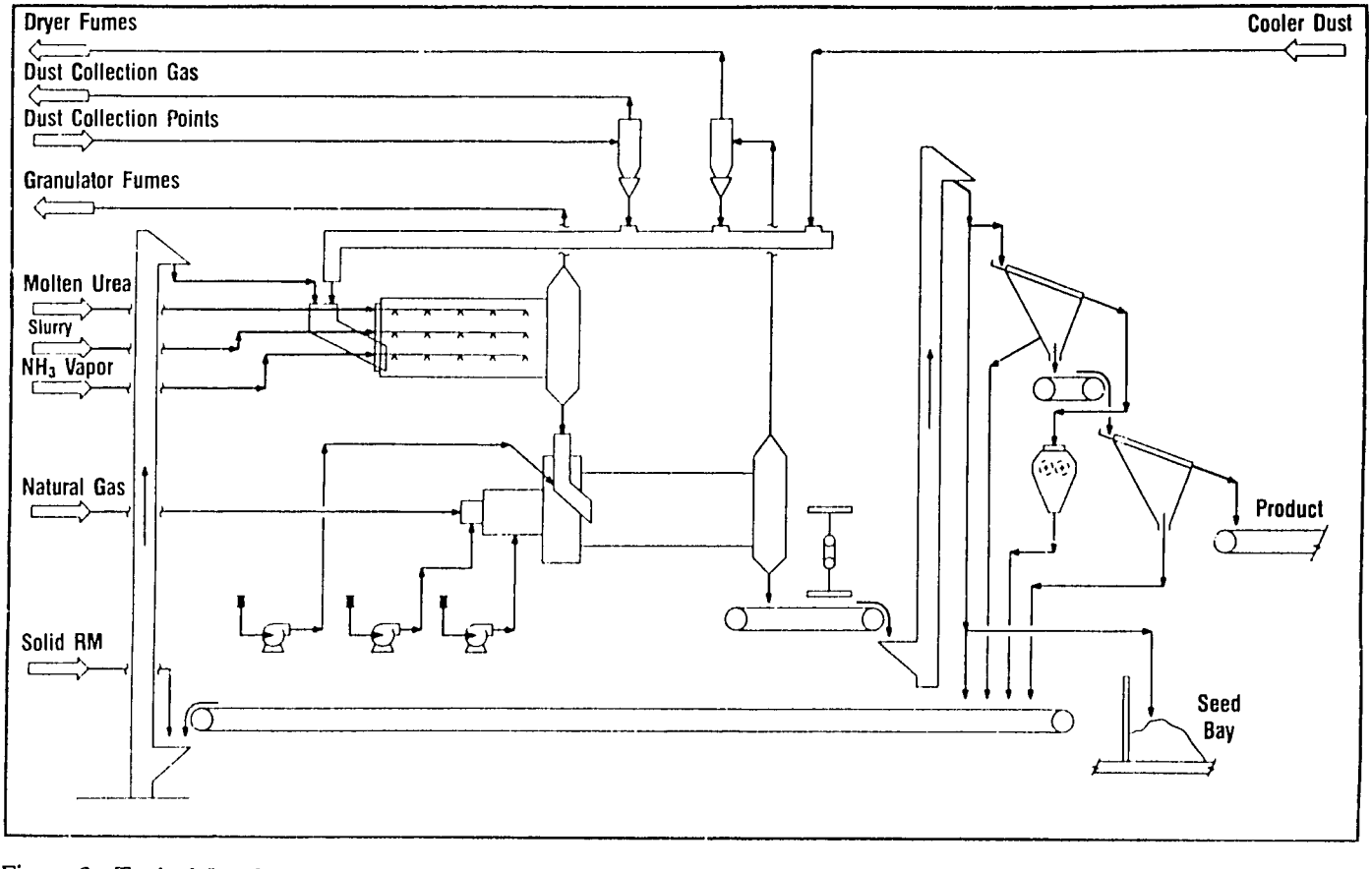


Figure 3. **Typical Jacobs Granulation Loop – Ultra-High Urea/NPK Grades.**

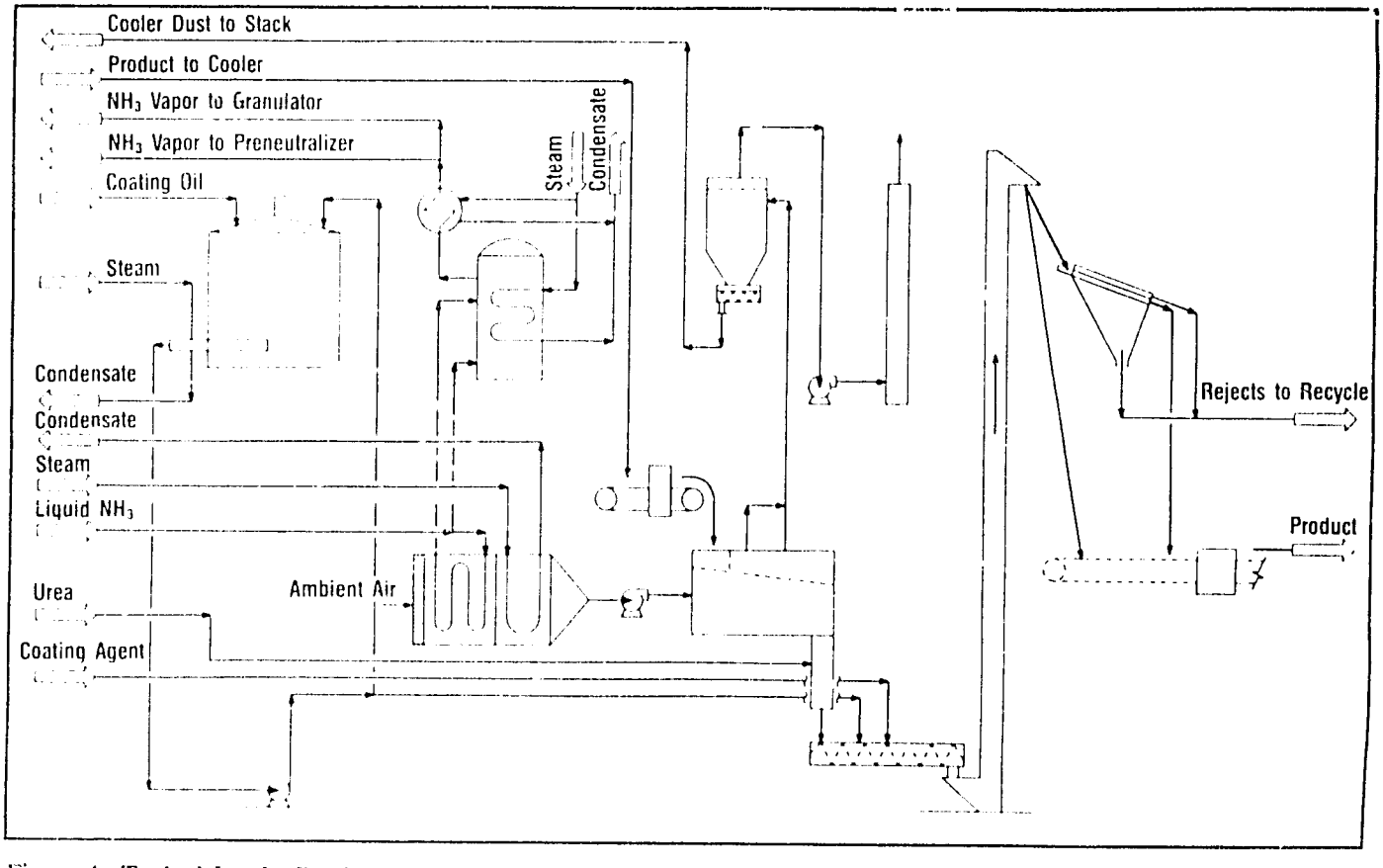


Figure 4. **Typical Jacobs Product Handling – Ultra-High Urea/NPK Grades.**

product dictated the initial NPK grade to be made. This required the use of a locally available, relatively coarse sand which comprised about 25% of the formula. While a finer filler would have improved granulation, the major problem caused by the coarse sand was the presence of river gravel which jammed the feeder.

The plant is set up to process urea as a melt or in solid form, but initially the feed was hardened granular urea, slightly smaller in size than the NPK product. This was fed, unground, to the recycle loop.

Liquid ammonia is fed to the plant and vaporized in a chiller provided for cooling the air used in the product cooler. Steam is available as a trim, but since ambient temperatures in Nigeria are high, steam consumption is low. The air chiller system is shown in Figure 4. The ammonia vapor is then used in the preneutralizer (Figure 2) and in the granulator sparger and pipe reactor (Figure 3).

Fresh water make-up is introduced in the tailgas scrubber (Figure 2) and advanced to the primary venturi scrubbers where part or all of the feed acid is added. The scrubber solution is then sent to the preneutralizer where the remaining feed acid can be added.

The slurry at about 120°C to 122°C is pumped to the granulator. Use of the pipe reactor is optional for either DAP or MAP formulations.

The slurry is distributed in the granulator by means of a few large nozzles. The granulator disperses this slurry over the recycle as a thin film which facilitates drying. Sparged gaseous ammonia provides a temperature boost in the granulator. Recycle rates for the NPK products are from 2.5:1.0 to 4.0:1.0.

The slurry coated solids are fed to a cocurrent dryer, where relatively low-temperature hot gas from the combustion chamber is drawn through by a combination of a push from the quench air fan and a pull by the dryer exhaust fan. Inlet gas temperatures are controlled according to the melting point of the particular grade.

Gas leaving the dryer is drawn to the dryer first stage scrubber, a venturi cyclonic scrubber, through a large rectangular duct shown in Figure 5, which is a view of the entire NAFCON granulation plant. The gases are finally scrubbed in the tailgas scrubber with recycled process water make up. This is a rectangular shaped packed scrubber located under the stack.

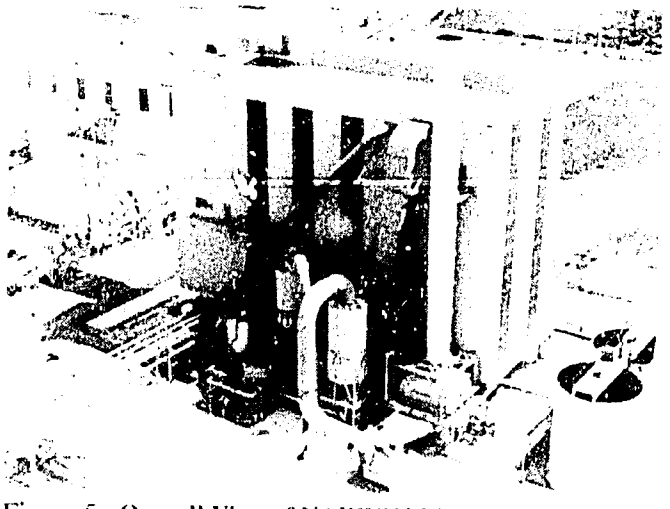


Figure 5. **Overall View of NAFCON Plant.**

The solids leaving the dryer pass through a lump grizzly which lifts and breaks any large lumps before they reach the screens. The screening is done, first on two single-deck oversize screens, where all the recycle is screened. The mixture of fines and product sized material is then metered with variable-speed belt feeders to the product screens at a rate matched to the desired product takeout.

The product size (-4.0 mm +1.0 mm) material is cooled in a fluid-bed cooler. The cooler operates with chilled air that has been reheated by a steam coil so that the relative humidity is low enough to prevent moisture absorption on the product granule surface.

Off gases from the cooler go to a bag collector which is equipped within an electric heating system so that it will stay dry at all times. The gases from the bag collector go to a separate stack.

After they are cooled the solids are sprayed with coating oil and then coated with a coating clay. The cooled and coated product is then given a final polishing screening before the material is sent to bulk storage.

Process Features

Some of the features of the Jacobs' process are listed below.

Formulations Containing Maximum Plant Food

Typical formulations which can be produced are shown in Tables 1 and 2. These materials need careful handling under controlled humidity conditions prior to bagging.

The plant uses urea for making NPK grades and also for grade adjustment of DAP. The plant does not have H_2SO_4 available.

Table 1. **High Urea-28-28-0 Formulations**

	N	P_2O_5	Composition (%)
18.7-50.1 (1.9 mole ratio, pH 7.65)[a]	10.56	28.28	56.45
Urea	17.72		38.53
H_2O, clay/oil conditioner			2.30
Filler			2.72
	28.28	28.28	100.00
14.6-53.3 (1.4 mole ratio, pH 6.6)[a]	7.75	28.28	53.06
Urea	20.53		44.64
H_2O, clay/oil conditioner			2.30
	28.28	28.28	100.00

a. 64.8% P_2O_5 in anhydrous acid.

Table 2. **High Urea Formulations (1.9 Mole Ratio)**

	N	P_2O_5	K_2O	Composition (%)
	19-19-19			
18.7-50.1 (1.9 mole ratio)	7.16	19.19		38.30
Urea	12.03			26.15
KCl 60			19.19	31.98
Moisture, clay/oil conditioner				2.30
Filler				1.27
	19.19	19.19	19.19	100.00
	35-17-0			
18.7-50.1 (1.9 mole ratio)	6.41	17.17		34.27
Urea	28.94			62.92
Moisture, clay/oil conditioner				2.30
Filler				0.51
	35.35	17.17		100.00
	DAP			
18.7-50.1 (1.9 mole ratio)	17.34	46.46		92.73
Urea	.84			1.83
Moisture, clay/oil conditioner				2.30
Filler				3.14
	18.18	46.46		100.00

Use of Gaseous Ammonia

The plant utilizes gaseous ammonia for all ammoniation and this results in several advantages. The ammonia vaporization is used to chill the cooling air making the cooler more efficient while using less air. Gaseous ammonia has a higher heat of reaction which causes more evaporation in the granulator and counters the chilling effect of the urea as it dissolves. Using gaseous ammonia

in the preneutralizer as well, instead of liquid ammonia, allows more water to be used in the scrubbing system.

Efficient Screening System

Single deck screens permit easier screen cleaning and maintenance. The product screens are not required to screen all the recycle and therefore are more efficient. In addition, a second stage polishing screen is provided. Since the grades produced are soft and hygroscopic, screening on single decks is particularly helpful.

Special Fines Conveyor

A specially designed, slow-speed, wide belt conveyor is used to convey fines. Many plants have used drag flight conveyors in this service. Drag flights have frequently involved very high maintenance and, in the operation on these grades, are difficult to empty thoroughly when the plant is down or shifts grades. The specially designed conveyor used here has a special enclosure and sealing arrangement that works very well in processing DAP or the urea-NPK grades.

Two-Speed Dryer

The plant utilizes a two-speed dryer to provide adequate detention for the NPK products and conversely to provide the throughput required for high rates on DAP. Table 3 shows the rates possible for plants convertible between urea-NPKs, DAP, and TSP.

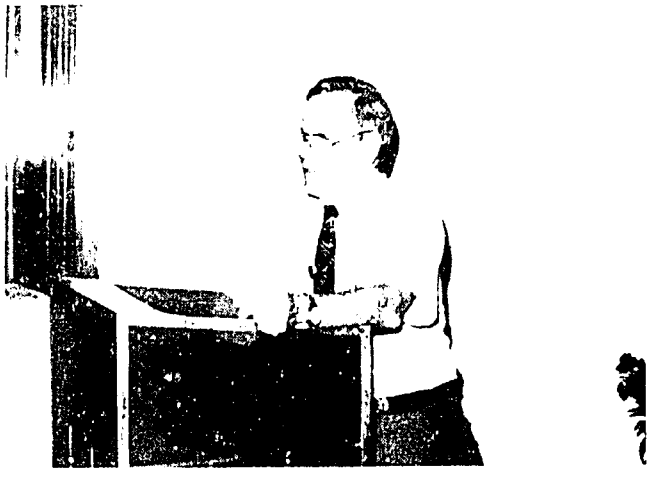
Table 3. **Jacobs' Two-Speed Dryer Conditions**

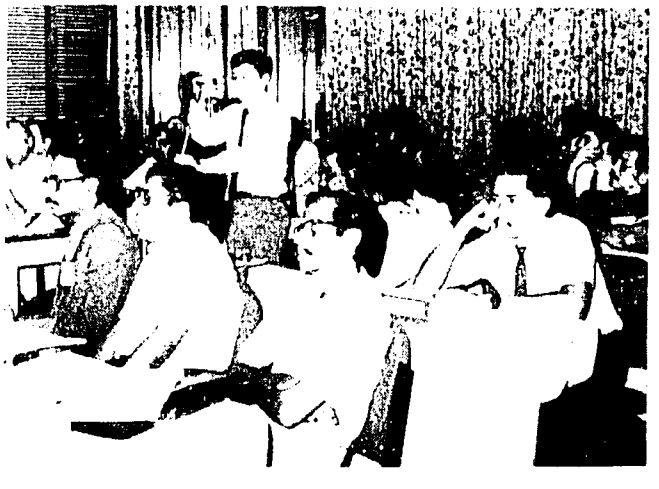
	19-19-19	18-46-0	TSP
Rate, mtph	50	80	50
Dryer throughput, mtph	200	400	460
Retention, minutes	12-16	6-8	6-8

Summary

The production of urea-NPK grades is generally considered to be more difficult than conventional DAP. Even NP with urea or NPK without urea can be considered substantially less of a problem to produce. Any downtime results in rapid moisture absorption on all surfaces where the solids are present. Concrete and steel surfaces become slippery. The plant stairs are best in grating rather than concrete. Even so, these can be slippery. Traction is maintained by using sand (filler) on concrete surfaces. Steam pipes provide heat to key places to dry out the equipment after shutdown.

Nevertheless, satisfactory NPKs can be made with urea, potash, and DAP or MAP, as demonstrated by the more than 5 million tons of 17-17-17 made by Madras Fertilizers and by this new NAFCON facility.





Impact of Fertilizer Formulation and Ambient Conditions on the Capacity of Direct-Fired Rotary Dryers

Vincent E. Leon and James J. Schultz, Fertilizer Production Specialists, International Fertilizer Development Center

Abstract

The drying capacity of a direct-fired rotary dryer in a fertilizer plant depends upon many variables, chief among which are: the critical relative humidity of the material being dried, the amount of moisture entering the dryer, the retention time, the relative humidity of the gasses leaving the dryer, the absolute humidity of the ambient air, the temperature and velocity of the air passing through the dryer, and the temperature sensitivity of the fertilizer being dried. This paper describes most of these variables and their effects on the drying capacity.

Introduction

Most fertilizer materials are quite hygroscopic – under certain conditions they can absorb a significant amount of moisture from the surrounding air. The moisture absorption characteristic of these materials is usually classified in terms of critical relative humidity (CRH). This CRH is defined as the relative humidity of the air at which the fertilizer material begins to absorb moisture. A knowledge of the CRH of the particular fertilizer product is essential when designing, evaluating, or predicting the performance of fertilizer dryers.

Determining the CRH of a Fertilizer Material

The CRH of a fertilizer is that point at which the partial pressure of water in the surrounding air equals the vapor pressure of the fertilizer material (1). Thus the CRH value of pure fertilizer salts can be determined by calculations based on the vapor pressure data. However, because of the complex nature of most fertilizer materials as a result of impurities, variations in composition, changes in water of crystallization, and eutectic-like properties, the CRH values are usually determined experimentally. The experimental procedure used to determine a fertilizer's CRH involves placing a sample of the material in a controlled temperature/relative humidity chamber (Figure 1). The CRH is determined by holding the chamber at a constant temperature while changing the relative humidity (RH) of the surrounding air (usually in 5 percentage point increments) and observing the RH at which the sample starts to gain weight by absorbing water vapor from the test chamber atmosphere. Details of this procedure are described in *Manual for Determining Physical Properties of Fertilizers* (2).

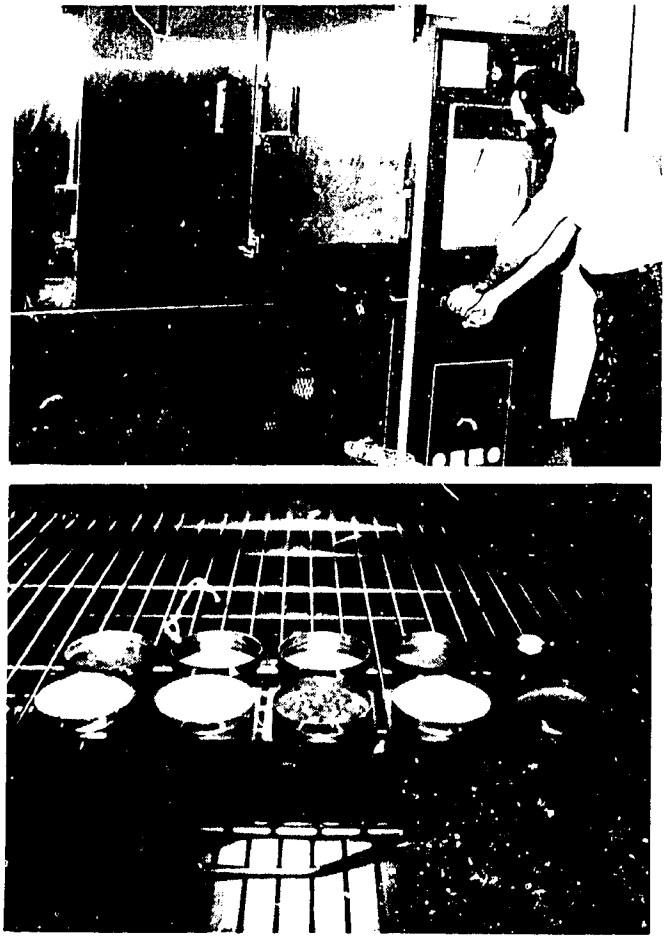


Figure 1. **IFDC Critical Relative Humidity Chamber.**

Since international trade of bulk fertilizers brought about the original interest in fertilizer CRH data, most CRH values are reported at a temperature of about 30°C. This temperature is typical of normal warm weather conditions under which bulk fertilizer is transported and stored. However in most cases these ambient temperature CRH values decline significantly when the tempera-

ture of the fertilizer is increased to levels that are normally encountered in fertilizer processing and drying operations. Therefore, the relationship between temperature and CRH must be well understood when using such data for dryer design purposes.

Application of CRH Data and Other Parameters to Fertilizer Plant Dryer Design

A knowledge of the CRH of the particular fertilizer product is essential when designing, evaluating, or predicting the performance of fertilizer dryers. Use of ambient air temperature (30°C) CRH data in designing the dryer can be very misleading and result in a unit that fails to meet the specified product moisture content. This is illustrated by observing the large variations in the CRH of common fertilizer materials (Figures 2 and 3) as a function of temperature. At 30°C the CRH values of most fertilizers are in the range of about 45% to 75% with monoammonium phosphate (MAP) being the highest (75%) and the urea ammonium phosphate-based NPKs (UAP-NPK) and nitrophosphate-based products being the lowest at about 45% to 50%. However, when these materials are subjected to elevated temperatures, the CRH values decrease rapidly and approach levels of 25% for the UAP-NPKs and some of the nitrophosphate and ammonium nitrate-based fertilizers.

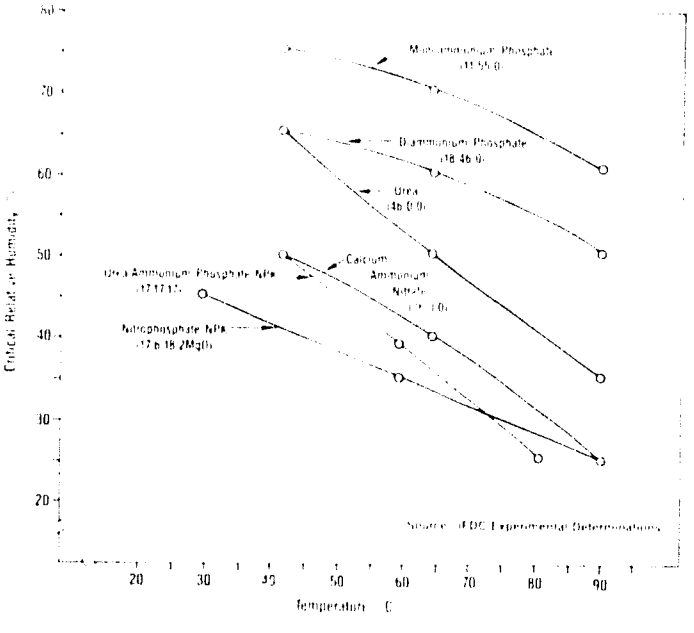


Figure 2. **Effect of Temperature on Critical Relative Humidity of Selected Fertilizers.**

It is this CRH-temperature relationship together with other important variables that ultimately determine the process design parameters required for a particular drying system. In addition to CRH, these design parameters include the (1) temperature and relative humidity of the ambient air, (2) solid material feed rate (throughput) and the evaporative load placed on the dryer, (3) retention time of material in the dryer required to achieve the desired product moisture level, (4) temperature sensitivity of the fertilizer, and (5) particle size and density of the fertilizer material and their relationship to the allowable gas velocity (airflow) that can be maintained in the dryer. The general effects of some of these variables on the drying capacity of a rotary dryer of a given size are discussed below.

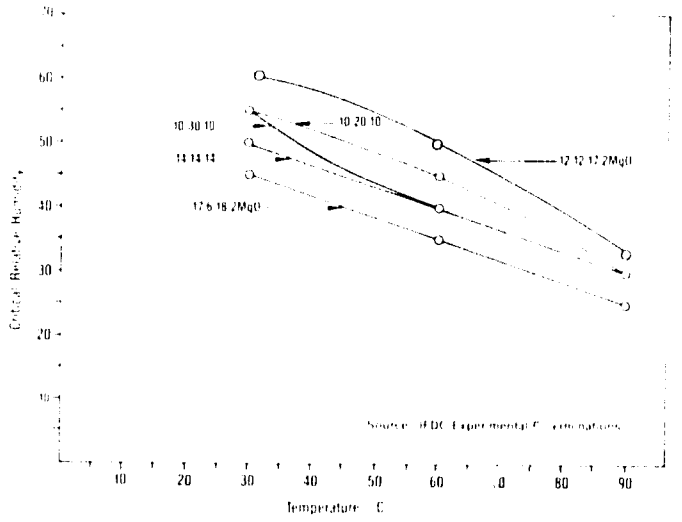


Figure 3. **Effect of Temperature on Critical Relative Humidity of Selected Nitrophosphate-Type Fertilizers.**

General Impact of Major Variables

The general effect of some of these major variables is illustrated in Figure 4. As the temperature and velocity (quantity) of drying air is increased, the capacity of a given dryer also increases. Conversely, as the moisture level (absolute humidity) in the ambient air used for drying increases or the moisture of the fertilizer material fed to the dryer increases, the capacity of the dryer decreases provided other conditions remain constant.

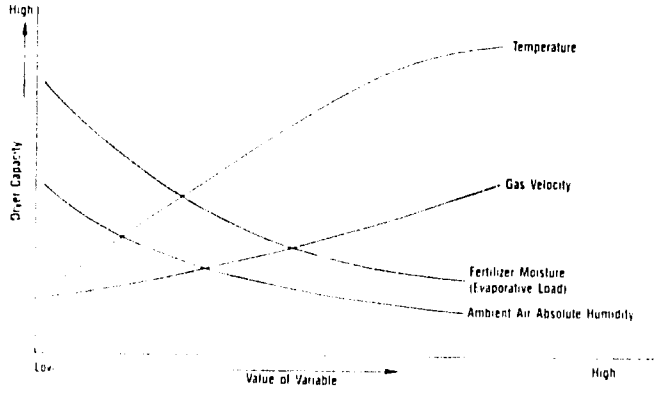


Figure 4. **General Effect of Major Variables on Dryer Capacity.**

Retention Time

For a dryer to achieve a given product moisture, the product must remain in the dryer for a certain amount of time (retention time) at the required drying conditions. In general, the lower the required product moisture the longer the required retention time. A review of commercial installations indicates that an average retention time of approximately 6 minutes, based on the Friedman-Marshall equation (3,7), is sufficient to achieve a product moisture level of about 1.2% in a diammonium phosphate (DAP) unit. On the other hand, the UAP-NPKs are normally dried to lower product moisture levels (about 0.7%) to minimize caking, and some commercial installations achieve this degree of drying with an average retention time of approximately 10 minutes. There is not much information published regarding the retention time required to achieve various moisture levels for different fertilizer grades (especially for the urea-based NPKs) and therefore, this appears to be an area where more work is needed. However, an average retention time of 10 minutes for NPKs and 6 minutes for DAP is assumed to be sufficient to achieve the moisture levels usually required. Table 1 shows equations used in estimating the average retention time of the solid material in a direct-fired rotary dryer.

Table 1. **Equations for Estimating the Residence Time in Rotary Dryers**

Derived By	Equation
Friedman and Marshal (3, 7)	$t = \frac{0.23\,L}{SN^{0.9}D} + \frac{0.6\,BLG}{F}$ (1)
Saeman and Mitchell (8, 9)	$t = \frac{L}{f(H)DNiS + mV}$ (2)
A. Hallstrom (10)	$t = \frac{L}{5.27\,DNi\tan\alpha + 0.002V^{1.4}}$ (3)

Nomenclature

- t = Residence time, minutes
- L = Dryer length, ft
- S = Slope = tan α, dimensionless
- D = Diameter, ft
- N = Rotational speed, rpm
- G = Gas flow rate, lb/hr ft²
- B = 5/ Dp, Dp = mean particle diameter, microns
- V = Gas velocity, ft/sec
- f(H) = 1 for fully loaded dryers; 2 for lightly loaded dryers
- m = Emperical constant. Assumed to be 0.0033 for fertilizer material
- α = angle of inclination, degrees
- F = Solids (dry) flow rate, lb/hr ft²

Notes

(1) Use negative sign for cocurrent flow and positive sign for countercurrent flow

(2) Use positive sign for cocurrent flow and negative sign for countercurrent flow

(3) For Hallstrom equation L and D are in meters and V in meters/second

Relationship Between CRH of the Product and RH of the Dryer Exit Gas

Adequate retention time alone will not guarantee that the desired moisture level will be achieved – it is equally important that the relative humidity of the gas leaving the dryer be maintained at a value lower than the CRH of the fertilizer leaving the dryer. A guideline used by some in the industry suggests that to ensure sufficient drying the gas leaving the dryer should have a wet bulb temperature that is 17°-22°C lower than the dry bulb temperature. While this guideline is satisfactory for some relatively high CRH fertilizers, such as DAP and MAP, it is not an exact criterion and rather inappropriate for grades having a low (25%) CRH value. Experimental work performed by IFDC suggests that the relative humidity of the dryer exit gas should be at least 5 to 10 percentage points lower than the CRH value of the fertilizer material (4). This criterion was used for the design of a commercial-scale urea-based NPK dryer with good results and will also be used as the basis for the examples that are discussed in this paper (5,6).

Absolute Humidity of the Ambient Air

The effect of the absolute humidity of the ambient air on the capacity of a dryer is shown in Figure 5. The conditions assumed in the preparation of Figure 5 as well as the other figures contained in this paper are listed below. Unless otherwise stated the same assumptions were used for all illustrations.

	DAP	UAP-NPK	Nitrophosphate-NPK
Dryer Diameter, m	3.66	3.66	3.66
Dryer Length, m	27.43	27.43	27.43
Maximum Loading, (nominal %)	20	20	20
Nominal Retention Time, min	6	10	10
CRH of Fertilizer @ 82.2°C, %	56	27	35
Recycle-to-Product Ratio	4:1	3:1	3:1
Solids Inlet Moisture, %	3.5	2.5	2.5
Solids Outlet Moisture, %	1.2	0.7	0.7
Solids Inlet Temperature, °C	79	79	79
Solids Exit Temperature, °C	79	79	79
Exit Gas Temperature, °C	82	82	82
Exit Gas RH, %	46	17	25
Fertilizer CRH minus Exit Gas RH (ΔRH)	10	10	[illegible]
Superficial Gas Velocity, m/s at Exit Conditions	2.6	2.6	2.6
Dryer Efficiency, %	65	65	65
Fuel Used	Natural Gas		

On the bases of the above criteria, it can be seen from Figure 5 that depending on the absolute humidity of the ambient air a given size dryer producing a 12-12-17-2 MgO nitrophosphate-based grade (or any fertilizer with a similar CRH) will have only about 55% to 65% of the drying capacity that could be achieved with DAP. For a low CRH fertilizer grade, such as the urea-based 17-17-17, the capacity of the dryer will be only about 25% to 43% of that achieved with DAP. At the assumed recycle-to-product ratios and range of absolute humidities, the production rates would range from about 86 mtph to 100 mtph for DAP, about 60 mtph to 84 mtph for the

nitrophosphate-based grade and only about 27 mtph to 54 mtph for the low CRH urea-based grade. It should be noted that changes were made to the dryer slope in these calculations to satisfy the maximum loading and the minimum retention time requirements. In all cases the relative humidity of the gas leaving the dryer was set at 10 percentage points below the expected CRH of the fertilizer at the dryer exit temperature.

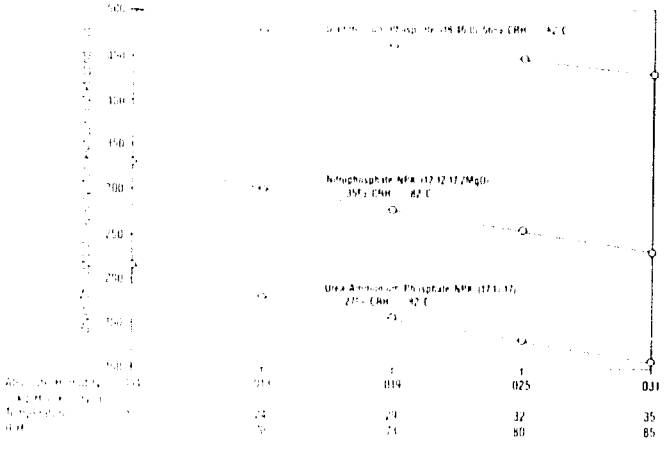


Figure 5. **Effect of Ambient Air Conditions on Dryer Capacity.**

The variations in the expected production capacities are significant, particularly for the lower CRH materials. The importance of knowing the local climatic conditions and CRH data for the specific fertilizer products prior to finalizing the design of a dryer or committing an existing plant to the production of a new fertilizer grade is clearly illustrated. It can be inferred from this comparison that a new NPK plant should be designed for the production of the lowest CRH grades, which could be required throughout the life of the plant. Figure 5 also helps to explain why problems with high product moisture are normally reported during hot humid periods, particularly in plants where the design of the drying systems did not fully incorporate the above criteria.

Temperature Sensitivity of the Fertilizer

Not all fertilizers can be subjected to the same drying temperatures. Some urea-based NPK fertilizers start softening and become quite plastic at about 70°C. If the dryer exit temperature is increased above this point, the granules may become excessively plastic, leading to uncontrolled agglomeration (production of oversize), buildup on the dryer internals, and difficulty in handling, screening, and crushing. Other urea-based NPKs behave quite differently and simply disintegrate at elevated temperatures. On the other hand many nonurea NPKs, as well as DAP, and MAP can often be dried at temperatures near 100°C without showing any significant softening or deterioration.

The effect of the maximum allowable fertilizer temperature on the capacity of a particular dryer is illustrated in Figure 6. This illustration is based on the previously assumed nitrophosphate process conditions using different temperatures of the dryer exit gas with a fixed absolute moisture content of the inlet air of 0.025 kg H_2O/kg dry air. For illustration purposes the same CRH temperature relationship as that of the 17-6-18-2MgO nitrophosphate grade (Figure 2) was assumed. The data (Figures 2 and 6) illustrate that even though the CRH of a given fertilizer significantly decreases with increasing temperature, the evaporative capacity of the dryer continues to increase with an increase in dryer exit temperatures (gas and solids). However, this exit temperature is limited by the temperature sensitivity of the particular fertilizer material.

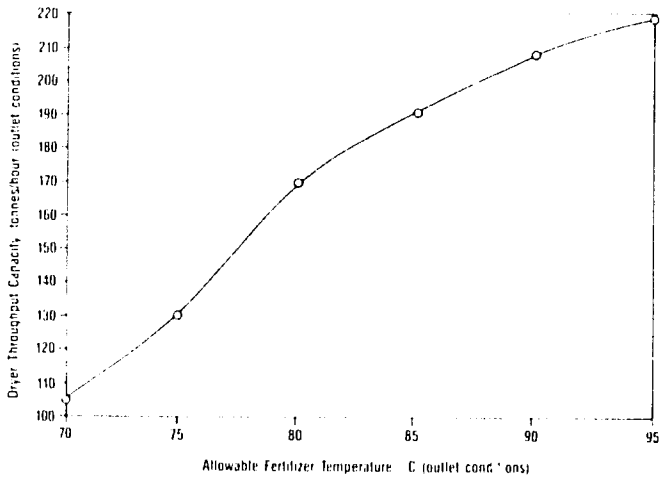


Figure 6. **Effect of Fertilizer Material Temperature Resistance (Sensitivity) on Dryer Capacity.**

Effect of Fertilizer Inlet Moisture

Figure 7 illustrates the decrease in drying capacity that can be expected with increasing fertilizer inlet moistures. This figure assumes that all other parameters, including the moisture content of the outlet material, remain fixed with a constant ambient air (combustion chamber air inlet) absolute humidity of 0.025 kg H_2O/kg dry air. As expected, an increase in the moisture content of the inlet fertilizer significantly increases the evaporative load on the dryer and, therefore, affects the capacity that can be achieved with a specific fertilizer grade, depending upon its CRH and temperature sensitivity. The degree to which the moisture content of the material fed to the dryer can be decreased depends on many factors including (1) the type of process, (2) the mode of operation of the plant including the level of operator skill, (3) the particular raw materials used, (4) the level of liquid phase required to obtain optimum granulation, (5) the level of slurry moisture required to obtain a pumpable slurry, and (6) the composition and concentration of the raw materials such as nitric, sulfuric, or phosphoric acids.

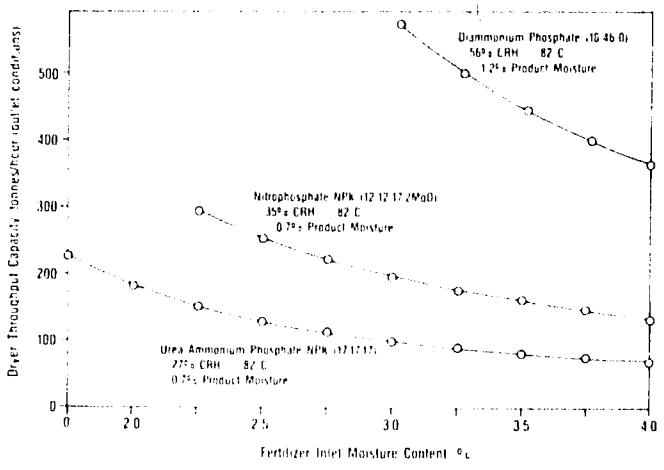


Figure 7. **Effect of Fertilizer Inlet Moisture Content on Dryer Capacity.**

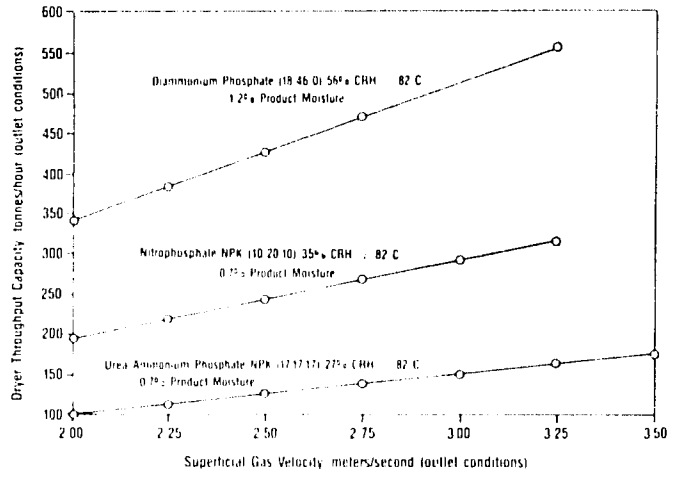


Figure 8. **Effect of Gas Velocity on Dryer Capacity.**

For example, a mixed-acid nitrophosphate process may use solid MAP to supply a portion of the product's phosphate. The use of MAP, which has a relatively low solubility, may require that the slurry contain about 20% free water to maintain a pumpable slurry that can be properly distributed (sprayed) in the granulator. By comparison a plant making the same NPK grade but using an ammonium phosphate process could probably operate the reactor (preneutralizer) at a point of maximum solubility and thus significantly decrease the slurry moisture content (to about 10%-15% free water) while still maintaining acceptable slurry fluidity. If it is assumed that there is no limitation on the concentration of the phosphoric acid available, the ammonium phosphate-based process could be operated at a much lower evaporative (drying) load, thereby achieving a higher production rate in the same size drying equipment.

Effect of Superficial Gas Velocity

Figure 8 illustrates the drying capacities that could be achieved for three different types of fertilizer at different superficial gas velocities (exit conditions). In commercial fertilizer installations these (empty shell basis) velocities range from about 1.5 to 3.6 meters per second (m/s). Some designers of rotary drying equipment recommend maximum velocities of about 2.5 m/s while others recommend velocities up to 3.6 m/s for granular fertilizers. On the basis of the performance of commercial installations, a design velocity of about 3.0 m/s appears to be adequately conservative for most ammonium phosphate fertilizers and many NPKs when the granule size is in the range of about 1-4 mm. In practice, the allowable superficial gas velocity will depend on the particle size distribution of the fertilizer material, the design of the dryer discharge breeching, and the design of the downstream dust collecting and gas scrubbing systems.

As a matter of interest some data obtained in an IFDC pilot plant-scale rotary dryer (0.92 m diameter, 7.31 m long) are shown in Figure 9. The shaded area represents the exit gas velocity at which particles of different diameters started to be entrained in the gas stream. The material used for this test was a fertilizer granular mixture with a specific gravity of about 1.7. Included in this figure are two curves calculated from a general equation found in the literature that estimates the minimum horizontal carrying velocity, and a curve based on the terminal (vertical) velocity of spherical particles in air (7). It can be seen from these data that the experimental values obtained with the IFDC pilot-plant dryer fall between the literature correlations and, in this case, closer to the predicted terminal velocities. These results seem to verify that the 3.0-m/s gas velocity criterion is adequate for 1- to 4-mm granular fertilizer material.

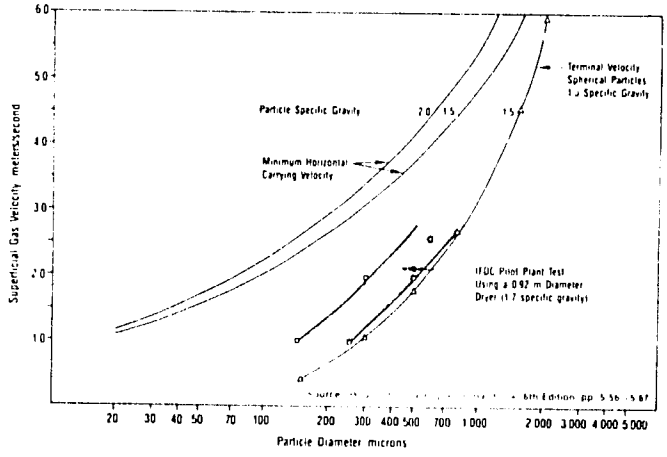


Figure 9. **Effect of Particle Size on Allowable Gas Velocity.**

Conclusions

The design of rotary dryers for use in NPK fertilizer plants is quite complex compared to that of dryers used in making straight MAP or DAP grades. The complexity is brought about by a number of unique factors including (1) variations in the chemical and thermal properties of the fertilizer materials; (2) the influence of ambient temperature and humidity conditions; (3) the large variations in the amount of moisture that must be removed by the dryer because of the numerous fertilizer grades that must usually be produced; and finally (4) the practical mechanical design, fabrication, and operating characteristics that must be considered.

Although many design criteria are available, no single set of criteria is applicable to all situations. Therefore, it is important to carefully evaluate the influence of the factors described in this paper, as well as those proposed by others, when designing a dryer. Much of the design criteria used for rotary dryers are also quite useful in designing rotary coolers.

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Questions and Answers
Compaction Granulation and Bulk-Blending Process Technology

Question
You mentioned the capacity of the Swiss compaction plant but could you give us some idea of the maximum capacity of a single compaction machine for urea-based NPK mixtures?

Answer (R. Zisselmar)
The compactor of the Swiss plant is a small machine of 560 mm width with a throughput of about 20 mtph, so the production rate of finished product is about 10 mtph.

Our biggest compactor has a throughput of 30-35 mtph. Depending on the feed material characteristics and finished product particle size distribution, the final product rate could be as much as 40%-60% of throughput capacity or up to about 20 mtph.

Question
You indicated some limitations on urea content in your compaction plant. Is it possible to produce 19-19-19 or 28-28-0 for example?

Answer (C. Rodriguez)
Based on our experience of 8 months operating our compaction plant in Guatemala, we should definitely maintain the urea content in our products below 30% to keep product quality under control. For this matter, we managed perfectly well with 15-15-15 grade using about 26% urea. With the 19-19-19 grade, the urea content goes up to 32% and it won't work. We solved the high urea problem by replacing some urea with standard ammonium sulfate which also gave us the sulfur needed for the crops. Of course, these reduced the NPK grade.

Question
Is it possible to produce TSP with micronutrients such as copper or zinc from 0.1% to 0.5% with the compaction process?

Answer (C. Rodriguez)
With very small amounts of micronutrients it is problematic. In the Guatemala plant, we add 2.5% borax to the NPK and we are planning to add 1% zinc to NPK.

Question
What is the minimum economic capacity of a compaction unit?

Answer (R. Zisselmar)
For technical and economic reasons, the throughput of a compactor should not be less than 5 mtph. This would be equivalent to about 2-3 mtph product. The economics of such a small plant would depend heavily upon the local conditions.

Question
How long can the compacted NPK product be stored?

Answer (C. Rodriguez)
Because of market conditions, we never store our product very long–5 days to 3 months. So far, we have not had any storage problem with our product, even when stored for 3 months.

Question
Are you experiencing clogging problems in your dedusting ducts? If yes, how do you clean these ducts?

Answer (C. Rodriguez)
We have experienced some buildup of dust in our ducts. The original design of the dedusting system has been modified to have better access to the ducts for easier cleaning.

Question
What is the frequency of downtime for mechanical breakdown and cleanup?

Answer (C. Rodriguez)
We foresee from 1 to 1.5 months for turnaround every year. At this time I would say that our downtime is minimum because we have two production lines. If something is wrong with one line, we still operate the plant with the other line. On the other hand, we just began to penetrate into the market and the production capacity is far beyond the current market demand, therefore we have not been

under pressure to increase the production rate and discover the true impact of maintenance-related downtime

Question
Is it possible to compact urea fines of less than 1.0 mm?

Answer (R. Zisselmar)
To compact urea of this size is a problem; because the soft urea fines will stick in the compactor feed system.

Question
Will compacted fertilizers slow down the release of nutrients to the crop compared with normal spherical granules of the same size?

Answer (R. Zisselmar)
We have not made any tests for comparison, but we expect no difference between compacted and granulated products.

Question
What is the capital investment for a typical compaction plant and what are the power and labor requirements?

Answer (C. Rodriguez)
Specifically for our plant of 30-mtph finished product, the investment for the land, buildings, equipment, and erection was about US $3 million (1986 cost basis). The power consumption averages about 12 kWh/mt of product. As far as manpower, we operate an 8-hour shift with 1 foreman and 5 operators. For the bagging and product loading onto trucks, we use an additional crew of eight workers.

Question
1. What is the temperature rise of the material across the roll press and how much cooling (temperature drop) is there on the flake conveyor?
2. What is the temperature of the material being bagged?
3. What is the effect of the product (or raw material) moisture on the performance of the compaction process?

Answer (C. Rodriguez)
1. The temperature of the flakes is about 50°-60°C or about 20°-25°C rise from the temperature of inlet material; the material is allowed to cool on the conveyor so that it will harden.
2. The temperature of the material being bagged is more than 30°C.
3. A high moisture content on the raw materials has a deteriorating effect on the performance of the compaction process.

Question
Earlier this morning Dr. Zisselmar said that for a plastic sheet product, a residence time is required before crushing. I note from Mr. Rodriguez's presentation that the residence time between compacting and crushing is less than 2 minutes. Is this sufficient for most efficient operation of the crushers?

Answer (C. Rodriquez)
I think that I have to agree with Dr. Zisselmar that a longer curing time would improve the product quality. One or two minutes of curing makes a lot of difference in how easily you can break the sheet, but we have not looked into the curing time effect at this time because I feel the plant has operated successfully.

Question
Can you use fine-size raw materials such as prilled urea, Minifos-type MAP and coarse MOP to make bulk-blended NPK fertilizers with size ranging from 0.5 to 1 mm? If not, why?

Answer (C. Rodriguez)
No, the use of different particle sizes of raw materials will result in segregation. This is one reason why we chose the compaction process so we could make a good product from nongranular or mismatched raw materials.

Question
Is it possible to blend granular urea with granular MOP and TSP?

Answer (C. Rodriguez)
No, urea is not compatible with TSP; the mixed product will have a lower CRH and a tendency to cake. Therefore urea/TSP blends are not advised.

Question
Why is the capital investment of US $8.7 million for the compaction plant presented in your paper so different from the investment of US $3.0 million reported by Mr. Rodriguez for the Guatemala plant of similar size?

Answer (J. Schultz)
The investment presented in the paper is used for comparison of different processes at the same location.

Although the absolute value for each process can vary considerably depending on location, existing infrastructure, exchange rate, method of project management, and other site-specific factors, it is quite likely that the relative economics between the indicated processes will not change. Some of the reasons for the low investment at the Guatemala plant may be attributed to a number of favorable factors, including relatively low local construction, engineering, and project management costs. The battery limits process plant cost indicated in my paper is US $4.6 million – not so much higher than Guatemala. However, with everything else added, the total fixed investment comes to US $8.7 million. Also, the plants described in my paper had a relatively large raw material storage facility because of the assumed remote location, thus adding considerably to the total cost.

Question

It is not fair to compare the economics of a chemical granulation plant to a compaction plant without referring to the production of intermediates onsite. If intermediates such as ammonia, nitric acid, and phosphoric acid are produced onsite, a chemical granulation plant would be more economical.

Answer (J. Schultz)

I agree, however, many chemical granulation plants in developing countries do not have on-site production of intermediates and the cost estimates presented in the paper apply to these cases that require 100% imported raw and intermediate materials. If you have production of intermediates onsite, you can certainly charge less to the granulation component and chemical granulation would be preferred. The plants used in my paper were quite small (120,000 mtpy) to fit the needs of many developing countries. Such small plants generally could not support the investment for on-site production of intermediates such as ammonia and acid.

Questions and Answers
Nitrophosphate Process Technology

Question
What is the electric power consumption per metric ton of 15-15-15 in Kemira nitrophosphate process? You mentioned in your presentation that removal and replacement of equipment could bring down power consumption. Could you please give some examples?

Answer (S. Swanstrom)
Power consumption for Kemira nitrophosphate NPK process is about 45-50 kWh/mt of product. An example of how Kemira can reduce power consumption by revamping an existing nitrophosphate plant is that of the RCF plant of Bombay, India. The RCF plant had originally two reaction lines with 34 reactors in total. Each reactor has 2 agitators, for a total of 68 agitators. This reaction system was replaced by 3 reactor tanks, each having one agitator. We also modified 4 of 6 spherodizers and increased the plant capacity from 1,100 mtpd to 1,500 mtpd with only 4 spherodizers. Therefore the plant power consumption is reduced significantly, but I do not know the exact power consumption at the RCF plant.

Question
In the Kemira nitrophosphate process, how do you use chemical reaction to reduce moisture content in the NPK slurry and how do you optimize the fuel consumption for drying the product?

Answer (S. Swanstrom)
In our process, the heat of reaction is utilized at maximum and no cooling or additional water is usually necessary in any process steps. The only water entering the process is through the raw materials and scrubber feed water. In order to reduce fuel consumption, the hot exhaust air from the cooler is recycled to the gas burner as dilution air.

Question
Do you experience any problem with slurry moisture when MAP is used as a P_2O_5 source?

Answer (S. Swanstrom)
The slurry moisture when using MAP as a raw material is many times a problem. However, this depends on the P_2O_5 nutrient content in the product grade. If you have a low P_2O_5 grade where the MAP requirement is low, you can use some sulfuric acid to digest the rock. In this case you are better off than if you have a high P_2O_5 grade with a high MAP requirement.

Question
In your scrubbing system, if you have a choice between nitric acid and phosphoric acid, which one would you use as scrubbing liquor?

Answer (S. Swanstrom)
Nitric acid is preferred because it is much cleaner than phosphoric acid. Fluoride emissions from the scrubber are also somewhat higher with phosphoric acid scrubbing than with nitric acid.

Question
Do you use any chemical to reduce NOx emissions and foaming in the acidulators?

Answer (S. Swanstrom)
Yes, we do. In the RCF plant, we use a defoamer to reduce foaming and urea addition to reduce NOx emissions. We also have cooling in the first reactor to keep down the temperature. In the RCF plant, reduction of NOx emissions was a key target.

Question
Ammonium nitrate-based fertilizers have low critical relative humidity (CRH). How is your plant maintained during shutdown?

Answer (S. Swanstrom)
We circulate hot air through the bag filters during plant shutdowns in order to keep the relative humidity in these units lower than the CRH of the fertilizer.

Question
How do you protect ammonium nitrate fertilizers from high humidity in areas such as Bombay?

Answer (S. Swanstrom)
The product should be coated and bagged quickly after production. Sometimes dehumidification of bulk storage is required. We have delivered our products to many tropical areas and as soon as they are packed, there is no problem. But if you store bulk materials for a long period

of time in very humid climate, any product will have problems.

Question
What is the maximum inlet temperature of hot air for drying ammonium nitrate-based fertilizer?

Answer (S. Swanstrom)
Usually the dryer inlet gas temperature is not a critical problem because it will reduce rapidly when it comes in contact with wet ammonium nitrate and therefore there is no decomposition of ammonium nitrate at the dryer inlet. However, the maximum gas inlet temperature for high ammonium nitrate NPKs should be restricted to 280°C.

Question
What is the N:P mole ratio in your scrubbing system? and what is the density of scrubbing liquor?

Answer (S. Swanstrom)
In our scrubbers, we prefer to talk about pH which is more or less the same as N:P mole ratio. We adjust pH to about 3.5. The density of the scrubbing liquid increases from the reactor gas scrubbers to the spherodizer gas scrubbers, but I don't remember the exact number at this time.

Question
Have you experienced caking problems in your NPK product? What specific anticaking agent do you use?

Answer (S. Swanstrom)
Yes, as do many other NPK producers, we sometimes have caking problems, especially if the product grade is strange and has not been produced before. Regarding coating materials, we use different types. These include oil combined with talc, oil-amine based types, and other surface chemicals. The coating of fertilizer is more an art than a science. There are so many suggestions in this field and the selection of the appropriate coating agent still depends on your preference. If you see an agent working well in your plant, you use it. Then you go to your neighboring plant, they use another agent which also works well too. There are many answers to what is the best coating agent.

Question
Regarding the product safety, how many of your products exhibit cigar burning?

Answer (S. Swanstrom)
We try to avoid cigar burning in our product as much as possible. However, in theory and in practice, it is entirely impossible to make them completely free of cigar burning. Therefore, some of our products are moderately cigar burning.

Question
In your mixed-acid process, are you experiencing any corrosion problem? If not, what type of material do you use for your equipment?

Answer (S. Swanstrom)
No, we are not experiencing any corrosion. Usually, Type-316L Stainless Steel is a good material for all equipment, but for the first reactor in which nitric acid is added, Uranus B6 is better. This, of course, also depends on the quality of the phosphate rock.

Question
In the nitrophosphate process, when there is a need for additional nitrogen for high N:P_2O_5 ratios, what is your recommendation for a supplemental nitrogen source above that (nitric acid) used to react with phosphate rock?

Answer (S. Swanstrom)
Usually we add ammonium nitrate as solution if we have ammonium nitrate production already onsite. Otherwise, we just increase the amount of nitric acid and ammonia to produce the ammonium nitrate in the reactors. Do not forget, of course, the possibility of adding solid raw materials in the granulation unit.

Question
Is there any plant which adds potassium chloride to the spherodizer instead of the slurry tank?

Answer (S. Swanstrom)
It is quite common to add potash to the recycle stream with a drum granulator or a pugmill but not with a spherodizer; I have not heard of anyone. We have tried potash addition to the spherodizer, but there were some problems with product quality. These trials were so short, so we are not ready to make any conclusions if it is really bad or not. I think that if some more trials were made, it might be a procedure that could be used.

Question
In the Kemira process you use nitric acid to recover ammonia in the scrubbing system. Do you experience the formation of ammonium nitrate aerosols in the system?

Answer (S. Swanstrom)
We have not experienced the formation of ammonium nitrate aerosols. The formation of ammonium nitrate aerosols is a mystery, but we have done a lot of research on this and it seems that if the gas entering the scrubber is saturated, there should be no formation of ammonium nitrate.

Question
In the nitrophosphate process, is it typical to add potassium chloride in the second neutralizer? Is it important to minimize the residence time to avoid explosion or cigar burning?

Answer (M. Jennekens)
The reason for minimizing the potassium chloride residence time is to avoid the reactions that lead to double salt formation. These double salts of potassium and ammonium nitrate show very high viscosities when concentrated to melts (for example, 99.3% solids) needed in prilling operations. In granulation processes where the slurry temperature and concentration is significantly lower, the reaction rate is also much lower and residence time is not important.

When you are talking about cigar burning or explosions, these have nothing to do with the potash residence time. Potassium chloride will react with ammonium nitrate downstream of the reaction section in any case. So the residence time of potash in the reaction system is not important. What is important with respect to the self-sustaining decomposition and possible detonation is the composition and water solubility. At certain compositions, fertilizers may be subject to self-sustaining decomposition and this is enhanced at lower water solubilities. In principle, one can say that for pure water-soluble fertilizer, the rate of self-sustaining decomposition is negligible; for 50%-60% or lower water solubility of P_2O_5, this is going to be, or can be, a problem depending on the composition you have.

Question
What is the recycle ratio with pan granulators for nitrophosphates, the grades produced, and the production rate?

Answer (E. Aasum)
The recycle ratio varies with the grade usually from 0.8 to 1.0. We have a pilot plant of 100-mtpd capacity. This unit has provided the technical data and background to design commercial-scale NPK units. Our existing commercial-scale ammonium nitrate and calcium nitrate units of 1,200 mtpd for a single train were developed in a similar manner from a 36-mtpd pilot-scale unit.

Question
We understand that Norsk Hydro has developed a suitable coating agent for hygroscopic material to reduce moisture pickup. What is the material and how much do you use?

Answer (E. Aasum)
The coating material is an amine/oil mixture used together with a solid coating agent. The amine/oil mixture contains about 17% amine and 83% oil. High AN fertilizers and fertilizer-grade AN are coated with about 0.1% of this amine/oil mixture and about 0.4% solid coating agent. We frequently use an amorphous silica coating agent of fine grain size. Of course, other inorganic compounds could be used such as kaolin or limestone. It is very important that the solid material be very finely grained, of course.

Question
What is the approximate atmospheric humidity in the nitrophosphate plant where you make 22-22-0 or 27-13-0? Is it very high and do you require dehumidification?

Answer (E. Aasum)
The atmospheric relative humidity in our plant is about 56% and we do not need dehumidification, even in coastal areas of Norway where the relative humidity is high. The CRH of our product is about 65% at 30°C.

Question
What types of problems are faced during crystallization of calcium nitrate when using rock phosphate containing high silica and high magnesium?

Answer (E. Aasum)
There are no problems with high magnesium and high silica (up to 12% silica) during crystallization.

Question
What is the highest 1:1 NP grade which can be made with high-quality phosphate rock and nitric acid without addition of external P_2O_5 nutrient, and what is the maximum quantity of calcium nitrate that can be separated?

Answer (E. Aasum)
Approximately 23-23-0 containing 80% water-soluble P_2O_5. More than 85% of the calcium nitrate can be separated.

Questions and Answers
Liquid-Phase NPK Granulation Technology and Plant Design Criteria

Question
What is the maximum amount of urea which can be added to the granulator without meltdown in downstream equipment?

Answer (G. Wesenberg)
For 27-27-0 grade, we use 740 lbs of urea per 2,000 lbs of NPK or about 37%.

Answer (D. Ivell)
We have used up to 50% urea in ammonium phosphate and urea grades.

Question
What is the number of NPK granulation plants built in the United States during the 1970s and 1980s compared with the number of bulk-blending plants built during the same period?

Answer (D. Leyshon)
I am not sure about the total number of NPK granulation plants which were built in the 1970s. I know not many. Jacobs Engineering designed and built two plants in the early 1970s and one plant was completed last year for Chevron Chemical in Wyoming by Badger Engineers, Inc. These are NP, not NPK plants.

Answer (J. Schultz)
In the United States bulk-blending plants are usually operated by farm service-type centers. There are approximately 5,000 farm service centers in the United States that engage in some type of blending. These are generally rather small operations that provide a variety of services including selling fluid fertilizers, solid fertilizers, pesticides, seeds, and other agricultural inputs. The total annual tonnage of fertilizers consumed in the United States is about 40 million tons of product, of which about 15 million tons is in the form of fluids (ammonia, urea-ammonium nitrate solution, and NPK fluids) and about 25 million tons in the form of solids. This amounts to an average tonnage of about 5,000 tons per blender. There are some blenders with 20,000 tpy or more capacity and the biggest is probably in the order of 100,000 tpy.

Question
What is now the total tonnage of granulated NPK produced in the United States per year and the number of NPK granulation plants in operation?

Answer (J. Schultz)
There is no official count today, but an IFDC survey in mid-July 1987 indicated 21 NPK granulation plants (not including the basic DAP units) still in existence in the United States with about 11 plants determined to be operating. There were about 200 such plants in the 1960s. These remaining NPK plants produce an estimated 1.5-2 million tons of product annually.

Question
What is the crushing strength of your product and what is the filler material?

Answer (D. Ivell)
The crushing strength is a subject that depends on how you actually measure it. Based on our method, the crushing strength of NPK is about 2.5-3.0 kg/granule as compared with 1.0-1.5 kg for ammonium nitrate prills. The filler material we use is sand.

Question
What type of crusher did you use when you decided to crush urea to less than 1 mm? Do you crush urea before you meter the process or after it has been weighed?

Answer (D. Ivell)
The type of crusher we actually used in the Turkey plant was the same type we used for oversize crushing—a high-speed (1,450 rpm) chain rotor/slow-speed (50 rpm) drum rotor. However, this type of crusher is not particularly efficient for crushing urea, therefore we intend now to use a swing hammer-type mill for urea crushing. The swing hammer-type mill should contain a grid in the discharge to ensure adequate crushing. In the original mill (chain and drum type) much of the urea passed through practically untouched. In the process I just described we crushed

urea before metering it, but it became a problem. The crushed urea tended to stick in the metering hopper. Therefore to solve this problem, we recommend that the crusher be installed after (downstream) metering the urea.

Question
What lining is used in your granulator and is it affected by the sulfuric acid? Does the sulfuric acid hydrolyze or decompose urea to ammonia?

Answer (D. Ivell)
We use a rubber lining which is specially made by a Swedish company for lining granulators. It is similar to the product made by Goodyear in the United States. It can withstand temperatures up to 110°C. The addition of sulfuric acid does not cause any damage to the rubber. No hydrolysis of urea due to the effect of sulfuric acid has been detected.

Question
Referring to the Turkey plant, what is the approximate dimension of the dryer, design air velocity in the dryer, and recycle ratio for 15-15-15?

Answer (D. Ivell)
The dimension of the dryer is 3.5 m diameter and 30 m long. Generally, the design air velocity is in the range of 2-4 m/sec. The recycle ratio for 15-15-15 is about 1.9. 15-15-15 was not produced in the Turkish plant during the commissioning period. It has, however, been produced in other plants at under 2:1 recycle ratio.

Question
What is the ammonia slip in the granulator in the Toros plant and how do you recover it?

Answer (D. Ivell)
The ammonia loss is about 1% from the granulator and we do not recover it.

Question
What is the formulation proposed for 18-18-18?

Answer (D. Ivell)
This grade can be produced using MAP route and adding urea and KCl.

Question
You said that the Rhewum-type electromagnetic driven screen is superior and more reliable than other types. Will you please give a detailed comparison between electromagnetic driven screens versus rotary vibratory screens, particularly with respect to efficiency and area required? Who supplies electromagnetic driven screens other than Rhewum?

Answer (D. Ivell)
The Rhewum screens have some advantages for good control of the screen efficiency because, apart from the mesh size, you also have the angle and the sensitive vibration. Also in the automatic cleaning cycle, there is an increase in vibration to increase the passing of scale (buildup). In the United Kingdom, we operated nine granulation plants and at one time none contained the Rhewum screens and in the fullness of time they all contained the Rhewum screens.

Comment (S. Swanstrom)
There are two types of Rhewum screens, and in practice, there are some problems with these screens.

Answer (D. Ivell)
We have experience with both types of Rhewum screens. One is the "U" type and the other is the "WA" type. The principal difference between the two types is that in one (the "U" type) the vibration arm is clamped through the mesh of the screen and the other (the "WA" type) transmits vibration by knocking on the screen. The U series screen is more effectively vibrated than the WA series. The U series is less prone to clogging therefore and also performs more efficiently. Since in solids granulation, recycle ratio and therefore production rate is directly related to screen performance, we prefer the U series screen when producing urea based NPK with our process. It is true however that it is much easier to change cloths on a WA series screen. If we were to produce a sticky grade via the slurry route where product has to be recycled (and therefore screening efficiency is not so critical) we may decide to select the WA type.

Comment (G. Wesenberg)
I have seen the Rhewum screens in a plant in Greece. I did not necessarily think that the performance of the Rhewum screen is much better than perhaps the Tyler Hummer. As you may know, the Tyler company has changed their type of vibrator unit. The original type was an electromagnetic unit. They also make other types and the latest type, called the V-85, is a simple variable-speed motor unit that imparts a very high frequency vibration to the screen cloth. You stand by it and you do not even realize that it is running (very quiet). The screen covers are very accessible because they are large rubber flap-type units with very good access. Regarding screen efficiency, this depends on the stroke and the type of material you are screening. You would have less efficiency with powdered material than with more granular materials. The screen cloth slot design is also important. The Tyler company has screens with slots running horizontally or

vertically. The horizontal ones, of course, have better efficiency, but the particles do not go through them quite as good as with the vertical ones.

Question
Would the use of a different crusher for the oversize material allow you to use 100% hot screening?

Answer (D. Ivell)
If the material to be processed does not have sticky characteristics, 100% hot screening can be used. For urea-based NPK grades, however, we could not recommend it. We do not know of a crusher which could avoid buildup problems if used to crush such grades hot. We have used double chain mills, flail and drum mills, and double cage mills for oversize crushing.

Question
When you crush urea are you experiencing any foaming or slurry pumping problems due to carryover of urea dust to scrubbing system?

Answer (D. Ivell)
No, because we have a dry collection system; no wet scrubbers. Certainly, if you are operating a slurry scrubbing system, excessive carryover of urea dust will undoubtedly cause foaming in the scrubber.

Question
Do you have any experience in granulation of urea and phosphate rock? Are there any problems in granulation?

Answer (J. Schultz)
We do have experience in that. In a plant in Malaysia, urea and phosphate rock, MOP, and kieserite are routinely granulated and the plant works quite well. The plant must, of course, include certain special features to accommodate urea with its difficult characteristics. These include an oversize dryer, a process cooler before screening, and dehumidification of the process plant and bulk storage area.

Question
What is the recycle ratio in your granulation plant using the pipe reactor, especially when urea-containing grades are produced? What is the size of your dryer?

Answer (G. Wesenberg)
The recycle ratio varies from 0.5:1 to 3:1 depending on the formulation, but the basic one would be close to 1:1. The nominal size of our dryer is 8 ft diameter and 50 ft in length for approximately 30 tph product rate, plus or minus from that depending on raw materials.

Question
What type of crushers are used in the MFL plant and what is the frequency of cleaning these crushers?

Answer (K. Krishnaswamy)
We use chain-type hammer mills. We clean the crusher every shift because the fertilizer material sticks to internals.

Question
The recycle ratio is quoted as 4:1. Is any product-size material returned to the recycle stream to maintain this recycle ratio?

Answer (K. Krishnaswamy)
Product-sized material is not returned to recycle.

Question
You said coating clay is ineffective. What type of clay is used and what is its size analysis? Is any oil or binder material used to cause adhesion of the clay to the fertilizer?

Answer (K. Krishnaswamy)
The coating clay is a fine material of 200-mesh size. There are many problems with coating clay. First, it is not an effective protection against moisture absorption, and second, it causes dust problems. We are looking into some specially manufactured anticaking agents. Although these anticaking agents are terribly expensive, they do the job. We do not use oil or any binder for the clay.

Comment (J. Schultz)
The use of clay for coating has been investigated by many in the industry for years. I think it is clear that the clay does not serve as an imperious shield against moisture. It does, however, give a little added protection against severe caking in that it weakens the salt bridges that form between granules so that when you reclaim a bag of fertilizer, the granules will not be welded together quite so hard and you are able to break the lumps apart easier.

Question
Does the automatic analyzer system include automatic sampling and sample preparation as well as analysis, or does it just do the analysis?

Answer (K. Krishnaswamy)
No, it just does the analysis.

Question
Have you tried to replace some of your potassium chloride with potassium sulfate to avoid cigar burning?

Answer (Chong Kok San)
Basically if you use potassium sulfate you will not have cigar burning. The only problem is that the cost of the product (potassium sulfate) is very high.

Question
What is the highest humidity in Malaysia and the duration for which this humidity will prevail? What is the ambient temperature at this time? Are you referring to the humidity in the general plant area or inside the warehouse?

Answer (Chong Kok San)
Basically the average relative humidity of Malaysia is about 80%, but we have dehumidified air in the process plant and its relative humidity varies from 47% to 55%. The outside temperature is about 28°-30°C and inside plant temperature varies from about 33° to 38°C. The raw material warehouse area is not dehumidified. The finished product is bagged directly from the production unit, no bulk storage is used.

Question
Does the use of coating oil on an explosive-like material such as ammonium nitrate or high ammonium nitrate fertilizer cause any safety problem?

Answer (Chong Kok San)
No. We have had no explosion incidents due to the use of coating oil in our plant. We do not have many contaminants and our coating oil level is very low, about 0.3%. The maximum concentration of ammonium nitrate in our product is 55% by weight.

Comment (E. Aasum)
In the nitrophosphate production, quite often our NPK products contain a large amount of ammonium nitrate and we use an amine/oil mixture. We also do this with regular fertilizer-grade ammonium nitrate. Of course, the most important thing is not to return the coated material to the wet (reaction) portion of the process.

Question
You mentioned about cleaning of the dryer manually with pneumatic chiseling instead of washing. How much time is required for good cleaning?

Answer (S. Chander)
The time required is 4-6 days to clean both dryers. The frequency of every 4-6 months.

Question
How durable is the lining material in your dryer?

Answer (S. Chander)
Our dryer has been operating for the last 12 years and we do not think that we have any problem with the lining. We do have problems with the dryer shell itself.

Question
Please explain the reason for the eccentricity of the dryer shell that you described?

Answer (S. Chander)
Well, it is very difficult. In fact, nobody knows for sure. With the dryer length being 43 m and supported only by rollers, the weight of the deposits that accumulate in the middle may be one of the reasons for the cracking of the shell.

Question
What is overall material recovery efficiency in your plant for ammonia, phosphoric acid, and other materials?

Answer (S. Chander)
About 95%-96%.

Question
In our experience it is necessary to reduce the product moisture of a 1-1-1 urea-ammonium phosphate-potassium grade to at least 1% and preferably 0.7%-0.8%. Have you not suffered from caking with product moisture as high as 1.5%?

Answer (S. Chander)
It is difficult to achieve a product moisture content of 1%. Therefore, we control our product moisture content in the range of 1.0%-1.5%.

Question
What is the approximate fuel consumption per metric ton of 19-19-19 and what product moisture does this refer to?

Answer (D. Ivell)
I have not precisely calculated, but for our solids-type granulation process we need about 2-2.5 liters of furnace oil for drying one metric ton of product like 18-18-18, the maximum grade we can make. We also need about 15 kg of steam per metric ton for injection directly into the granulator.

Question
In India we have many solid fertilizer granulation plants and SSP granulation plants. Almost all the plants have

drum granulators, only two have pan granulators. Our experience with the pan granulators is that although the granulometry is much better, the strength of the granules is very poor. Hence, overall we are not happy. The question to you is this – What is your experience in granulating solid mixed fertilizers with pan granulators and can you suggest ways and means for improving the strength of the granules?

Answer (E. Aasum)
This is an area in which we have not been working. Our experience has been only limited to melt granulation of urea and ammonium nitrate.

Comment (J. Schultz)
Your point is very well taken and, from the work we have been involved in with pan granulators, it seems that you need a densification step after the initial granule formation in the pan. The granule is formed nicely in the pan and then it is a good idea to go to a rotary drum of some kind to consolidate it, especially when superphosphate is present. There are many different techniques for improving the performance of any type of granulator, but each one has to be examined separately.

Question
For good control of product nutrient content, from which point in the process flow do you collect your representative samples?

Answer (S. Chander)
We take two samples at a time; one is at the granulator outlet and the other is the product itself.

Question
How many minutes after correction in the granulator feeds does it take for the change to occur in the product analysis?

Answer (S. Chander)
Residence time from granulator discharge to finished product is about 30 minutes.

Comment (J. Schultz)
In agglomeration-type NPK plants it may take from 6 to 8 hours for a change in the granulator feeds to be fully manifested in the product, but about 80% of the change usually manifests itself in the first 2-4 hours in most plants, depending upon the recycle ratio and material load in the plant. This can be calculated quite accurately. Unless the time lag is well known in your plant, it can be very disruptive to change feed rates to correct short-term deviations in analyses.

Question
In your presentation you have indicated a residence time of 10 minutes for 17-17-17 and 12-12-17 grades. However, in Indian conditions we feel that this may not be adequate and a residence time of 14-15 minutes will be required. How do you explain this higher residence time? Is it due to the lower atmospheric temperature assumed in your study?

Answer (V. Leon)
The actual retention time required to achieve a given moisture level is an area where more work is needed. The assumed retention time of 10 minutes used in my paper is based on the calculated retention time of several commercial NPK plant dryers that exhibit a moisture content of less than 1%. The calculated retention time for these particular NPK dryers varied from 8.2 to 10.6 minutes based on the Friedman Marshall equation. It should be noted that the calculated retention time can vary significantly depending on the parameters used and on the particular equation used to calculate the retention time. My personal opinion is that some dryers are overdesigned (and some underdesigned) and that further work could strengthen present dryer design criteria.

Question
Do you experience any buildup problems with your ammonia spargers?

Answer (K. Govindarajan)
There are more problems with horizontal ammonia sparger pipes. In retrofitting a plant, liquid ammonia should be fed using a vertical sparger (injector) arrangement similar to what was described by Mr. Ivell.

Question
Can urea melt or solution be used in the granulator for making 19-19-19 grade?

Answer (D. Leyshon)
We are planning to use urea melt in the future. Use of urea solution will disturb the heat balance due to the water content of the solution.

Question
How does the particle size of the potassium chloride (KCl) affect the granulation and thus the plant performance?

Answer (D. Leyshon)
Fine KCl is desirable; standard grade potash is what's normally used. Granular potash is not used.

Question
Does the height of weir or dam at the granulator discharge affect the quality (granulometry) of the product?

Answer (D. Ivell)
Yes, because the weir height will affect the bed depth.

Question
Do you slope your granulator and, if so, how much?

Answer (D. Ivell)
Yes, from 1° to 3°.

Question
The double pipe process requires higher rates of sparged ammonia per ton of product than the conventional process. What special design features are incorporated to reduce ammonia losses?

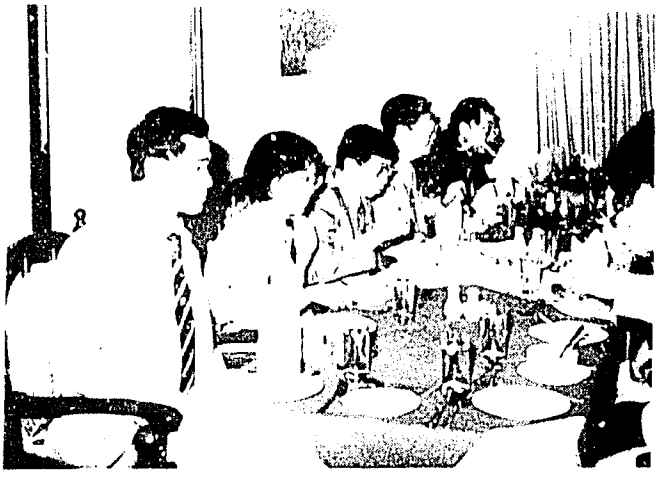
Answer (K. Govindarajan)
Addition of sulfuric acid to the scrubbing system will help to absorb ammonia hence reduce ammonia losses.

Question
The recycle ratio for DAP is given as 4:1. Is this for a pipe reactor or preneutralizer process?

Answer (D. Leyshon)
Preneutralizer process.

Question
Could you give specifications of the coating oil that you said is used.

Answer (D. Leyshon)
The oil is more or less similar to 30 weight motor oil.



Session Chairmen/Speakers/Technical Resource Persons

Agricultural College and Research Institute – Dr. T. S. Manickam
India — Dean

Chemical Company of Malaysia Berhad – Mr. Chong Kok San
Malaysia — Fertilizer Plant Manager

Consultant – Dr. K. S. Chari
India

ESCAP/FAO/UNIDO Fertilizer Advisory, Development and Information Network for Asia and the Pacific (FADINAP) – Mr. P. Hjortlund
Thailand — Marketing Economist

Mr. A. G. Vaes
Team Leader

FACT Engineering and Design Organisation – Mr. P. K. Ramasubbu
India — Deputy General Manager (Process)

Mr. N. Natarajan
Deputy Chief Engineer (Process)

FEECO International, Inc. – Mr. F. P. Bell
U.S.A. — Director, Fertilizer & Ag-Chemicals

Mr. G. H. Wesenberg
Vice-President (Process Engineering)

Fertiplant Engineering Company Pvt., Ltd. – Mr. S. R. Doshi
India — Director

Fertiliser Association of India – Mr. B. K. Jain
India — Director (Technical)

Dr. S. Nand
Senior Research Officer

Mr. S. Seetharaman
Regional Executive

Fertilizantes Quimicos de Guatemala (FERQUIGUA) – Mr. C. Rodriguez
Guatemala — General Manager

IMC Fertilizer, Inc. – Mr. M. M. Handley
U.S.A. — Director of Technical Services

Mr. J. L. Medbery
Consultant

International Fertilizer Development Center – Mr. V. Leon
U.S.A. Fertilizer Production Specialist

Dr. D. H. Parish
Director, Outreach Division

Mr. J. J. Schultz
Fertilizer Production Specialist

Jacobs Engineering Group, Inc. – Mr. D. W. Leyshon
U.S.A. Technical Director

Kemira Engineering – Mr. S. Swanström
Kemira Oy Assistant Director
Finland Kemira Engineering

Madras Fertilizers, Ltd. – Mr. K. R. Krishnaswami
India General Manager

Maschinenfabrik Köppern GmbH & Co. KG – Dr. R. Zisselmar
Germany Head of Department – Briquetting, Compaction, and Size Reduction

Norsk Hydro a.s. – Mr. E. Aasum
Norway Manager, Process Section

Dr. C. D. Sutton
Fertilizer Consultant

Norsk Hydro Licensing – Mr. D. Ivell
Norsk Hydro Fertilizers Limited Senior Chemical Engineer
England

Southern Petrochemical Industries Corporation, Ltd. – Mr. K. Govindarajan
India Executive Director

Stamicarbon, bv – Mr. Math Jennekens
Netherlands Manager, Process Engineering
P Fertilizers

The A. J. Sackett & Sons Co. – Mr. L. Taylor
U.S.A. President

Zuari Agro-Chemicals, Ltd. – Mr. S. Chander
India General Manager

Delegates

Mr. Hasanul Morshed
General Manager
Bangladesh Chemical Industries Corporation
BANGLADESH

Mr. J. Kangastalo
M.Sc. (Chemical Eng.)
Kemira Oy
FINLAND

Mr. J. Poukari
Head of Fertilizer Research
Kemira Oy
FINLAND

Mr. N. Arulprakasam
Southern Petrochemical Industries Corporation, Ltd.
INDIA

Mr. V. Behal
Senior Production Manager
Hindustan Lever, Ltd.
INDIA

Mr. B. Sripathi Bhat
Shift Operation Engineer
Mangalore Chemicals and Fertilizers, Ltd.
INDIA

Mr. P. V. Dilip
Assistant Operation Engineer
Southern Petrochemical Industries Corporation, Ltd.
INDIA

Mr. O. P. Gaur
Indian Farmers Fertiliser Cooperative, Ltd. (IFFCO)
INDIA

Mr. V. K. Goyal
Plant Supt.--DAP
Zuari Agro Chemicals, Ltd.
INDIA

Mr. N. K. Gupta
Deputy Chief Engineer
Hindustan Fertilizer Corporation, Ltd.
INDIA

Mr. Om Prakash Gupta
Assistant Supt.
Indian Farmers Fertilizer Co-Operative Limited
INDIA

Mr. M. Kalyanaraman
Rashtriya Chemicals & Fertilizers, Ltd.
INDIA

Dr. T. N. Kumar
The Fertilisers and Chemicals Travancore, Ltd.
INDIA

Mr. N. Natarajan
Deputy Chief Engineer
Fact Engineering and Design Organisation
INDIA

Mr. Y. R. Pakkala
Rashtriya Chemicals & Fertilizers, Ltd.
INDIA

Mr. R. G. Pillai
Deputy Gen. Manager
The Fertilisers and Chemicals Travancore, Ltd.
INDIA

Mr. D. Singh
Production Manager--DAP
Hindustan Lever, Ltd.
INDIA

Mr. S. L. Subramanya
Madras Fertilizers, Ltd.
INDIA

Mr. T. R. Thacker
Gujarat Narmada Valley Fertilizer Co., Ltd.
INDIA

Mr. C. Thomas
Madras Fertilizers, Ltd.
INDIA

Mr. J. S. Vasani
General Manager
Hindustan Dorr Oliver
INDIA

Mr. R. Verghese
Sr. Process Eng.
Indian Farmers Fertiliser Cooperative, Ltd.
INDIA

Mr. Yusuf Budianto
P.T. Petrokimia Gresik
INDONESIA

Mr. Apit Syakib Ruslan
P.T. PUSRI
INDONESIA

Mr. Hae-Won Yoon
Manager of Urea Dept.
Korea Fertilizer Company
KOREA

Mr. Karim B. Sabid Khan
Manager
National Farmers Association
MALAYSIA

Mr. K. C. Ramakrishnan
Manager
FPM Snd. Bhd.
MALAYSIA

Mr. R. Saad
Project Eng.
Chemical Company of Malaysia
MALAYSIA

Mr. S. S. Sidhu
Works Manager
Chemical Company of Malaysia
MALAYSIA

Mr. Ming Lei Chen
Sr. Chemical Engineer
Shanghai Research Institute
PEOPLE'S REPUBLIC OF CHINA

Mr. Teresito I. Dano
Head, Technical Services
Atlas Fertilizer Corp.
PHILIPPINES

Mr. H. E. Guerrero
Manager, Plant Operations
Planters Products, Inc.
PHILIPPINES

Mr. J. E. Hapitan
Senior Process Engineer
Philippine Phosphate Fertilizer Corp.
PHILIPPINES

Mr. Abdullah M.B. Al Nasser
Managing Director
National Fertilizer Co., Ltd.
SAUDI ARABIA

Mr. Riyadh I. Al-Saad
Operations Manager
National Chemical Fertilizer Co.
SAUDI ARABIA

Mr. Sakchai Intasotti
Regional Warehouse Manager
Marketing Organization for Farmers
THAILAND

Mrs. Kanda Roopcharoen
Thai Central Chemical Co., Ltd.
THAILAND

Mr. Kamol Triviboonvanich
Thai Central Chemical Company, Ltd.
THAILAND

Mr. Yongyuth Youngpadej
Thai Central Chemical Co., Ltd.
THAILAND