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ECONOMIC AND TECHNICAL ASPECTS IN  
SOME DIFFERENTIAL NPK PROCESSES

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1 INTRODUCTION

The manufacturing processes of fertilizers largely depend on the available raw materials and the desired fertilizer grades. In various contexts comparisons have been made with processes based on different raw materials, and they show that the situation mainly depends on the market prices of raw materials and domestic raw material production, and that the differences in local conditions do not always allow a general comparison to be made.

In the following we shall nevertheless attempt to compare certain fertilizer processes, ammonphosphate and phosphonitric processes with their special modifications, which are presently applied in Kemira Oy, and which all use sulphuric acid as the basic raw material. In spite of the common starting point there are differences in the processes and raw materials, and also in the properties of the products and the costs. When making comparisons it must be remembered that the plants have been constructed at different times within a period of seven years. The processes have since been developed further and the starting points have changed. On the other hand, local conditions and requirements, such as the use of weak sulphuric acid as raw material in Process 1, have a considerable effect on the process, the product quality and the production costs.

Owing to their local characteristics and different ages the processes are not comparable all the way through, but anyhow their particular properties and their applicability to different local conditions and requirements will be revealed in the description. To facilitate comparison, all capacities have been reduced to 200 000 t/a.

## 2 PROCESSES

Kemira uses several different fertilizer processes and produces for instance these grades : 15-20-15, 15-25-10, 15-15-15, 20-10-10, 10-20-20, 7-24-14, 11-11-22. Production has been optimized, meaning that each process is only used in the manufacture of grades for which it is most suitable. With sulphuric acid as basic raw material, phosphoric acid or monoammonium phosphate (MAP) are mainly used as the phosphorus raw material. Some processes also use small amounts of phosphate rock with nitrophosphate principle.

For the comparison we have chosen three processes, which are used for production of the above mentioned high-analysis NPK fertilizers. The processes each specialize in certain main products, having however in common grade 15-20-15, which therefore has been chosen as comparison grade. It is not the best possible grade for all three but anyway makes comparison possible. The processes have been constructed at different times, which naturally complicates the comparison, especially as concerns investments.

### 2.1 Process 1 - special ammonphosphate process

This method (1), which has been developed and designed by Kemira, is being used at our Kokkola plant. One of its raw materials is the so-called scrubber acid (30 %  $H_2SO_4$ ) from the manufacture of sulphuric acid. Other raw materials are N-solution, MAP, KCl or  $K_2SO_4$ , and trace elements. The process has been developed especially for the use of weak sulphuric acid and MAP. In the process (Appendix 1) weak sulphuric acid is first neutralized with N-solution and the solution is then concentrated in the vacuum evaporator. Powdered MAP is dissolved in the concentrated solution in the reactor. At the same time N-solution is added to obtain the correct nutrient rate and to improve the solubility of MAP. Potassium and trace elements are added in the final reactor after which we have a slurry containing all raw materials. The slurry overflows in the granulating drum where granulation takes place with recycle and is then dried in the drying drum. The granules are screened and crushed and the separated final product cooled and coated. The recycle ratio with

this grade is 1 : 6. Reactor gases are washed in the scrubber. Dusts are removed from the cooling and drying gases in cyclones, after which the drying gases are washed in the gas scrubber. Gas scrubbing waters are pumped to the pre-reactor and then concentrated in the evaporator.

The special feature of this process is that it enables the problematic weak scrubbing acid to be used. The idea is that concentration is done with a neutralized solution, whose corroding effects are not insurmountable. The method was introduced in 1970 and it has been used mainly for production of grades 15-20-15, 10-20-20, 7-24-14 and 15-15-15, the three last-mentioned suiting the process best.

## 2.2 Process 2 - ammonphosphate process

This so-called ammonphosphate based process, which is applied at Kemira's Uusikaupunki plant, uses ammonia nitric acid, phosphoric acid, KCl or  $K_2SO_4$ , plus sulphuric acid and trace elements when required. Also unfiltered phosphoric acid slurry has been used as part of the phosphorus raw material. In Process 2 (Appendix 2) nitric acid and phosphoric acid are neutralized with ammonia in the reactor, and the obtained NP slurry is led to the blunger type granulator, where granulation is done together with KCl powder and recycle. Then follow drying, screening, crushing and coating in the normal way. The recycle ratio with grade 15-20-15 is 1 : 10.

Reactor gases are washed in the scrubber with a solution containing phosphoric acid. Dusts are collected from drying and cooling gases by cyclones, and drying gases are washed in the scrubber. The gas scrubbing waters are fed in the reactor.

The process has been used from 1966 for the following fertilizer grades : 15-20-15, 20-10-10, 10-20-20, 15-25-10, 7-24-14, 15-15-15. The best grades for the process are 7-24-14 and 10-20-20.

### 2.3 Process 3 - phosphonitric process

This so-called phosphonitric process has been developed and constructed (Appendix 3) by Kemira Oy. Its raw materials are nitric acid, ammonia, phosphoric acid, phosphate rock, KCl and  $K_2SO_4$ , and sulphuric acid and trace elements when required. If phosphate rock and phosphoric acid are used as phosphorus raw material, phosphate rock is digested by nitric acid in the first reactor of the line. Phosphoric acid is only added in the next two reactors, where also neutralization with ammonia takes place. Potash is added in the third reactor. Also the dust returning from the process is fed in the third reactor. From there the slurry flows as overflow into the buffer tank, after which it is sprayed in the spherodizer. In the granulation process the slurry is sprayed on the surface of the recycled granules. Drying with hot combustion gas takes place in the same apparatus directly after granulation. Then follow screening, crushing, cooling and coating of final product. The recycle ratio with grade 15-20-15 is 1 : 2.5.

Reactor gases are washed in scrubbers. Dust is collected from drying gases by dry method in cyclones and the gases are washed in the scrubber. Cooling gases are purified with bag filters, after which they are used in the drying as secondary air. All scrubbing waters and process waters as well as the nutrient-containing rainwaters of the area are returned to the process. Thus no nutrient-containing water escapes from the process.

The process is applied in our newest fertilizer plant constructed in 1972 at Siilinjärvi. The grades have been mainly 15-20-15, 20-10-10, 10-20-20 and 15-25-10. Grades 15-20-15 and 15-25-10 suit the process best.

### 2.4 Investments

As already mentioned the processes have been constructed at different times and from slightly different basis. It is therefore somewhat difficult to compare the investments even using index

adjustment (material costs and labour costs) since it does not indicate all changes in their right proportions. Below are presented the equipment investments for the processes, adjusted to early 1976 price level.

Process 1	Process 2	Process 3
\$ 7.2 million	\$ 6.2 million	\$ 5.7 million

The investment required by Process 1 is clearly the heaviest. This is caused by the evaporator and the equipment for the treatment of weak sulphuric acid.

The smaller distinction between the other two mainly results from the different granulation-drying system, Process 3 being notably more economical.

### 3 CONSUMPTION FIGURES

#### 3.1 Raw materials and their consumption

The raw materials used in the processes depend on local conditions and the production of intermediate raw materials. Differences lie in the use of nitrogen and phosphorus. As nitrogen raw material, Process 1 uses N-solution in addition to the  $\text{NH}_3$  nitrogen of MAP, the others use ammonia and nitric acid. As to phosphorus, Process 1 uses MAP, Process 2 phosphoric acid and phosphoric acid slurry, Process 3 phosphate rock and phosphoric acid. The raw material consumption and costs for grade 15-20-15 in different processes are presented in Table 1.

The table shows that Process 3 has the lowest raw material costs (comparison figure 100). The figure for Process 2 is 5 % and for Process 1 10 % higher than for Process 3.

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TABLE 1

	<u>100 %</u> <u>kg/ton</u>	<u>N</u> <u>kg/ton</u>	<u>P<sub>2</sub>O<sub>5</sub></u> <u>kg/ton</u>	<u>K<sub>2</sub>O</u> <u>kg/ton</u>	<u>Price</u> <u>index</u>
<u>PROCESS No. 1</u>					
Raw Materials					
MAP 11,3 % N	381	45	200		70
50 % P <sub>2</sub> O <sub>5</sub> 6 % H <sub>2</sub> O					
KCl	250			150	16
N-solution 41 % total N 24 % NH <sub>3</sub> 60 % NH <sub>4</sub> NO <sub>3</sub> 16 % H <sub>2</sub> O	224	109			23
H <sub>2</sub> SO <sub>4</sub> 30 %	143				0,7
Borate 14 % B	2				0,3
Total	<u>1000</u>	<u>154</u>	<u>200</u>	<u>150</u>	<u>110</u>
<u>PROCESS No. 2</u>					
Raw Materials					
NH <sub>3</sub>	128	105			20
HNO <sub>3</sub> 60 %	216	48			14
H <sub>3</sub> PO <sub>4</sub> -slurry 28 % P <sub>2</sub> O <sub>5</sub>	194		67		17
H <sub>3</sub> PO <sub>4</sub> 48 % P <sub>2</sub> O <sub>5</sub>	210		133		37,8
KCl 60 %	250			150	16
Borate 14 % B	2				0,3
Total	<u>1000</u>	<u>153</u>	<u>200</u>	<u>150</u>	<u>105</u>

TABLE 1 (continued)

	<u>100 %</u> <u>kg/ton</u>	<u>N</u> <u>kg/ton</u>	<u>P<sub>2</sub>O<sub>5</sub></u> <u>kg/ton</u>	<u>K<sub>2</sub>O</u> <u>kg/ton</u>	<u>Price</u> <u>index</u>
<u>PROCESS No. 3</u>					
Raw Materials					
Phosphate rock	125		48		7
NH <sub>3</sub> 60 %	250	56			16
NH <sub>3</sub>	114	94			18
H <sub>3</sub> PO <sub>4</sub> 43 % P <sub>2</sub> O <sub>5</sub>	234		152		42,4
H <sub>2</sub> SO <sub>4</sub> 93 %	15				0,3
KCl 60 %	250			150	16
Borate 14 % B	2				0,3
Total	<u>1000</u>	<u>150</u>	<u>200</u>	<u>150</u>	<u>100</u>



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The differences can be analyzed by examining the index of the main nutrient in each process. For the comparison the MAP cost has to be artificially divided between nitrogen and phosphorus in proportion with the nutrient contents.

Costs for nitrogen :

	<u>Process 1</u>	<u>Process 2</u>	<u>Process 3</u>
N-solution	23	-	
MAP	13	-	
NH <sub>3</sub>		20	18
HNO <sub>3</sub>		14	16
Price index    Total	36	34	34

The so-called refined intermediate raw materials of Process 1, N-solution and MAP, raise the cost with two units in respect to the others.

Costs for phosphorus raw materials :

	<u>Process 1</u>	<u>Process 2</u>	<u>Process 3</u>
MAP	57		
H <sub>3</sub> PO <sub>4</sub> 28 % P <sub>2</sub> O <sub>5</sub>		17	
H <sub>3</sub> PO <sub>4</sub> 48 % P <sub>2</sub> O <sub>5</sub>		38	
Phosphate rock			7
H <sub>3</sub> PO <sub>4</sub> 43 % P <sub>2</sub> O <sub>5</sub>			42
Price index    Total	57	55	49

The combination phosphate rock + phosphoric acid in Process 3 is 8 units cheaper than Process 1 and 6 units cheaper than Process 2.

The price of potassium raw material is the same for all processes and the effect of other raw materials is very small. The phosphorus raw material is mainly responsible for the differences in the raw material costs.

3.2 Utilities consumption

TABLE 2 Utilities consumption per product ton

	<u>Process 1</u>	<u>Process 2</u>	<u>Process 3</u>
oil kg/kWh	20/214	12/128	15/161
electricity kWh	65	61	52
steam kg/kWh without concentration	60/ 45	174/131	72/ 54
steam kg/kWh with concentration	180/136		
Total without concentration kWh	324	320	267
Total with H <sub>2</sub> SO <sub>4</sub> concentration kWh	460		

The calorific value of fuel oil has been converted to kWh with the coefficient 1 kg oil = 10,7 kWh. Steam has been converted to kWh with the coefficient 1 kg steam = 0,756 kWh.

Table 2 gives some utilities consumption figures for the processes, according to which consumptions in Process 3 are lowest. It uses scrubbed cooling gas as secondary air in drying, which means quite considerable savings. The high steam consumption in Process 2 results from the fact that drying gases are pre-heated with steam, which on the other hand means a low oil consumption. In Process 1 the consumption of energy is about the same as in Process 2 if the evaporation of weak sulphuric acid is excluded. The steam required for the evaporation increases the consumption of energy considerably.

3.3 Operating and maintenance costs

TABLE 3 Operating and maintenance costs per product ton.

	<u>Process 1</u>		<u>Process 2</u>		<u>Process 3</u>	
	\$	h	\$	h	\$	h
operation	1.28	0.225	1.40	0.245	0.69	0.121
help work	0.68	0.120	0.26	0.045	0.26	0.045
maintenance work	1.04	0.182	0.95	0.167	0.69	0.121
maintenance material	0.64		0.72		0.68	
<b>Total</b>						
without concentration	3.64		3.33		2.32	
<b>Total</b>						
with concentration	3.92					

Table 3 shows the operating and maintenance costs of 15-20-15 with the three methods. The differences are considerable, and naturally the costs are lowest in the latest plant or Process 3. It has the highest automation degree and consequently a small operating personnel. Also the maintenance costs of the new plant are lower.

The costs in Process 1, concentration excluded, come quite close to the figures of Process 2, but the concentration causes a clear increase. The high costs are mainly due to the complicity of the method, which also means a greater number of personnel and higher maintenance costs.

Effective operating times per year are as follows :

Process 1	310 d/a
Process 2	310 d/a
Process 3	325 d/a

The most important reason for the differences is cleaning requirements. In Processes 1 and 2 the drying drum requires regular and frequent cleaning. In this respect the spherodizer used in Process 3 is much easier.

#### 4 PRODUCT QUALITY

The quality of the product depends on the raw materials, chemically and physically, and on the production method. The chemical and physical properties of grade 15-20-15 with different processes are presented in Table 4. The effect of the raw materials shows clearly in the chemical analysis of the product. Differences in nitrate, sulphate and calcium contents are quite marked, and the same applies also to the compound analysis by X-ray diffraction. Only the product made by Process 1 contains double salt  $(\text{NH}_4, \text{K})_2 \text{SO}_4$  and on the other hand  $\text{NH}_4\text{NO}_3 \times 2 \text{KNO}_3$  only appears in products made by Processes 2 and 3.

Product qualities were previously examined in regard to dust formation (2) and it was then stated that one reason for the earlier dust problems of the product made by Process 1 was the high sulphate content or, in other words, an unfavourable  $\text{SO}_4 : \text{NO}_3$  ratio. The change of the MAP grade eliminated the dust problems.

The physical properties of the products indicate the strength of the granules. The attrition percentage refers to attrition in the test performed under standard conditions. Pore volume indicates the quantity of pores in the granule and the solidity of the granules. In Table 4 the figures for strength and pore volume describe the storage properties of the granules, and attrition the tendency for dust formation in the drying, cooling, and general handling of the granules.

The processes under examination all have different granulation methods. In principle they use slurry granulation at least partly, but the properties of the slurries and the granulation methods are different and so are the product grades. Processes 2 and 3 give good round granules and dust formation in the production is very slight. The shape and physical properties of the granules made by Process 1 are not quite as good and the handling of the product causes notably more dust formation.

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TABLE 4

	15 - 20 - 15		
	Process 1	Process 2	Process 3
Chemical analysis %			
- NH <sub>4</sub> -N	12,0	10,4	9,3
- NO <sub>3</sub> -N	3,0	4,6	5,7
- P <sub>2</sub> O <sub>5</sub>			
total	20,0	20,0	20,0
water soluble	18,0	16,2	14,7
- K <sub>2</sub> O	15,0	15,0	15,0
- SO <sub>4</sub>	16,3	8,2	3,9
- Ca	0,5	2,8	3,5
Compound analysis by X-ray diffraction %			
- NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>	25	25	20
- (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	3	3	3
- NH <sub>4</sub> Cl	14	15	17
- KNO <sub>3</sub>	3	6	9
- KCl	4	3	
- (NH <sub>4</sub> ,K) <sub>2</sub> SO <sub>4</sub> (65:35)	12		
- (NH <sub>4</sub> ,K) <sub>4</sub> SO <sub>4</sub> (NO <sub>3</sub> ) <sub>2</sub> (50:50)	32	22	8
- NH <sub>4</sub> NO <sub>3</sub> x 2 KNO <sub>3</sub>		16	26
- CaHPO <sub>4</sub>			3
- Precipitated apatite		9	12
- Precipitated iron phosphate	6		
Physical properties of granule			
- force to break granule, kp	8-10	12	12
- attrition %	1-7	0,7-0,5	0,2
- pore volume ml/g	0,025-0,08	0,02	0,008
Quantity of dust t/h			
- after drying drum	0,5-2	0,5-1	0,5-0,8
- after cooling drum	0,5-1	0,2	0,02
Capacity t/h	30	30	30

Earlier it was possible to use a blunger as the granulator in connection with Process 1, but the result was not so good as with the granulating drum. When using the granulating drum, granulating conditions can be more carefully controlled and granulation optimized.

Storage tests have been made with the products under comparison, and they show that after 6 months' storage practically no clogging occurs. If some kind of distinction is wanted, it could perhaps be said that 15-20-15 by Processes 2 and 3 have slightly better storage properties than that made by Process 1. The reason might be the different coating system. Process 1 uses oil-amine mixture with talcum, while Processes 2 and 3 use fuel oil and talcum. The latter method has proved superior and will soon be adopted in Process 1 as well.

## 5 ENVIRONMENTAL PROTECTION

The processes have closed water circulation systems. All leakage and washing waters and gas scrubbing waters are fed in the process and evaporated. In Process 1 the nutrient containing waters are fed in the pre-reactor and then led in the evaporator, where they are concentrated. In Processes 2 and 3 the waters are fed in the reactors, where they are evaporated by reaction heat. The concentrations of the acids used in these processes have been chosen so that the neutralization temperatures are sufficiently high to evaporate the waters.

In all processes reactor gases are washed in scrubbers. Dust is first removed from the drying and cooling gases by dry method in cyclones or bag filters. With Process 3 the bag filter has been used successfully for cleaning of cooling gases. Drying gases are also washed as the efficiency of the cyclones is not quite sufficient and the gas also contains gaseous impurities. Processes 1 and 2 use impingement scrubbers and Process 3 floating bed scrubbers. For scrubbing fine fertilizer dust these types differ very little.

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There are more differences with regard to scrubbing of gases. Table 5 shows emissions from the different processes. The figures show that the amount of ammonia from Process 1 and 2 is notably higher than from Process 3, and that more dust escapes from Process 1 than from the others.

TABLE 5

		<u>Process 1</u>	<u>Process 2</u>	<u>Process 3</u>
Gas volume	Nm <sup>3</sup> /h	200 000	200 000	200 000
Dust	kg/h	60	12	10
NH <sub>3</sub>	kg/h	100	100	15
NO <sub>x</sub>	kg/h	4	not measured	15
F	kg/h	0.07	0.7	0.3

6 SUMMARY

In the foregoing we have sought to draw some technical and economical comparisons between three fertilizer processes which are used by our company. The basis for the comparison has been grade 15-20-15 with a capacity of 200 000 t/a. The three processes have been constructed at different times within a period of seven years. During that time the processes have naturally been developed further and requirements concerning the quality and raw material have changed. The processes all have their special features, particularly Process 1 which uses weak sulphuric acid. This causes additional investments and higher consumption figures but on the other hand takes care of the waste acid problem.

When the processes and products are examined from the technical point of view it can be seen that they are different. The use of weak sulphuric acid, scrubbing acid, in Process 1 makes it more complicated than the other two, and also the rest of the raw materials slightly restrict the possible formulas. Process 1

(special ammonphosphate process) can be considered an exceptional process, constructed according to local requirements concerning the use of raw materials, and this should be kept in mind when comparing it with the other processes.

Process 2 (ammonphosphate process) and Process 3 (phosphonitric process) have a more general nature. Process 2 is quite common ammonphosphate based process, which can be utilized in the production of very many high analysis fertilizer grades. The process uses ordinary equipment and is easy to control. Process 3 mainly stands out for its phosphorus raw material basis and granulation-drying method. The phosphorus raw material can be either a combination of phosphate rock and phosphoric acid, which naturally affects the amount of water soluble phosphorus in the product, or phosphoric acid alone. Granulation and drying takes place in a spherodizer, of which the experiences are very good. This process is very flexible regarding raw materials and products, and uncomplicated to operate.

The equipment investments of Processes 2 and 3 are more or less the same. Process 1 is clearly more expensive, owing to the special equipment required for the concentration of weak sulphuric acid.

As concerns raw materials and operating costs, Process 3 is the most economical, its raw material costs being 10 % lower than those of Process 1 and 5 % lower than Process 2. The difference is above all due to the use of phosphate rock. The higher costs of Process 1 are caused by the price of the refined raw materials MAP and N-solution. Process 3, recent and far automatized, is found superior when comparing the utility figures. Process 1 is handicapped by its complicity, but if concentration is excluded the utility figures for Processes 1 and 2 are very much the same.

No major differences occur in the product quality. The raw materials naturally cause differences in the chemical composition. The physical properties are slightly better with Process 3.

If one process needs to be pointed out as superior concerning the product quality Process 2 and 3 could be placed before Process 1, although the differences are very small indeed.



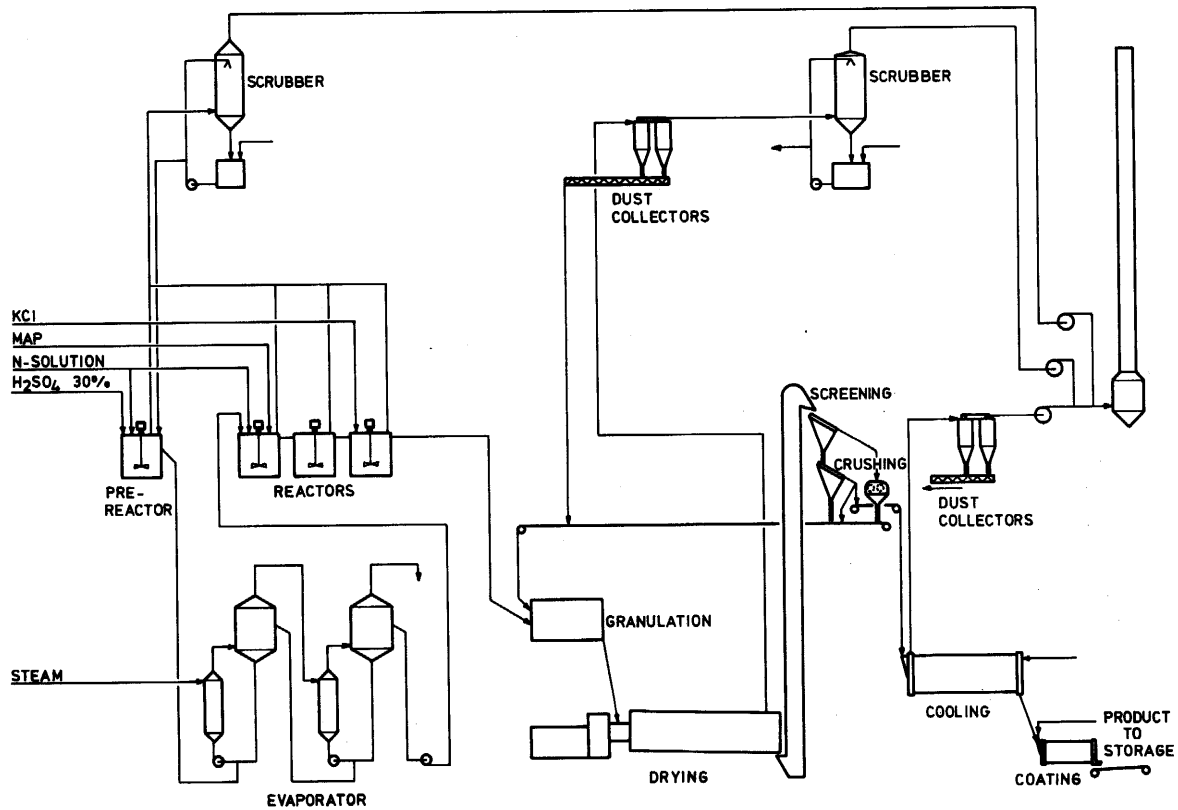
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From the point of view of environmental protection Process 3, being the most modern of the three, reaches the best values. This is self-evident as the regulations on environmental protection have become stricter and the newest process of course has the best equipment.

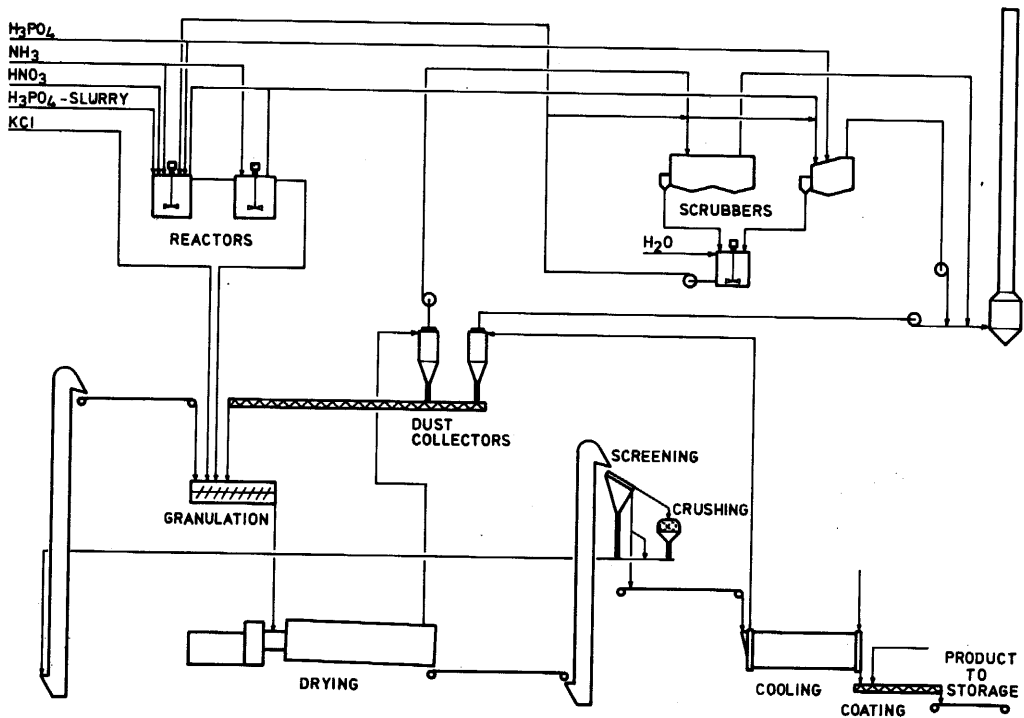
As a conclusion it can be stated that based on the chosen criteria, the phosphonitric process (3) is the best alternative in our conditions. The ammonphosphate process (2) and the special ammonphosphate process (1) are very much equal but the difference in raw material prices makes Process 2 slightly more economical. It could naturally be asked whether the chosen criteria are correct, but as mentioned in the beginning, different conditions mean different criteria, and this evaluation was made on the basis of ours.

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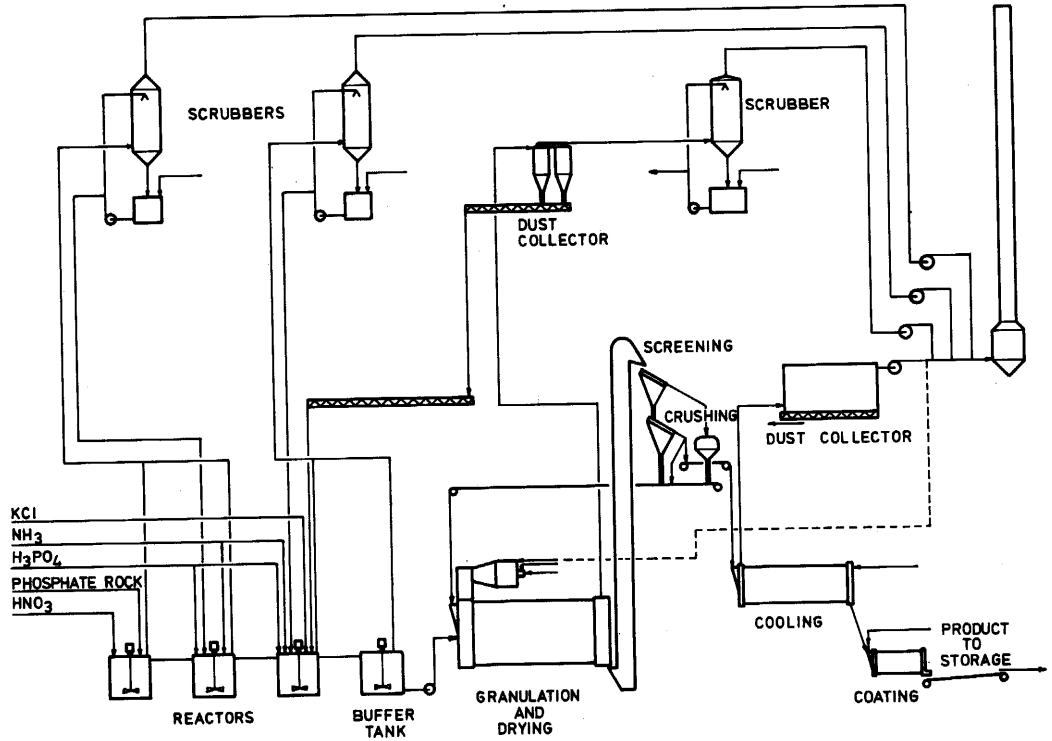
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NPK - PROCESS 1



NPK-PROCESS 2



NPK-PROCESS 3