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Comparison of the economics of three processes for  
manufacturing granular compound or complex fertilisers

By Ph. Moraillon, (Péchiney-  
St. Gobain, France).

The consumption of compound or complex fertilizers has increased enormously during the last ten years, while there has at the same time been a trend towards fertilizers with a high nutrient content. In order to meet the increasing demand, manufacturers must periodically consider installing new plant. Of the many problems raised by expansion, the most important is unquestionably the choice of the most economic process. This is a difficult matter in view of the large number of processes available and the great variety of raw materials and intermediate products that can be used.

We shall try to compare the economics of three very widely used processes:

Process I - Manufacture of complex fertilizers based on ammonium sulphate and ammonium phosphates and produced by neutralizing a mixture of sulphuric and phosphoric acids with ammonia, adding a potassium salt, granulating and drying. All the nitrogen in the product is ammoniacal, and the  $P_2O_5$  is mainly water-soluble (varying between 94 and 96% according to the iron/aluminium content of the phosphate rock used in the manufacture of the wet-process phosphoric acid).

Process II - Manufacture of fertilizers based on ammonium nitrate and monocalcium phosphate and obtained by adding a hot concentrated neutral solution of ammonium nitrate, preferably manufactured in the same factory, to a mixture of superphosphate (single, triple or enriched) and a potassium salt, with simultaneous addition of ammonia to neutralize the free acidity of the superphosphate, followed by granulation and drying. The product contains a slight excess of ammoniacal

over nitrate nitrogen (according to the degree of neutralization of the superphosphate); the  $P_2O_5$  is virtually all water-soluble (90-95%):

Process III - Manufacture of complex fertilizers based on ammonium nitrate and dicalcium phosphate and obtained in the following way:

Acidulation of the phosphate rock with a mixture of nitric, sulphuric and phosphoric acids; ammonia injection resulting in the formation of dicalcium phosphate and calcium sulphate to the stage where only about 10% of the  $P_2O_5$  remains in the form of monocalcium phosphate; addition of a potassium salt; granulation; drying.

In the fertilizer thus obtained, the nitrogen is half ammoniacal and half nitrate, and nearly all the  $P_2O_5$  is citrate-soluble, only 10-15% being water-soluble.

We shall examine the raw material requirements and the manufacturing costs for these 3 processes. To avoid vagueness, we shall take a definite formula, for example 14-14-14.

#### Raw Materials

Let us assume that the phosphate rock contains 33.5%  $P_2O_5$ , with an analysis closely resembling Morocco 75% rock. The potassium salt is a chloride with 60%  $K_2O$  content.

The theoretical composition of the 14-14-14 grade obtained by each of our three processes is given in Table I.

TABLE I

	Process I	Process II	Process III
NH <sub>3</sub>	170	89	85
HNO <sub>3</sub>		300	315
H <sub>2</sub> SO <sub>4</sub>	355		16
H <sub>3</sub> PO <sub>4</sub>	193.2		80
(P <sub>2</sub> O <sub>5</sub> )	(140		(58.0
(H <sub>2</sub> O)	(53.2		(22.0
Impurities in Phos. Acid	23.8		9.8
Phos. rock with 33.5% P <sub>2</sub> O <sub>5</sub>			253
Super. enriched to 36.2% available P <sub>2</sub> O <sub>5</sub>		387	
Potassium Chloride	233	233	233
Coating powder	10	10	10
Total residual H <sub>2</sub> O	15	20	16
Total	1000.0	1039	1017.8
Subtract		39	17.8
Total	1000	1000	1000

Notes on table of raw materials:

Process I - NH<sub>3</sub> bound with H<sub>2</sub>SO<sub>4</sub>: 123.

NH<sub>3</sub> bound with H<sub>3</sub>PO<sub>4</sub>: 47, hence a molecular ratio  
 $\text{NH}_3/\text{H}_3\text{PO}_4 = 1.40$ .

Process II - NH<sub>3</sub> bound with superphosphate: 8.

NH<sub>3</sub> bound with HNO<sub>3</sub>: 81.

The amount to be subtracted from the total, 39,  
represents total water introduced by the super.

Process III - The amount to be subtracted from the total, 17.8,  
represents the water contained in the phosphate rock,  
the water formed during the reactions (decomposition  
of CaCO<sub>3</sub>, formation of SiF<sub>4</sub>), gases given off  
(CO<sub>2</sub>, SiF<sub>4</sub>), a total of about 7% by weight of the  
phosphate rock.

If it is desired to avoid using sulphuric acid in Process III,  
the amounts of phosphate rock and phosphoric acid should be  
adjusted accordingly so as to give a H<sub>3</sub>PO<sub>4</sub>/rock ratio = 0.38 by

weight, with the addition of an inert substance (sand, dolomite or gypsum).

### Industrial Consumption

To calculate from Table I the actual consumption of raw materials per ton of product manufactured, we must add losses in the plant and any likely excess consumption: we shall use the following weighting:

$\text{NH}_3$ : 2% in processes I and II; 3% in process III;  $\text{HNO}_3$ : 2%  
Other materials: 1%.

Thus the consumption of raw materials, expressed in kg/1000 kg of 14-14-14 product is:

TABLE II

	Process I	Process II	Process III
$\text{NH}_3$	173.5	90.8	87.5
$\text{HNO}_3$		306	321.3
$\text{H}_2\text{SO}_4$	358.5		16.2
$\text{P}_2\text{O}_5$ from phos. acid	141.5		58.6
Phosphate rock			255.5
Enriched super.		391	
Potassium chloride	235.5	235.5	235.5
Coating powder	10.1	10.1	10.1

### Consumption of primary raw materials

Three intermediate products appear in the above table: nitric acid, phosphoric acid and enriched superphosphate. To enable comparisons to be made, we give below their equivalents in the primary raw materials  $\text{NH}_3$ ,  $\text{H}_2\text{SO}_4$  and phosphate rock.

Nitric acid: with a 95% yield, 1000 kg of  $\text{HNO}_3$  are produced from 284 kg  $\text{NH}_3$

Phosphoric acid: assuming an average yield of 94% from the process, raw materials consumption per ton of  $\text{P}_2\text{O}_5$  would be as follows:

Morocco phosphate rock, 33.5%  $\text{P}_2\text{O}_5$  = 3170 kg;

$\text{H}_2\text{SO}_4$  = 2700 kg.

Enriched Superphosphate (with 36.2% available  $P_2O_5$ ):

Industrial consumption per ton:-

phosphate rock	457
$H_2SO_4$	121
$P_2O_5$ from phosphoric acid	225

or in terms of primary raw materials:

phosphate rock:	$457 + 713 = 1170$
$H_2SO_4$	$: 121 + 607.5 = 728.5$

Note that instead of enriched superphosphate a mixture of one third single superphosphate (18.6% available  $P_2O_5$  after curing) with two thirds triple super (45% available  $P_2O_5$ ) may equally well be used. The advantage of making enriched superphosphate directly is that the use of 93%  $H_2SO_4$  allows a weaker phosphoric acid to be used, (47.5% instead of 50%  $P_2O_5$ ), giving a slight saving on concentration.

We can now compile a table showing the consumption of basic raw materials for each process per 1000 kg. of 14-14-14.

TABLE III

	<u>Process I</u>	<u>Process II</u>	<u>Process III</u>
NH <sub>3</sub>	173.5	$90.8 + 87 = 177.8$	$87.5 + 91.3 = 178.8$
H <sub>2</sub> SO <sub>4</sub>	$358.5 + 382 = 740.5$	285	$16.2 + 158.1 = 174.3$
Phos. rock	449	458	$255.5 + 185.8 = 441.3$
Potassium chlor.	235.5	235.5	235.5
Coating material	10.1	10.1	10.1

This table shows particularly clearly the differences in sulphuric acid consumption.

To show the differences even more clearly, let us call A the amount of primary raw materials common to all three processes.

Then  $A = 173.5 NH_3 + 174.3 H_2SO_4 + 441.3$  phosphate rock +  
 $235.5 KCl + 10.1$  coating material.

Table III then becomes:

TABLE IV

	<u>Process I</u>	<u>Process II</u>	<u>Process III</u>
Common materials	A	A	A
NH <sub>3</sub>		4.3	5.3
H <sub>2</sub> SO <sub>4</sub>	566.2	110.7	
Phosphate rock	7.7	16.7	

Let us also recapitulate the amounts of intermediate products needed in each case per ton of 14-14-14:

TABLE V

HNO <sub>3</sub> - kg		306	321.3
Phosphoric acid, kg. P <sub>2</sub> O <sub>5</sub>			
with 32% P <sub>2</sub> O <sub>5</sub>	141.5		
with 47.5% P <sub>2</sub> O <sub>5</sub>		88.0	58.6
Enriched super in kg		391	

#### Cost of manufacture

In order to calculate the differences in production costs from the data given above, we must set a value on the raw materials used and estimate the cost of manufacture of the actual fertilizer and of the intermediate products used in making it.

We shall use the following expressions:

N = value as used of NH<sub>3</sub> (in francs per kg)

S = " " " H<sub>2</sub>SO<sub>4</sub> (fr/kg)

P = " " " phosphate rock (fr/kg)

K = value as used of raw materials A common to all processes in francs per ton of 14-14-14

n = cost of manufacturing and storing HNO<sub>3</sub> (fr/kg)

p = cost of manufacturing and storing 32% phosphoric acid (fr/kg P<sub>2</sub>O<sub>5</sub>)

c = cost of concentrating phosphoric acid to 47.5% P<sub>2</sub>O<sub>5</sub> (fr/kg P<sub>2</sub>O<sub>5</sub>)

s = cost of manufacturing enriched superphosphate (fr/kg) to include rock grinding, actual manufacture, conveying, storing, taking from store, grinding and handling the super to the granulation plant.

$f_1, f_2, f_3$  = cost of manufacturing and storing 1 ton of 14-14-14 made by process I, II or III.

$R_1, R_2, R_3$  = total cost of 1 ton of 14-14-14 made by process I, II, or III

From Tables IV and V we obtain the figures:

$$R_1 = K + 566.2 S + 7.7 P + 141.5 p + f_1$$

$$R_2 = K + 4.3 N + 110.7 S + 16.7 P + 306 n + 88 (p + c) + 391 a + f_2$$

$$R_3 = K + 5.3 N + 321.3 n + 58.6 (p + c) + f_3$$

These formulæ enable us to determine the most economic process with regard to raw material prices and production costs in any particular factory.

In calculating the production costs, the following points must be borne in mind:

- the phosphate rock, from whatever source, does not need grinding in the case of process III where the rock is treated with a mixture of nitric, sulphuric and phosphoric acids

- this is also true of many types of rock, particularly those of African origin, for the manufacture of phosphoric acid

- manufacturing costs (including capital expenditure) for the final granulated product differ appreciably from one process to another.

For instance, the amount of water to be evaporated, which determines the size of the drying and granulating plant, is much greater in the slurry processes I and III than in process II where a mixture of solids is granulated by a hot concentrated solution of ammonium nitrate. With 14-14-14, manufactured by process I for example, the slurry before the addition of the potassium chloride must contain at least 22% water or it will not be sufficiently fluid.

In process III about the same amount of water is supplied by the acids used.

In both cases this means that some 200 kg of water must be removed per ton of finished product.

The consequent consumption of fuel oil is approximately: 22 kg/ton for process I (high temperature gas).



25 kg/ton for process III (gas temperature limited). For process II, where the amount of water to be evaporated per ton of finished product is only about 70 kg, fuel oil consumption is of the order of 11 kg/ton.

In process II the tonnage to be recycled is about twice the production tonnage, while in processes I and III it depends on the techniques used:

- if the slurry is mixed with the recycled material, recycled tonnage is 6-8 times production tonnage for 14-14-14.

- if the slurry is sprayed into the drier, recycled tonnage falls to about twice production tonnage. But, though attractive, this technique unfortunately requires very liquid slurries. In many cases, this means that the water content of the slurry has to be increased and the drier must be larger, and hence fuel consumption is higher. This technique is, therefore, not economically advantageous except in certain special cases.

- a third technique, i.e., injecting the ammonia into the granulator, allows both water content and recycled tonnage to be reduced. This, however, requires the addition of a scrubber for ammonia recovery.

In practice, in the present state of technology, a given drier/granulator unit has a production capacity of more than twice as much in process II as it has in processes I or III. For the same capacity, therefore, capital expenditure will be appreciably higher for process I and higher still for process III, which needs an expensive reactor. Manufacturing costs, especially fuel and electricity costs, vary similarly.

Against this, process II requires the previous manufacture of superphosphate, for which the rock must be ground, and which must be stored and cured. This involves considerable capital expenditure and handling costs.

#### Worked example

In order to estimate the different total costs resulting from the three processes, we shall use figures based on the experience of a French factory for the cost of raw materials as used and the cost of manufacturing (including depreciation, but excluding

overheads):

N = 0.35	francs per kg	NH <sub>3</sub>
S = 0.055	"	H <sub>2</sub> SO <sub>4</sub>
P = 0.079	"	Morocco rock 75%
n = 0.022	"	HNO <sub>3</sub>
p = 0.062	"	P <sub>2</sub> O <sub>5</sub> from 32% P <sub>2</sub> O <sub>5</sub> phosphoric acid
c = 0.034	"	P <sub>2</sub> O <sub>5</sub> from 47.5% P <sub>2</sub> O <sub>5</sub> phosphoric acid
s = 0.013	"	enriched superphosphate
f <sub>1</sub> = 22	francs per ton of 14-14-14 manufactured by process I	
f <sub>2</sub> = 19	"	" " process II
f <sub>3</sub> = 24	"	" " process III

f<sub>1</sub>, f<sub>2</sub> and f<sub>3</sub> were based on an average production of about 10 tons/hour; the important point, however, is not their absolute value but the differences between the production costs of the various processes.

Using the above figures, we can construct the following table of total cost in fr/ton of manufacturing 14-14-14.

	<u>Process I</u>	<u>Process II</u>	<u>Process III</u>
Raw materials:			
Common to all	K	K	K
NH <sub>3</sub>		1.51	1.85
H <sub>2</sub> SO <sub>4</sub>	31.16	6.09	
Phosphate rock	0.61	1.32	
Total raw materials	K+31.77	K+8.92	K+ 1.85
Manufacturing costs:			
Nitric acid		6.74	7.07
Phos. acid with 32% P <sub>2</sub> O <sub>5</sub>	8.77	5.45	3.63
Concentration of phos.acid.		2.99	1.99
Enriched superphosphate		5.08	
Finished granulated product	22	19	24
Total manufacturing costs	30.77	39.27	36.69
Overall total	K+62.54	K+48.19	K+38.54

The differences between the production costs are therefore:

$$R_1 - R_2 = 14.35 \text{ fr/ton}$$

$$R_1 - R_3 = 24.0 \quad "$$

$$R_2 - R_3 = 9.65 \quad "$$

There is a significant difference in favour of process III (nitric acid treatment of phosphate rock). For example, for a small factory making only 80,000 tons/year of 14-14-14, the annual savings due to using process III would be :

compared with process I - 1,920,000 francs

compared with process II - 772,000 francs

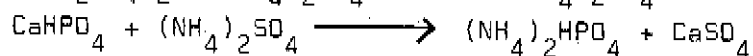
If it is essential for the  $P_2O_5$  to be water-soluble, then process II must be chosen.

It will be noted that the difference between processes II and III (9.65 fr/t) is greater than the saving on raw materials (7.07 fr/t), the latter being mainly due to the saving in sulphuric acid (6.09 fr/t).

#### NOTE

For a good understanding of the underlying reasons for these differences in total cost, it is sufficient to recall a few simple principles:

- 1) the incorporation of ammonium sulphate in compound fertilizers, even if it is manufactured on site, is an expensive way of providing nitrogen. To fix 1 kg. of nitrogen requires 3.5 kg of  $H_2SO_4$  and the price of sulphuric acid is generally much higher than the cost of converting 0.5 kg of ammoniacal nitrogen into  $HNO_3$ , which is what is needed to obtain 1 kg of nitrogen in the form of ammonium nitrate.
- 2) the nitrogen in ammonium phosphates must be calculated at the same rate as for ammonium sulphate, because according to the theoretical equations :



it will be seen that from the point of view of raw materials consumption, monoammonium phosphate is equivalent to a mixture of monocalcium phosphate and ammonium sulphate, while diammonium phosphate is equivalent to a mixture of dicalcium phosphate and ammonium sulphate.

The nitrogen in ammonium phosphates is therefore just as

expensive as in ammonium sulphate.

3) as regards the available forms of  $P_2O_5$ , the manufacture of mono-acid phosphates (dicalcium or diammonium) gives an appreciable saving of sulphuric acid (35-40%) as compared with the manufacture of di-acid phosphates (monocalcium or monoammonium). Thus, dicalcium and diammonium phosphates are a cheaper form of  $P_2O_5$ .

Monoammonium phosphate contains the most expensive forms of both nitrogen and  $P_2O_5$ . Hence the manufacture of fertilizers based on ammonium sulphate and monoammonium phosphate, such as 11-48-0 and 16-20-0, seems to make nonsense from the economic point of view. It may, however, be justified in certain cases by agronomic considerations or questions of hygroscopicity.

The case of Complex Fertilizers with only partly water-soluble  $P_2O_5$

In some countries we have seen in recent years a tendency to prefer fertilizers containing a high proportion of water-soluble  $P_2O_5$ , e.g., 50% to those complexes which are essentially based on the dicalcium form of  $P_2O_5$ . Process III may be adapted in two different ways for the manufacture of a fertilizer of this more water-soluble type.

Process IIIA : Manufacture of a fertilizer based on ammonium nitrate, monocalcium phosphate and dicalcium phosphate. As regards the process producing dicalcium phosphate, all that is needed is to increase the proportion of sulphuric and phosphoric acids and to stop the ammoniation at a lower pH.

Process III B : Manufacture of a fertilizer based on ammonium nitrate, dicalcium phosphate and monoammonium phosphate. Compared with the normal process, the amount of nitric acid should be reduced and the sulphuric and phosphoric acids increased in suitable proportions.

It would appear that producers use process III B exclusively, probably because there are certain difficulties in granulating a slurry containing both monocalcium and dicalcium phosphate.

We shall now compare the economics of process III B with those of process II (mixing a solution of ammonium nitrate with superphosphate) for the production of a 20-20-0 NP fertilizer.

Let us suppose that we wish to obtain 50% of the  $P_2O_5$  in a water - soluble form by process III B (as against about 90 % by process II)  
Theoretical composition of the fertilizer in each case

	<u>Process II</u>	<u>Process III B</u>
$NH_3$	127	133.5
(bound to $HNO_3$ )	(115.5)	(109.2)
(bound to $H_3PO_4$ )		( 24.3)
(bound to the superphosphate)	11.5	
$HNO_3$	428	405
$H_2SO_4$		21.8
$H_3PO_4$		188.4
(P <sub>2</sub> O <sub>5</sub> )		(136.5)
(H <sub>2</sub> O)		( 51.9)
Impurities in phos. acid		23
Morocco rock		206
Triple Super. (45% P <sub>2</sub> O <sub>5</sub> available)	445	
(P <sub>2</sub> O <sub>5</sub> from phos. acid)	(148)	
(Phosphate rock)	(170)	
Coating material	20	20
Total residual H <sub>2</sub> O	25	16
<b>TOTAL</b>	<b>1045</b>	<b>1013.7</b>
Subtract	45	13.7
<u>TOTAL</u>	<u>1000</u>	<u>1000</u>

NOTES

Process II - we have assumed the following raw materials consumption per ton of triple superphosphate with 45% available  $P_2O_5$ :

$P_2O_5$  from concentrated phosphoric acid (50%  $P_2O_5$ ): 382 kg.

Morocco rock - 382 kg, or as  $P_2O_5$  : 428 kg.

The amount subtracted from the total - 45 - represents the total water content of the superphosphate.

Process III B - The amount of  $H_3PO_4$  used in the formation of di-calcium phosphate equals:

$$\text{Phosphate rock} \times 0.35 = \text{H}_2\text{SO}_4 = 206 \times 0.35 = 21.8 = 50.4$$

There is thus  $188.4 - 50.4$  left to fix the  $\text{NH}_3 = 138 \text{ H}_3\text{PO}_4$ , which gives a molecular ratio as follows:-

$$\frac{\text{NH}_3 \text{ bound to } \text{H}_3\text{PO}_4}{\text{H}_3\text{PO}_4} = 1.012$$

The amount equivalent to water-soluble  $\text{P}_2\text{O}_5$  is  $138 \times \frac{71}{98} = 100$  or 50% of the available  $\text{P}_2\text{O}_5$ .

The amount subtracted from the total - 13.7 - corresponds to the water of the phosphate rock, the water formed in the reactions, and the  $\text{CO}_2$  and  $\text{SiF}_4$  evolved.

Industrial raw materials consumption, with allowances for losses and excess consumption

	<u>Process II</u>	<u>Process III B</u>
NH3	129.5	137.5
HNO3	436	413
H2SO4		22
$\text{P}_2\text{O}_5$ from phosphoric acid		138
Morocco rock		208
Triple Superphosphate	450	
(P2O5 from phosphoric acid	(150	
(Phosphate rock	(173	
Coating material	20.2	20.2

Consumption of basic raw materials

	<u>Process II</u>	<u>Process III B</u>
NH3	$129.5 + 123.8 = 253.3$	$137.5 + 117.5 = 255$
H2SO4	405	$22 + 373 = 395$
Phosphate rock	$173 + 476 = 649$	$208 + 437 = 645$
Coating material	20.2	20.2

It will be seen that process III B gives only a slight saving of sulphuric acid, as compared with process II.

Assuming that  $A = 253.3 \text{ NH}_3 + 395 \text{ H}_2\text{SO}_4 + 645 \text{ phos. rock} + 20.2 \text{ coating material}$ , we obtain the following final table for primary raw materials and intermediates required to manufacture 1000 kg of 20-20-0 fertilizer.

	<u>Process II</u>	<u>Process III B</u>
<u>Raw materials.</u>		
Common to all	A	A
NH <sub>3</sub>		1.7
H <sub>2</sub> SO <sub>4</sub>	10	
Phosphate rock	4	
<u>Intermediates</u>		
HNO <sub>3</sub>	436	413
P <sub>2</sub> O <sub>5</sub> from phos. acid. (50% P <sub>2</sub> O <sub>5</sub> )	150	138
Triple superphosphate	450	

Total cost

Using the values established above, we arrive at the following figures for total cost:

	<u>Process II</u>	<u>Process III B</u>
<u>Raw materials</u>		
Common to all	K	K
NH <sub>3</sub>		0.60
H <sub>2</sub> SO <sub>4</sub>	0.55	
Phosphate rock	0.32	
Total raw materials	K + 0.87	K + 0.60
<u>Manufacturing costs</u>		
Nitric acid	9.6	9.1
Phosphoric acid with 50% P <sub>2</sub> O <sub>5</sub>	14.7	13.5
Triple superphosphate	5.85	
Finished granulated product	19	27
Total manufacturing costs	49.15	49.6
Overall total	K + 50.02	K + 50.20

There is virtually no difference between the two total costs, with regard to both raw materials and manufacturing costs. Nevertheless, process II has the following advantages:  
- much lower capital expenditure, the granulating plant being

much simpler and less extensive than for III B.

- in the final product about 90% of the  $P_2O_5$  is water-soluble compared with 50% in process III B.

It is the presence of monoammonium phosphate which cancels out the saving represented by the formation of dicalcium phosphate. It would be much more attractive to make a mixture of dicalcium and monocalcium phosphates.

In addition to the direct process starting from phosphate rock, which possibly gives rise to a certain amount of difficulty with granulation, we should like to mention a mixed process which gives excellent results: this consists of reacting the phosphate rock with nitric, sulphuric and phosphoric acids, ammoniating normally as in process III, then adding ammoniated superphosphate which brings in an equal amount of  $P_2O_5$ . This process would show a slight saving over process III, but would, however, require a larger granulation plant.

#### Conclusions

If we assume the conditions to be those of an integrated factory making the acids consumed, the granulated complex fertilizers with the lowest total cost will be those based on ammonium nitrate and dicalcium phosphate obtained by acidulation of phosphate rock by nitric, sulphuric and phosphoric acids, with subsequent ammoniation of the resulting slurry.

At the opposite end of the price scale we find fertilizers based on ammonium sulphate and ammonium phosphates, obtained by neutralizing with ammonia a mixture of sulphuric and phosphoric acids. Between these two extremes, but closer to the first than to the second, we have fertilizers based on ammonium nitrate and monocalcium phosphate obtained by mixing a concentrated solution of ammonium nitrate and superphosphate (single, enriched or concentrated).

Complex fertilizers based on ammonium nitrate, dicalcium phosphate and monoammonium phosphate, with 50% of the  $P_2O_5$  in water-soluble form, obtained by acidulating phosphate rock with a mixture of phosphoric and nitric acids followed by ammoniation, make no appreciable saving of sulphuric acid compared with fertil-



izers based on ammonium nitrate and monocalcium phosphate (superphosphate) and cost almost the same to manufacture. On the other hand, the plant requires a higher capital expenditure. Obviously the foregoing conclusions can be vitiated by certain special economic conditions, for instance, local availability of residual sulphuric acid or ammonium sulphate at a very low price. Moreover, the customer's demands must be respected: if the customer wants non-hygroscopic fertilizers without nitric acid and with water-soluble  $P_2O_5$ , we cannot do otherwise than supply him with fertilizers based on ammonium sulphate and phosphates, although they are more expensive to make. If hygroscopicity is not important, it would be advantageous to manufacture urea-superphosphate mixtures, the price per unit of nitrogen in urea being in general no higher than in ammonium nitrate.

It is very difficult, if not impossible, to choose a process which will meet all future demands. No-one can make long-term predictions as to the direction of changes in customers' requirements, neither as regards quality nor tonnage. The best solution is to have a plant which can work equally well with one or other of two processes, or with a combination of these processes. At the very least, a plant designed to run according to a certain process must be able to be adapted with a few minor modifications to operate a different process.

We must also take into account the large differences in production capacity of a given plant according to the techniques employed. For example, if we substitute a superphosphate based mixing process for a process where phosphate rock is reacted with nitric acid, this enables the production of an existing plant to be more or less doubled. This is one way of meeting increased sales with minimum expenditure while awaiting the erection of new plant. The alternate use of both processes during the same year will enable the exact annual tonnage required to be produced at the lowest total cost, while at the same time arranging production to suit the seasonal peaks in fertilizer dispatch.

DISCUSSION

Mr. Ph. MORAILLON (France) : The papers presented to ISMA Technical Conferences, this morning as well as on previous occasions, show that there are in existence a very large number of processes for manufacturing granular compound or complex fertilisers. In order to obtain a given formulation, one may choose between various possible raw materials according to the requirements of different techniques. The problem arising for the manufacturer is to select the most economic process in the particular circumstances of his factory.

In my paper I have tried to establish a simple method of comparison and to demonstrate the essential differences in production costs. As far as raw materials are concerned, the processes differ mainly in regard to the consumption of sulphuric acid. The fertilisers in which the nitrogen is in ammoniacal form only, i.e. ammonium sulphate or ammonium phosphates, require the direct or indirect provision of large quantities of sulphuric acid to fix the nitrogen. It is more economic to introduce the nitrogen in the form of ammonium nitrate, provided that nitric acid is available at a normal price, which is the case for a factory which converts its own ammonia into nitric acid. The solubilisation of  $P_2O_5$  requires more or less sulphuric acid, according to the grade of phosphate obtained. It is more worthwhile to manufacture mono-acidic, di-calcium or di-ammonium phosphates, than di-acidic mono-calcium or mono-ammonium phosphates.

Production costs depend upon the number of stages required to obtain the final fertiliser and on the granulation costs proper. The latter vary mainly according to the amount of water to be evaporated. In brief, it seems that in the case of a factory having its own nitric acid manufacturing capacity, the fertilisers with the lowest production costs are those based on ammonium nitrate and di-calcium phosphate: whilst the most costly fertilisers are the ammonium sulpho-phosphates.

In order to maximise profit, however, one must always bear in mind the production capacity of the existing installation, in relation to the process used and the sales possibilities. These considerations can lead to a preference, at least provisionally, for fertilisers based on ammonium nitrate and superphosphate. In a given granulation plant one can, in fact, produce roughly twice as much compound fertiliser from this mixture as in the case of complex fertilisers based on ammonium nitrate and di-calcium phosphate. I hope the various compound fertiliser manufacturers present today will come forward with their own opinions on this question and tell us of their own experience.

Mr. I. WENNBERG (Sweden) : Mr. Moraillon has covered his subject in such an excellent and comprehensive manner that he may well have taken all the life out of our discussion before it starts. Nevertheless, I should like to broaden certain aspects.

Firstly, fertilisers have no economic value at all until they have reached the soil in whatever form they may take. Secondly, from that time on, their value is established only by crop response. It may seem awkward to bring up such simple, basic statements, but I have seen so many such economic comparisons where these points have been forgotten that I think they are worth re-stating. Mr. Moraillon has avoided making any mistakes in this respect by choosing a definite formula, 14-14-14, and bringing the chemical nature of the compared products to a region where the agronomists have still scope for argument amongst themselves.

A comparison of the flexibility of the different processes would be a useful addition to Mr. Moraillon's evaluation. It is of value if a particular process can be adapted to follow particular market trends. Thus flexibility with regard to the  $N : P_2O_5$  ratio, or the effect on capacity brought about by decreasing the  $K_2O$  content, or the way in which formula variations affect the overall concentration of plant nutrients in the product are all important aspects.

Reverting to the straight cost comparison, Mr. Moraillon has shown very clearly the connection between sulphuric acid consumed in the processes and final costs, giving a balance on the credit side for less use of sulphuric acid and on the debit side the cost of the various methods of achieving the same effect without sulphuric acid. Without criticising the generalisations made in the descriptions of the various methods and processes with regard to the chemical nature of the compounds, I should like to draw attention to the wide variation in results obtained by ammoniation. For instance, recent patent applications show that one can easily change 33% water solubility to 50% water solubility of the  $P_2O_5$  in the product. Furthermore, developments in evacuation techniques may change the conclusions one can draw from this paper, regarding both capital costs and production costs.

Mr. MORAILLON : With regard to the relative agronomic value of the fertilisers produced according to the different processes, as I mentioned in my paper, this varies according to circumstances. There may be areas where ammoniacal nitrogen is used, and other areas where nitro-ammoniacal nitrogen is preferred. This question, therefore, depends on customers' requirements; but if nitrogen is required in ammoniacal form, one can do little else than produce ammonium sulpho-phosphate.

With regard to the flexibility of this process, I have also noted on the last page of my paper that the essential quality of any process is flexibility: one should be able to adapt it to variations in both formulation and sales volume. This is why I propose a solution by which fertilisers can be produced in the same plant either by a process of solubilising phosphate rock by means of nitric, sulphuric and phosphoric acids, followed by ammoniation, or by a process using super-phosphate and concentrated solutions of ammonium nitrate. The second process undoubtedly gives a much greater production capacity in the same plant and also permits considerably wider variation of the formulas produced. In fact, practically any formulation can be produced in this way.

Mr. A. GEORGIU (Greece) : As is well known, complex fertilisers are becoming increasingly important throughout the world. This is also the case in Greece, where ammonium sulpho-phosphate (16-20-0) is gradually tending to replace superphosphate. There are various reasons for this, one of which is that complex fertilisers permit a reasonable balance to be maintained between nitrogen and  $P_2O_5$ . Thus, the points of view put forward by Mr. Moraillon have often been discussed and examined by us; but the essential thing is that no fertiliser can be considered solely from the point of view of costs of production. Chemical fertilisers are not abstract materials. They are not things which can be considered merely from the point of view of the producer. Essentially, they must be considered from the consumer's stand-point. Agronomic factors are therefore so essential that they can completely reverse the economic aspects indicated by Mr. Moraillon. If, as is the case with us in Greece, one is obliged to produce a 16-20-0 fertiliser, one must bear in mind the fact that sulphur is not merely a ballast in the fertiliser, but is, on the contrary, an essential element in plant nutrition. A fertiliser such as is proposed by Mr. Moraillon, containing no sulphur, is considered by us as inadequate for plant nutrition.

A second aspect to be considered is that the sulphur, particularly in the form of sulphate, acidifies the soil. In this way it contributes to an acceleration of  $P_2O_5$  assimilation and prevents the occurrence of reversion caused by the alkaline soils which exist mainly in the Mediterranean area.

I should therefore like to draw your attention to the fact that ammonium sulpho-phosphate - and I say this because ammonium sulpho-phosphate contains no potash - must in any case contain sulphate ions, the sulphur content of which is from an economic and agronomic point of view essential.

But these fertilisers must also be assimilated in a reasonable manner when they are put into the soil. There is therefore a third point of view : the assimilability of the nitrogen. As you know, nitrogen in nitrate form is assimilated very rapidly, while ammonia must first be nitrified by the soil bacteria. In view of

the higher temperatures in Mediterranean countries, ammonia is assimilated more slowly than nitrate, but the acceleration of its nitrification by the higher temperatures means, in effect, that the ammonia does in fact react sufficiently rapidly to correspond to plant requirements.

Mr. MORAILLON : I completely agree with Mr. Georgiou concerning the importance which must be attached to agronomic considerations. Mr. Georgiou has quoted the case of 16-20-0. This fertiliser undoubtedly has a maximum sulphur content if it is produced from mono-ammonium phosphate and ammonium sulphate, but it still has a very considerable sulphur content if it is produced from ammonium nitrate and enriched superphosphate. The 16-20-0 formulation is not so rich as to exclude the possibility of using enriched superphosphate, which is essentially a mixture of triple and ordinary superphosphates, and I think that the amount of sulphur which would be carried to the soil in this way would be largely adequate.

With regard to the process of solubilisation by nitric, sulphuric and phosphoric acids, followed by ammoniation, the amount of sulphur present in the form of calcium sulphate in this fertiliser would undoubtedly be very small. If you refer to the table on page 3 of my paper, you will see that in the case of 14-14-14 I have put 16 kg/ton of sulphuric acid. One could even perhaps go a little further than this, because I have proposed a fairly high level of impurities in the phosphoric acid; but, even so, this does not give many sulphate ions. In the 16-20-0 formulation, which is less rich than the 14-14-14, there would be more sulphuric acid, because the phosphate rock would be reacted with a sulpho-phosphoric mixture. Thus the fertiliser would probably contain an adequate amount of sulphur from the agronomic point of view.

In any case, there remains the intermediate process, using superphosphate and ammonium nitrate, and this gives a large quantity of sulphur which would certainly be agronomically adequate.

With regard to the form of the nitrogen, ammoniacal nitrogen has certainly been preferred for a long time in the Southern part of France; but, at the present time, there seems to be a swing in the other direction, and the nitrogen of ammonium nitrate is becoming increasingly sought after, even in areas with a hot climate.

Mr. P. NOUYRIGAT (France) : I should like to ask Mr. Moraillon to what extent, in his parameter "s" which corresponds to the production costs of enriched superphosphate, the decrease in the cost price, which can be achieved by producing triple superphosphate in situ, might affect his conclusions as to the cost comparison of the various processes. In particular, I see that a certain amount of the expenditure included in this "s" relates to transport, handling, etc., of the superphosphate as far as the factory expenditure which it would be difficult to suppress. Is the effect of this expenditure negligible or, has it, on the contrary, a certain importance?

Mr. Ph. MORAILLON : These expenses are, in fact, fairly important. In the example I quoted, they have been evaluated at 13 NF per ton of enriched superphosphate, and this is, obviously, the weak point of the process based on superphosphate, because it presupposes an intermediate stage of manufacture. On the other hand, it has the advantage of economising on granulation proper, in view of the simplicity of the process using the ammonium nitrate - superphosphate mixture by comparison with the processes involving slurries. Thus if you lose in one respect, you gain in another; but, as I have observed, if you compare complex fertiliser production processes, where there is a plant with sufficient capacity, the costs of production are a little higher for the process involving the intermediate superphosphate stage than for the direct process. The direct process based on ammonium nitrate and di-calcium phosphate makes a saving which is larger than the saving in sulphuric acid, or, in other words, there is not only a saving in sulphuric acid but in other manufacturing costs also.