

ISMA* Technical Conference

Orlando, Florida, USA

23-27 October 1978

**In 1982, the name of the International Superphosphate Manufacturers' Associations (ISMA) was changed to International Fertilizer Industry Association (IFA).*

THE EFFECT OF IMPURITIES ON THE PRODUCT QUALITIES OF MAP

Authors : I A Brownlie
E Davidson
T R Dick
I S E Martin

Scottish Agricultural Industries Limited, Edinburgh, Scotland.

SUMMARY :

In 1963 SAI presented a paper at the ISMA Technical Conference in Helsinki describing a new powder form of MAP. This product was given the trade name 'PhoSAI' and provided a new P_2O_5 intermediate for making concentrated granular fertilisers from solid raw materials. 'PhoSAI' was originally developed as a more concentrated replacement for single superphosphate but it was also foreseen that powder MAP could provide a high-grade product suitable for phosphate rock producers to export and convenient for their customers to use in their granulation plants.

Since 1963 the use of MAP intermediates has become well established and several other MAP processes have been developed although the products do not necessarily all have the same properties.

'PhoSAI' has been made from phosphoric acid derived from Morocco, Florida, Nauru, Senegal, Togo, Gafsa, Kola and Jordan phosphate rocks and has always shown good storage and granulation characteristics when used in all types of granulation plant. The process has been licensed to companies in Canada, Japan, Pakistan, Turkey, Tunisia, Holland and the USA. Tunisia was the first developing country to start vertical integration of its phosphate production in the 1950's and is now the first rock producing country to operate the SAI process. The Tunisian plant built at Gabes by Ressources Tunisie, a member of the Windmill Holland group, has been in production since 1976.

This paper outlines the research work⁴⁻⁶ carried out by SAI over the last few years and suggests that reasons for the good product qualities of 'PhoSAI' are to be found in the process conditions used in its manufacture which determine the nature and location of the impurities.

INTRODUCTION :

The structure of the fertiliser phosphate industry is changing rapidly towards the vertical integration of phosphate rock and phosphatic fertiliser production, the fertiliser usually being in the form of an intermediate such as triple superphosphate (TSP), monammonium phosphate (MAP) or diammonium phosphate (DAP). In the USA this has been the normal situation but until recently there was not much sign of vertical integration elsewhere except in Tunisia where the low grade uncompetitive rock led to the establishment of phosphoric acid and TSP facilities. Now most of the major rock producers have projects to upgrade the value of their exports and an increasingly important P_2O_5 intermediate is powder MAP.

For many years MAP took a poor second place to granular DAP and granular TSP but with the advent of cheap methods of making powder MAP, its rise in importance has been dramatic. In the published statistics of world fertiliser production it is not easy to separate the different forms of ammonium phosphate but with new MAP projects now out-numbering those for DAP it is fairly obvious that MAP has gained general acceptance. As pioneers of the manufacture and use of powder MAP 17 years ago SAI is especially aware of this change in attitude.

For over 100 years single superphosphate was in many ways the ideal phosphate intermediate as it could be stored easily in bulk, was an excellent granulation aid and could be granulated by itself to give a granular product. In more recent times the tremendous growth in demand for plant nutrients and rapidly rising transport costs have made it increasingly necessary to use more concentrated phosphate fertilisers. First came triple superphosphate containing 45% P_2O_5 compared with around 20% for single superphosphate, then ammonium phosphates mainly produced as DAP in the USA where large vertically integrated plants were built near the Florida phosphate rock deposits. Both TSP and DAP are sold in granular form mostly for bulk blending into compounds. Granular products are not really suitable for subsequent granulation with other raw materials and the cost of their production further reduces their attractiveness as intermediates. DAP has further disadvantages, especially its tendency to lose ammonia in the drying stage and to cause reversion of water soluble P_2O_5 to the insoluble form if superphosphate is present.

SAI PROCESS FOR POWDER MAP :

The first commercial process for making powder MAP was introduced by SAI in 1961. Before that time only granular MAP was available but SAI needed a product to replace the single superphosphate which the company was using on its own granulation plants and supplying to customers. Such a product had to satisfy four conditions.

1. Low cost production.
2. Granulation properties comparable with those of normal superphosphate.
3. Capable of being stored in bulk without caking.
4. Easy to transport and handle in bulk with conventional equipment.

A mini granular form of MAP, produced on the Dorr Oliver granulation plant commissioned at SAI's Leith Works in 1957, provided a temporary, although expensive and not very satisfactory, phosphate intermediate until a simple process was developed to produce the powder form of MAP known by the trade name 'PhoSai'.

The SAI process depends on the relationship between the solubility of ammonium phosphate and its N:P atomic ratio (Fig. 1) and is carried out in two stages. Phosphoric acid is neutralised with ammonia gas to N:P ratio 1.35, near the maximum solubility of ammonium phosphate, to give an easily handleable slurry with low water content. This MAP/DAP slurry is then acidified in a moisture disengagement unit (MDU) with further phosphoric acid to reduce the N:P ratio to 1.0 (MAP) thereby bringing the ammonium phosphate back to its solubility minimum and converting the slurry to a solid. The product obtained is a powder containing 6% H₂O. A typical flow diagram is shown in Fig. 2.

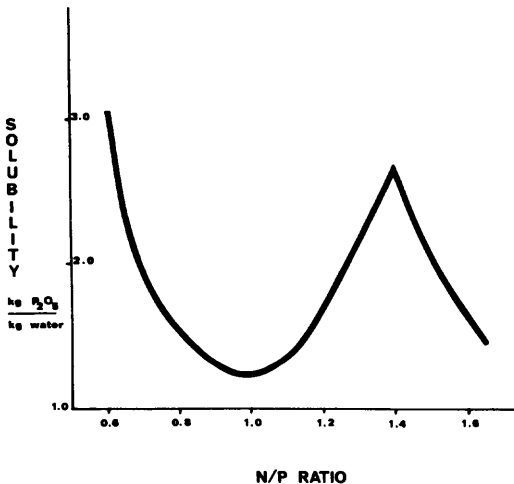


Fig. 1 - Solubility curve for ammonium phosphate.

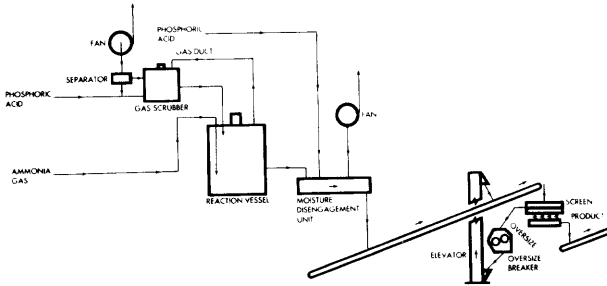


Fig. 2 - Flow diagram of SAI process for MAP.

PROPERTIES OF 'PhoSAI' :

'PhoSAI' MAP satisfied all the required conditions and also gave further advantages, the importance of which became increasingly clear as experience was gained in its use. These advantages may be summarised as follows.

1. Phosphoric acids with high solids content can be used for its production.
2. 'PhoSAI' can be granulated by itself simply by adding steam to give granular MAP.
3. Concentrated fertilisers can be made on conventional granulation plants without loss of output.
4. Less moisture is required for optimum granulation compared with other solid concentrated P_2O_5 sources and therefore drying costs are lower.
5. 'PhoSAI' provides a cheap method of storing P_2O_5 in concentrated non-caking form for long periods. This is especially advantageous when temporary storage is required at short notice.
6. 'PhoSAI' is compatible with all other fertiliser raw materials.
7. 'PhoSAI' can be ammoniated to produce granular DAP.
8. Sulphate-'PhoSAI' : By replacing part of the phosphoric acid feed with sulphuric acid (94% H_2SO_4), a range of products known as sulphate-'PhoSAI' can be made. The strength of phosphoric acid used has to be reduced to compensate for the low water content of the sulphuric acid so that powder intermediates can be made ranging from 11% N, 52% P_2O_5 (MAP) using 42% P_2O_5 phosphoric acid to 16% N, 25% P_2O_5 using only 26% P_2O_5 acid. Sulphate-'PhoSAI' contains

ammonium sulphate in powder form which is easier to granulate than crystalline ammonium sulphate.

9. Energy : The SAI process provides a very efficient way of converting P_2O_5 from a liquid to a solid form as there is no recycle and no fuel is used for drying. Full advantage is taken of the heat of reaction, as about 90% of the available energy is used to evaporate sufficient water to produce a solid product containing 6% H_2O . The remainder of the heat appears as sensible heat in the MAP and steam produced, and in the air used to remove steam. Most processes for MAP intermediates are said to use phosphoric acid containing 49% P_2O_5 which requires about 27% more energy for concentration than the 42% P_2O_5 acid used in the SAI process. Sulphate-'PhoSAL' can of course be made from filtrate phosphoric acid without any concentration.

'PhoSAL' can be shipped directly by road, rail or sea transport without any further treatment. If MAP has to be dried to 1% before shipping, as has been reported for some products, further energy input is required.

GRANULATION WITH 'PhoSAL' :

In 1961 a concentrated fertiliser material containing around 6% moisture was regarded as highly unusual but SAI's customers rapidly converted to using 'PhoSAL' when they became aware of its many advantages. It could be stored, handled, transported and granulated like superphosphate - it even looked like superphosphate.

As a result of the experience gained in using powder MAP, SAI's new granulation plant, commissioned in 1971 at Aberdeen, was based on the use of solid raw materials including 'PhoSAL'. This meant that a low recycle ratio of around 1:1 could be used which gave a high degree of flexibility and allowed frequent product changes to be made with minimum plant down-time. This was especially important at Aberdeen where a large range of compounds had to be made including organic - based horticultural fertilisers. As the formulations had widely varying P_2O_5 requirements, the acid storage capacity would have been inadequate without the smoothing effect of the MAP store. In fact one of the main advantages to be gained from the use of powder intermediates is the operational flexibility which they give. Production schedules are easier to plan and high output rates can be maintained on sulphuric and phosphoric acid plants. By making sulphate-'PhoSAL', these rates can be achieved even when phosphoric acid evaporators are off-line.

EFFECT OF IMPURITIES :

The importance of impurities in phosphatic fertilisers was highlighted in the 1950's when several American coke producers converted their ammonia recovery units from ammonium sulphate production to the production of ammonium phosphate from furnace grade phosphoric acid. It was found that granular fertilisers based on pure phosphoric acid were difficult to make and had unsatisfactory storage qualities and this led to a considerable amount of work particularly by TVA, which showed that the addition of impurities such as iron and aluminium compounds can lead to significant improvements. SAI's research work also showed that it was impossible to granulate pure crystalline monammonium phosphate on conventional granulation plants by using steam.

It is therefore interesting to examine the effect of impurities on the properties of MAP intermediates more closely. MAP crystals made by the SAI process from pure phosphoric acid have an average size of around 400 microns but when wet process acid is used the impurities modify the crystal habit and the average crystal size is reduced, the actual size varying with the impurities present. Different acids give different effects which are clearly related to the different components of the acids but the relationship is not clear. In an attempt to clarify this relationship a series of experiments was carried out in SAI's Research Department using samples of synthetic acid. These were made by adding to 50% P_2O_5 laboratory grade phosphoric acid known quantities of iron, aluminium, magnesium, silicon, fluorine, sodium and calcium, the impurities commonly present in wet process phosphoric acid. The synthetic acids were ammoniated to an N:P ratio of 1.35 and a moisture content of 14% (typical for the SAI process). This liquor was then placed in a wide necked vacuum flask and stirred while enough of the parent acid was added to bring the N:P ratio to 1.0. The resultant slurry was stirred for 10 seconds before samples were smeared on microscope slides for photomicrographic examination. No significant cooling occurred during the acidulation stage and the slurry at N:P = 1.0 contained about 50% of the MAP in a precipitated form. It was found that only iron and aluminium could modify the crystal habit of MAP on their own although all the impurities could act with each other to interfere with crystallisation. Fig. 3 summarises the results obtained from a simple system containing aluminium, iron, magnesium and fluorine with the Fe:Al atomic ratio kept constant at 1:2 while the magnesium and fluorine contents varied. Within the shaded area very small crystals of MAP were produced (Fig. 5) and acids with compositions lying outside the shaded area yielded comparatively large crystals (Fig. 6). A further set of experiments was carried out on acids with an Fe:Al ratio of 2:1 and once again crystallisation of MAP was affected over a range of magnesium and fluorine concentrations (Fig. 4.).

While the exact nature of these phenomena is not known, the laboratory work has shown that most common impurities in phosphoric acid can affect the crystallisation of MAP in the SAI process which explains why acid made from different phosphate rocks produces different sizes of MAP crystal. Despite this difference in crystal size, the good storage and granulation properties of 'PhoSAL' are unaffected by the type of acid used for its manufacture.

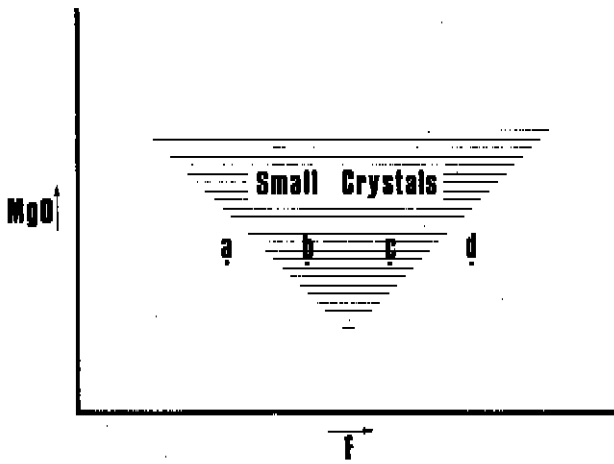


Fig. 3 - Effect of MgO and F content on MAP crystal size (Fe:Al = 1:2)

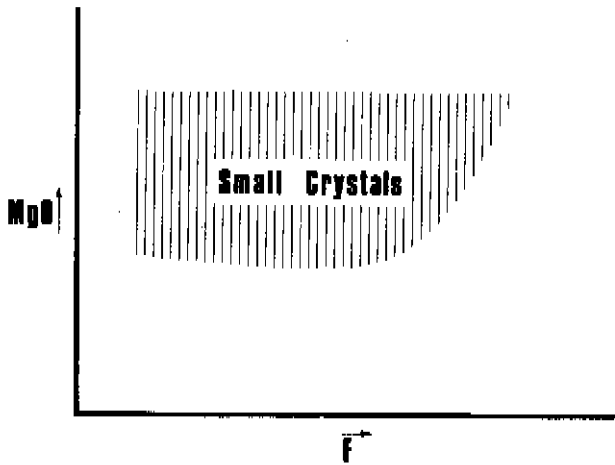


Fig. 4 - Effect of MgO and F content on MAP crystal size (Fe:Al = 2:1)

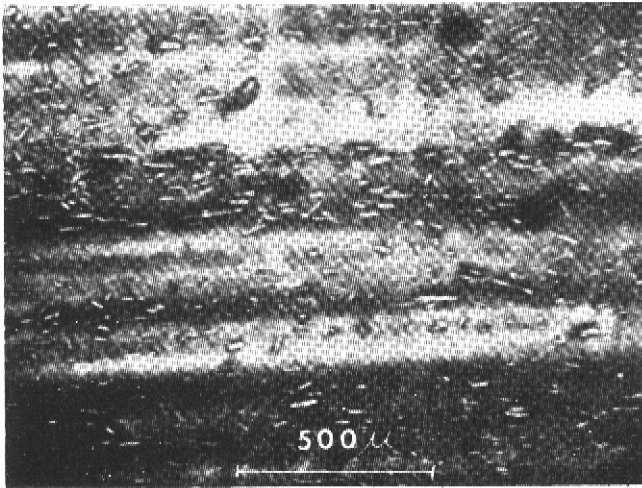


Fig. 5 - Photomicrograph of MAP crystals inside shaded area.

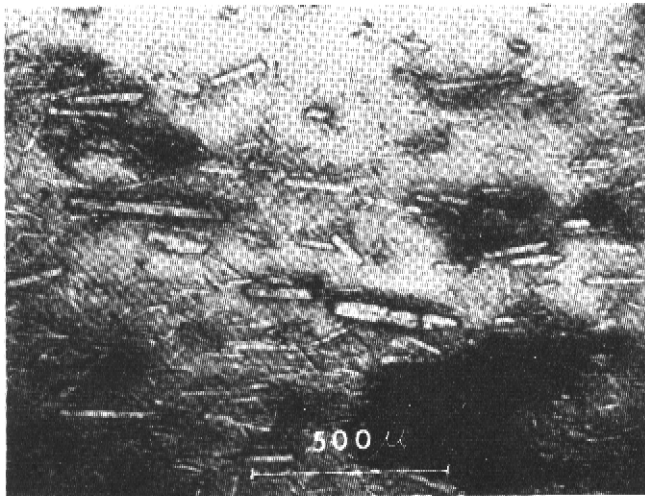


Fig. 6 - Photomicrograph of MAP crystals outside shaded area.

RELATIONSHIP BETWEEN CRYSTAL SIZE AND PARTICLE SIZE :

Although 'PhoSAI' after milling and screening always has the same powdery appearance, the material leaving the moisture disengagement unit (MDU) can vary from a fluffy powder to a fairly coarse grained material. Microscopic examination of this un-screened 'PhoSAI' made from different wet process phosphoric acids shows a relationship between the particle size distribution and the average crystal size present. The powdery material can be seen to be a mixture of individual crystals and loose aggregates of crystals whereas the coarser material consists of firmer aggregates of smaller crystals. It has already been shown that certain combinations of impurities can affect crystal growth so that small MAP crystals are formed and it now appears that these small crystals can lead to coarser 'PhoSAI' particles.

To understand why different phosphoric acids can lead to different particle sizes in 'PhoSAI', it is worth considering elementary crystal theory. When the solubility of the dissolved phase in a saturated solution is reduced by cooling or by solvent evaporation, then supersaturation will increase until a critical level is reached when nucleation occurs followed by crystal growth. If the rates of nucleation and crystal growth are more rapid than the rate of development of supersaturation then orderly crystal growth will occur. However, in the presence of a nucleation or growth inhibitor the rate of development of supersaturation can exceed the rate of removal of the dissolved material and consequently supersaturation can build up to a stage where massive nucleation occurs resulting in the precipitation of large numbers of very small crystals.

In the case of the SAI process, where precipitation of MAP occurs progressively as the MAP/DAP liquor is acidulated, the impurities present in some phosphoric acids can slow down the rate of crystal growth to such an extent that excessive supersaturation occurs leading to the precipitation of large numbers of small crystals which bind together to form aggregates. With other acids this effect is less and the rate of crystal growth is fast enough to avoid excessive supersaturation.

While the size range of the unscreened material has no effect on the properties of the final product there could be advantages in producing a powdery material directly from the MDU, as screening would be easier and less energy would be needed to break the larger sized particles. Two possible methods of controlling the size range of the material leaving the MDU, i.e. methods of controlling the MAP crystal size, were therefore examined.

1. Altering the impurity content of the acid.
2. Modifying the process to alter the rate at which supersaturation is generated.

Laboratory and Pilot Plant Work :

- 1) A sample of 40% P_2O_5 Morocco acid was treated with sodium sulphate and allowed to settle thereby removing from suspension the calcium sulphate and precipitating sodium silicofluoride. The decanted supernatant acid contained magnesium, fluorine, iron and aluminium with Fe:Al = 1:2 so that the overall analysis fell within the range covered by the synthetic system shown in Fig. 3. The fluorine content of the acid could be increased simply by adding ammonium hydrogen fluoride to enable the MAP pilot plant to run with acid of analyses corresponding to points on the line a,b,c and d in Fig. 3. Acids a and d yielded powdery material containing large crystals while acids b and c yielded coarser material consisting of small crystals. This work demonstrated that the physical nature of the product could be controlled by adjusting the ratios of the impurities in the phosphoric acid and adds support to the reasons given for the formation of coarse 'PhoSAI'. As this method involved the addition of chemicals, the second approach was investigated more closely.
- 2) Using the laboratory technique described in the section on "Effect of Impurities" it was found that acidulation of the MAP/DAP liquor from N:P 1.35 to N:P 1.0 could yield slurries of varying fluidity. At one extreme these could be very fluid and contain large, well formed crystals while at the other extreme they could be viscous or even solid and consist of masses of very small crystals. High viscosity slurries could be avoided by carrying out the acidulation in two stages, i.e. by mixing the MAP/DAP liquor with only part of the phosphoric acid required and then after a suitable time delay adding the remainder of the acid. The increase in fluidity was always accompanied by a marked increase in the MAP crystal size because the two-stage addition of acid allowed crystals to form in the initial mixing stage thereby avoiding excessive supersaturation with the consequent precipitation of large numbers of small crystals. The technique was successfully tested in the laboratory on a number of slurries made from various wet process acids.

Plant Modifications :

Following these promising laboratory results, the pilot plant was modified for further study of the two-stage acidulation technique. A secondary reaction vessel was fitted with provision for distributing the secondary phosphoric acid between the secondary vessel and the MDU as shown in the simplified flow diagram in Fig. 7. The slurry at N:P ratio 1.35 overflowed from the primary to the secondary vessel where a proportion of the secondary phosphoric acid was added to reduce the N:P ratio to between 1.28 and 1.07. This slurry then overflowed to the MDU where the remainder of the phosphoric acid was added to give an N:P ratio of 1.0. Tests were made with phosphoric acid made from Morocco, Gafsa, Kola, Jordan and Senegal rocks and the promising laboratory results were confirmed.

With unmodified feeds the crystals were very small and tended to form aggregates. The addition of 20% of the acid to the secondary vessel had little effect on crystal size but increasing the proportion to 40%, 60% and 80% produced large crystals. The crystal size decreased again when operating conditions returned to normal.

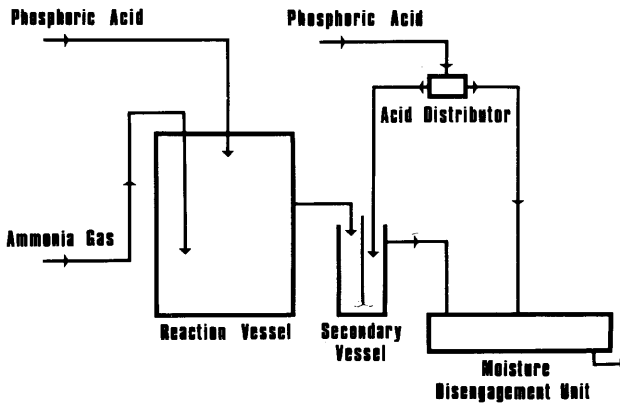


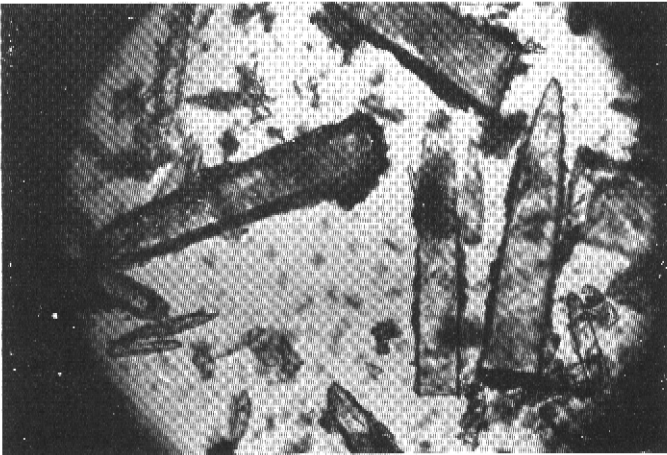
Fig. 7 - Flow diagram of modification to 'PhoSAT' plant.

The next step was to test this modification on the full scale by installing a secondary reaction vessel at SAI's Aberdeen Works. The slurry from the primary reaction vessel could either pass through the new vessel or bypass it via the existing channel to the MDU. This system has confirmed the laboratory and pilot plant results when using phosphoric acid made from Morocco, Jordan and Senegal rocks. Figs. 8 and 9 show the dramatic increase in crystal size which can be obtained when using acid from Senegal rock.



500,μ

Fig. 8 - Photomicrograph of MAP crystals from unmodified full scale system.

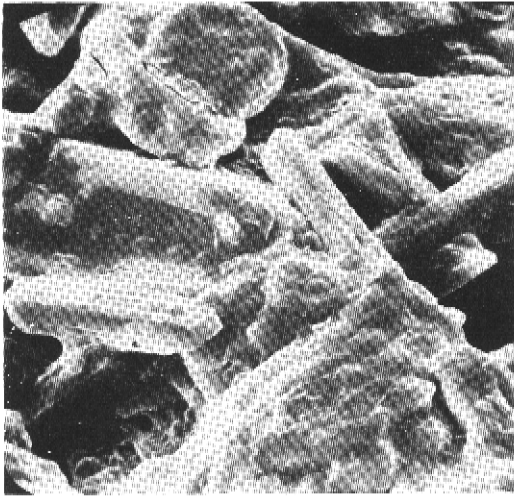


500,μ

Fig. 9 - Photomicrograph of MAP crystals when 60% of secondary acid is added to secondary vessel.

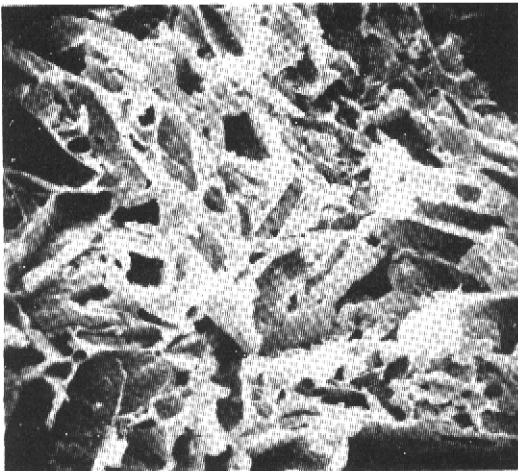
NATURE AND LOCATION OF IMPURITIES :

Scanning electron micrographs (SEM's) show that the impurities in 'PhoSAl' are distributed on the surface of the MAP crystals (Fig. 10) and, if 'PhoSAl' is carefully leached with water, a relic structure of insoluble material with the rectangular cavities from which the MAP crystals have been dissolved can be clearly seen (Fig. 11). X-ray diffraction indicates that the impurities are largely in an amorphous form.



50 μ

Fig. 10 - S.E.M. of 'PhoSAl' showing MAP crystals with coating of amorphous insolubles.



50 μ

Fig. 11 - S.E.M. of relic structure from leached 'PhoSAl'.

If, however, MAP is made by a process in which the impurities have less control over crystal growth, the product has a markedly different structure. This was shown by a series of experiments in which samples of 'PhoSAl' made from different acids were moistened to 15% heated to 170°C under pressure and then flash dried to around 6% moisture. The products obtained were in the form of small spheres < 3mm in diameter.

Microscopic examination of the flash dried products revealed that the crystal size was small, all the products looked similar irrespective of acid source and they were very different from the parent 'PhoSAl' samples. The insolubles did not have the appearance of amorphous membranes and if the MAP was leached with water no coherent structure remained. The insoluble material merely collapsed into a heap of individual particles indicating that the insoluble material does not coat the MAP crystals as it does in 'PhoSAl'. All these observations can be understood in terms of the process conditions used. The crystallisation stage was estimated to be complete within one second whereas with 'PhoSAl' this stage lasts about 20 seconds. It is therefore probable that crystallisation in the flash dried process is too rapid for the impurities to exert any significant effect on the crystal size or to allow surface layers of insolubles to be developed. Also, the temperature involved in these experiments (170°C) was considerably higher than that of the SAl process (125°C) and it is known that elevated temperatures can alter the form and composition of the complexes formed by the impurities present in MAP.

PRODUCT QUALITY :

The physical difference between 'PhoSAl' and the flash dried forms derived from it are made clear by the differences in their storage and granulation properties.

Storage Properties :

The storage properties of 'PhoSAl' are not affected by particle size or by moisture content while those of the flash dried forms are affected by both. Fig. 12 shows the difference in behaviour of 'PhoSAl' and flash dried MAP under laboratory caking tests.

This difference can be readily understood when the stability of the two different forms of MAP crystal to recrystallisation during storage is examined. Under moist conditions the crystal size of insoluble inorganic salts tends to increase in order to reduce the inter-crystalline surface area and therefore the excess free energy of the system. The recrystallisation tendencies of 'PhoSAl' and flash dried MAP were examined in accelerated tests by moistening samples to 12% moisture and storing them in sealed containers at 20°C. After 14 days the samples were re-examined and dramatic crystal growth was seen to have occurred in all the flash dried samples (compare Figs 13 and 14). In the case of 'PhoSAl' there was no significant crystal growth. As the driving force for recrystallisation is excess surface free energy, crystal growth can be expected to be more rapid and more marked in the material containing small crystals and therefore having a greater inter-crystalline surface area. However, the proportion of small crystals in 'PhoSAl' did not significantly decrease during the test indicating the presence of a stabilising effect which is lacking in the flash dried form. If a material recrystallises on storage it is to be

expected that the individual particles will form crystal bridges and bind together.

The fact that the caking propensity of flash dried MAP is lower at low moisture contents can also be understood in terms of crystal stability. As pointed out above, the rate of recrystallisation increases with increasing moisture content and therefore reducing the moisture content tends to freeze the crystals in an unstable state and retard the development of caking in stored material.

As mentioned in the previous section, the crystallisation stage of the SAI process is sufficiently slow to enable the impurities to play a dominant role in controlling the crystal size. It also allows the impurities to form a coating on the crystal surfaces which can provide a physical barrier between the MAP crystals and block the sites at which crystal growth and hence recrystallisation might occur. In the case of flash dried MAP, although the same elements are present as impurities, it has been shown that they neither control the crystallisation stage nor coat the MAP crystals with the result that the impurities are not able to exert any stabilising influence on the MAP crystals.

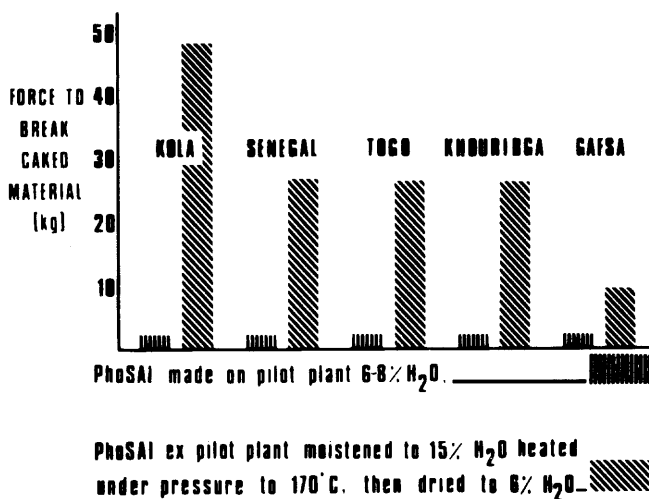


Fig. 12 - Caking propensity of 'PhoSAI' and flash dried MAP.

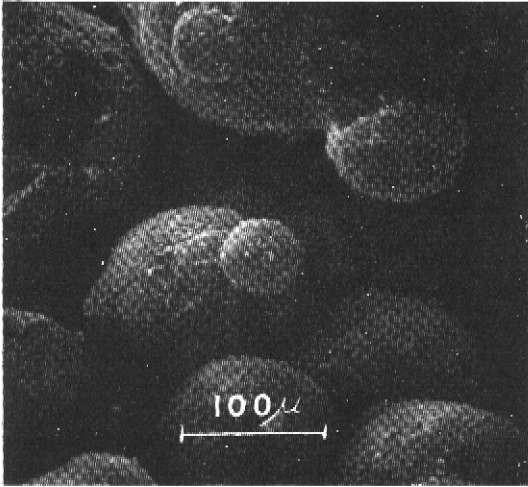


Fig. 13 - S.E.M. of flash dried MAP before ageing test.

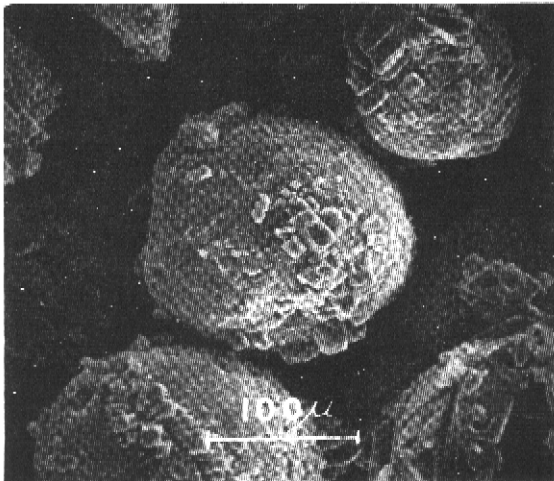


Fig. 14 - S.E.M. of flash dried MAP after ageing test.

Granulation Properties :

The granulation properties of the two forms of MAP were also found to be different which seemed surprising as both forms were impure and previous experience indicated that the presence of impurities conferred good granulation properties. It is common knowledge that MAP slurries or solids made from wet process phosphoric acid have much better granulation properties than equivalent materials made from furnace grade acid but recent developments on both laboratory and plant scales have shown that these views were too simple. It now appears that the granulation properties of MAP can also be affected by the process of manufacture and SAI's laboratory investigations suggest that the granulation properties of solid MAP depend not only on the presence of impurities but on their form and location.

The laboratory granulation test was based on a 12:12:18 formulation containing MAP, ammonium sulphate and potassium chloride, which is usually relatively difficult to granulate, and imposes a severe demand on the ability of the MAP to bind the ingredients together. All the ingredients were screened to less than 2.8mm, mixed and moistened to 11.5% H₂O before being placed in a rotating drum at 80°C for a fixed time. After each test, material from the drum was dried and screened over a 2.8mm screen to determine how much agglomeration had occurred.

The conditions used were similar to those in solid feed granulation processes and were found to be reproducible and to provide a reasonable basis for comparing the granulation power of the various samples of MAP. When flash dried and equivalent 'PhoSAL' samples were compared, the granulating power of 'PhoSAL' was found to be greater in each case, see Table I. Finely ground flash dried samples were also tested to make sure that the poor granulation properties of the flash dried material were not due to its physical form causing a slow rate of solution and therefore a slower rate of dispersal of the MAP throughout the other ingredients. However, fine grinding did not significantly improve the granulation properties. The granulation ability of flash dried MAP was in fact little better than that of potassium chloride, ammonium sulphate or pure MAP.

TABLE I - Granulation Tests on Togo and Morocco MAP :

Particle Size	TOGO			MOROCCO		
	'PhoSAL' (%)	Flash Dried (%)	Flash Dried Ground <100 mesh BSS (%)	'PhoSAL' (%)	Flash Dried (%)	Flash Dried Ground <100 mesh BSS (%)
> 2.8mm	94	3	7	69	6	3
< 2.8mm	6	97	93	31	94	97

It was also found that it was impossible under the same test conditions to granulate flash dried MAP on its own to form granular MAP whereas with 'PhoSAl' this is a simple operation.

Once again, the difference in behaviour can be understood in terms of the nature of the impurities.

The insoluble material in the flash dried product does not coat the MAP crystals, whereas in 'PhoSAl' the amorphous gel-like material occupying the inter-crystalline spaces probably plays an important part in the granulation process by assisting particles to bind together.

There is also evidence which shows that the membranes of impurities serve as an inter-crystalline adhesive only when they are attached to the MAP crystals. This was obtained from a series of granulation tests in which 12:12:18 was made with samples of flash dried MAP to which had been added the insolubles from an equivalent quantity of the parent 'PhoSAl'. As the results in Table II show, the addition of 'PhoSAl' insolubles had little effect on the granulation properties and therefore the contribution made by the insolubles seems to be lost when they are detached from the surface of the MAP crystals.

TABLE II - Effect of 'PhoSAl' Insolubles on Flash Dried MAP :

Particle Size	TOGO			MOROCCO	
	No Additive	+ Insolubles	Ground to <100 mesh BSS + insolubles	No Additive	Ground to <100 mesh BSS + Insolubles
	%	%	%	%	%
>2.8mm	3	10	6	6	3
<2.8mm	97	90	94	94	97

CONCLUSIONS :

Optimum granulation and storage properties can be obtained for an MAP intermediate when it is made under process conditions which allow impurities to affect crystallisation and to coat the MAP crystals. Also, the temperature used in the manufacturing process should be as low as possible.

Although some of the work which has been described in this paper involves complex chemical and physical changes the SAI process is basically simple and easy to operate and has been in full scale commercial use for 17 years.

REFERENCES :

1. Brownlie I A, Graham R, 1963 ISMA Technical Conference, Helsinki.
2. Hemsley J D C, 1968 Fert. Ind. Round Table, Washington.
3. Mortenson E N, 1970 Fert. Ind. Round Table, Washington.
4. European Chemical News, 1973, July 6, p 28.
5. Brownlie I A, 1973 Amer. Chem. Soc., Chicago.
6. Davidson E, Martin I S E, 1973 Fert. Ind. Round Table, Washington.
7. Brownlie I A, Davidson E, Dick T R, 1977, Proc. No 162, Fert. Soc., London.
8. Brownlie I A, 1977 Fert. Ind. Round Table, Washington.
9. "Phosphorus & Potassium", 1974, No 70, March/April, p 32-37.
10. "Physical Properties of Fertilisers", TVA 8th Demonstration, 1970.
11. Ando J, Akiyama T, 1972 ISMA Technical Conference, Seville.
12. Anderton P H, Kolmeier N W, 1976, "Phosphorus & Potassium", No 86, Nov/Dec, p 39-43.

