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THE USE OF A PRESSURE NEUTRALISER FOR SLURRY GRANULATION

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INTRODUCTION

In the production of granular di-ammonium phosphate (DAP), and NPK fertilizers based on ammonium phosphate slurry, there are many variations on a theme with respect to the phosphoric acid neutralisation step. The equipment used falls into three main categories:-

Atmospheric Reactors
Pipe Reactors
Pressure Reactors

Each type has certain advantages and at the same time limitations. The objective of this paper is to discuss Pressure Neutralisation in slurry granulation using the Norsk Hydro Fertilizers (NHF) Draught Tube Reactor (DTR).

We describe briefly the NHF Slurry Granulation process, incorporating the DTR, before moving to a more detailed discussion of the process, with particular emphasis on pressure neutralisation, including:-

- the theory of pressure neutralisation.
- details of the development and the design of the DTR.
- recent operating experience using pressure neutralisation in slurry granulation, including the production of grades as diverse as DAP, 16:20:0, 11:33:22 and 8:26:26.
- possibilities for retro-fitting existing slurry processes based on atmospheric neutralisation.

NHF DAP PROCESS

The outline flow diagram for the NHF DAP process is given in Figure 1.

Phosphoric acid and ammonia are fed under flow control to the draught tube reactor. The pressure in the reactor is automatically controlled at 1 bar g by the release of the reaction steam through a control valve. The temperature in the reactor is automatically controlled at 142-145°C by the addition of water.

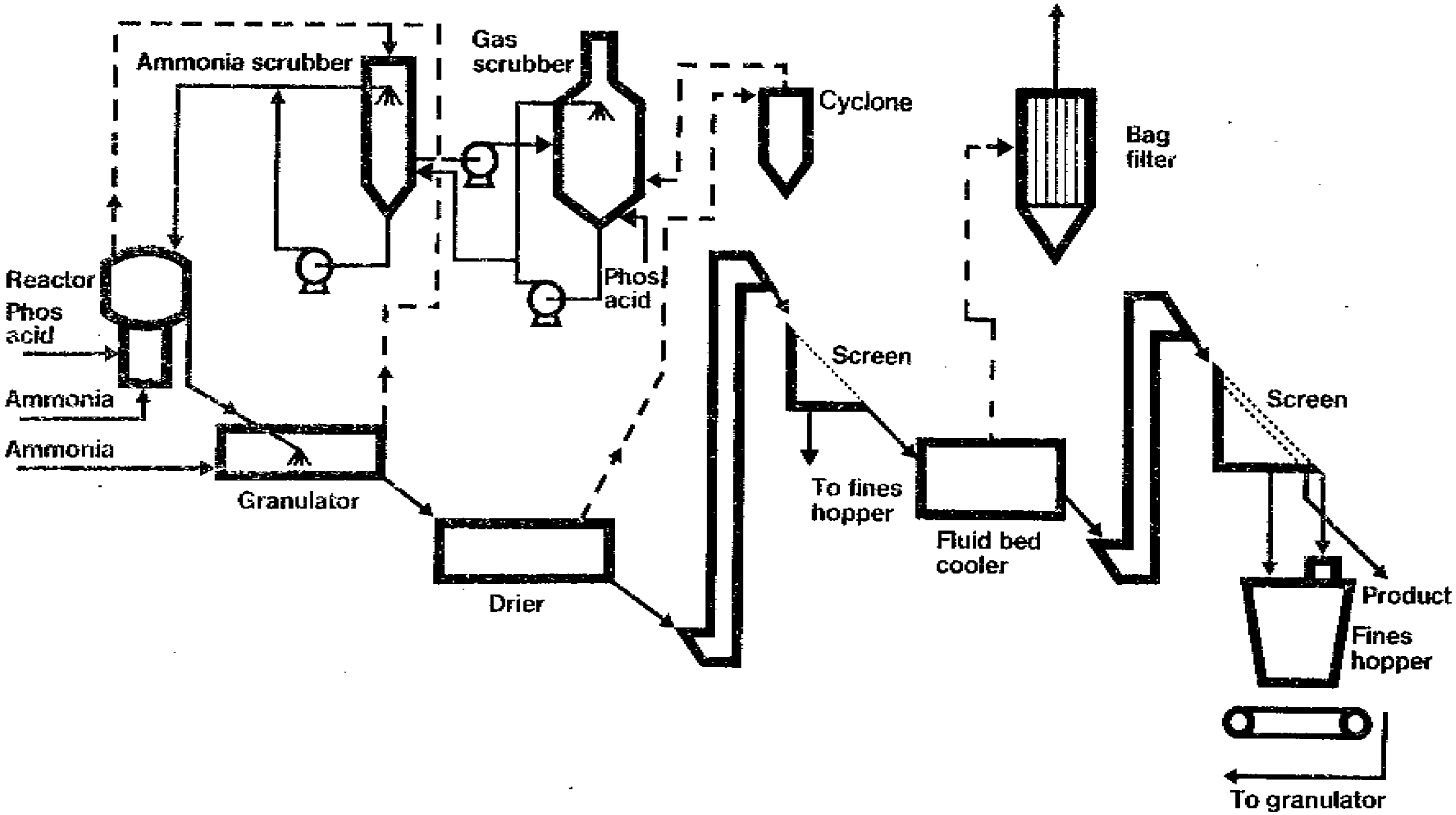
Ammonium phosphate liquor from the reactor, with a molar ratio of around 1.5:1, is fed together with recycled fines to the rotary granulator. Ammonia is added to achieve the required product analysis.

Granulated material is dried and then elevated to the primary screening section where undersize granules are separated and returned to the granulator via the fines hopper. If required some product can also be returned at this stage.

Product and oversize material after screening is cooled, in a fluid bed cooler and elevated to the secondary screening station which incorporates double-deck screens. Oversize is removed, crushed, and fed to the fines hopper. Residual undersize is also removed and recycled to the fines hopper. A proportion of the product can be crushed and returned to the fines hopper. Recycle is metered back from the fines hopper to the granulator at a constant rate so that granulation is maintained at the optimum condition at all times.

Figure 1.

Norsk Hydro Fertilizers DAP Process



The process operates with a recycle ratio of under 4:1 compared with 5-6:1 for plants with atmospheric reaction systems.

Steam discharged from the reactor and the air stream from the granulator are scrubbed with the incoming phosphoric acid in the ammonia scrubber to remove the majority of the ammonia. The exhaust from this vessel is ducted to the counter-current gas scrubber together with the air stream from the drier cyclones. A dilute solution of phosphoric acid is used to clean the gas stream which is finally discharged to atmosphere. The liquid effluent from the gas scrubber is returned to the reactor via the ammonia scrubber and the process is therefore liquid effluent free.

The dust in the air stream from the cooler and dust extraction system are fed to bag filters for recovery of the dust. The air streams leaving both bag filters are almost free of dust and can be discharged to atmosphere without scrubbing. In fact the air from the bag filters is sufficiently clean to be used as dilution air for the air heater thereby saving 15-20% of fuel costs for drying.

The process is flexible and can be readily adapted to produce grades such as 16:20:0 by replacing part of the phosphoric acid feed with sulphuric acid. In addition a solids intake and metering system can be incorporated to feed solid raw materials such as urea, potash etc. thus allowing grades such as 19:19:19 and 11:33:22 to be made.

THEORY OF PRESSURE NEUTRALISATION

The reaction between ammonia and phosphoric acid is highly exothermic. All ammonium phosphate slurry processes, be they based on atmospheric, pipe or pressure neutralisation, utilise the heat generated to evaporate water. The amount of water to be evaporated and therefore the thermal balance of the process is determined by the initial phosphoric acid strength and the final condition of the ammonium phosphate slurry. In order to minimise both equipment size and utility consumptions in the granulation section of the process it is desirable to operate with the lowest possible water content in the ammonium phosphate slurry. This is achieved by operating at the point of maximum solubility.

The crystallisation points of ammonium phosphate solutions with water contents varying between 5-20% are shown in Figure 2. The curves illustrate that the solubility of ammonium phosphate is at a minimum at 1:1 N to P mole ratio and at a maximum at around 1.45:1 (i.e. 55% mono-ammonium phosphate, 45% di-ammonium phosphate).

The advantages of pressure neutralisation are derived from two facts of physical chemistry:-

a) The solubility of ammonium phosphate increases with temperature.

b) The boiling points of solutions increase with increased pressure. This is illustrated in Figure 3 where boiling point curves, at atmospheric pressure and 1 bar g, have been superimposed on crystallisation curves.

Therefore, by applying pressure to the reaction system, the temperature of the ammonium phosphate solution can be elevated above its atmospheric boiling point. In this way a pressure reactor can be operated at much lower water contents relative to atmospheric reactors because solubilities can be achieved which are not possible under atmospheric conditions.

Figure 2. Crystallisation Points of Ammonium Phosphate Solutions

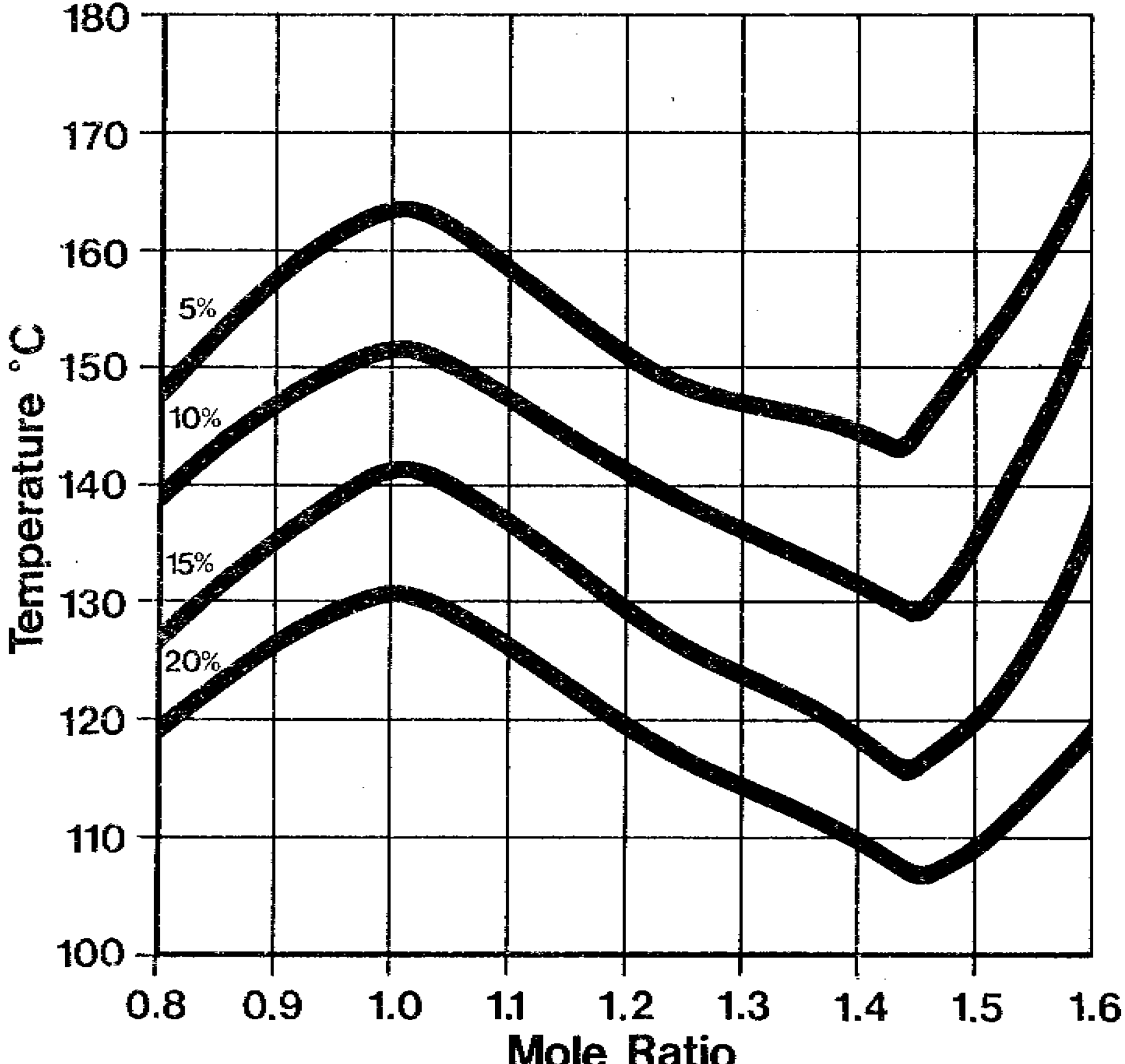
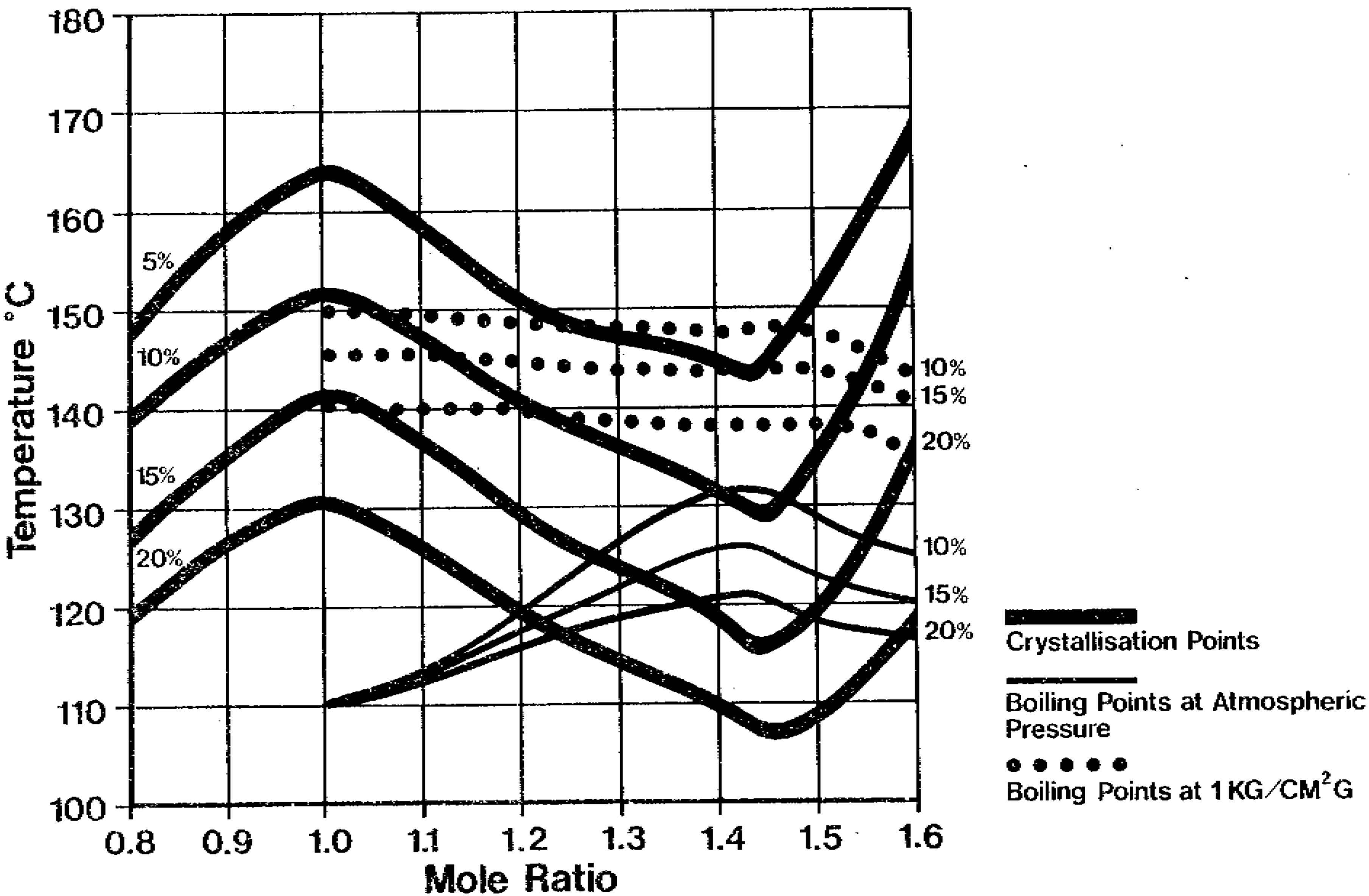


Figure 3. Effect of Pressure on Boiling Points of Ammonium Phosphate in water



The pressure reactor is always operated in such a way as to produce a true solution of ammonium phosphate and therefore the term "slurry" granulation is, in fact, a misnomer. Operating with a true solution as opposed to a slurry ensures that problems normally associated with slurry handling are eliminated.

The typical DAP operating conditions for pressure and atmospheric reactors are compared in Table 1.

Table 1

Reactor/Granulator Operating Conditions

	Pressure	Atmospheric
Reactor		
Operating Pressure, bar g	1.0	0
Operating Temperature, °C	142-145	120
N:P Molar Ratio	1.5:1	1.4:1
Water Content, %	12-15	20
Granulator		
Operating Temperature, °C	80-85	85
N:P Molar Ratio	1.8-1.85:1	1.8-1.85:1
Water Content, %	2-2.5	3
Recycle Ratio	4:1	6:1

The lower reactor water content for pressure neutralisation leads to smaller equipment in the solids handling section corresponding to the lower recycle ratio. Fuel consumption is reduced by almost 50 percent due to a combination of lower granulation moisture and lower recycle ratio. Apart from these obvious advantages there are other benefits from pressure neutralisation:-

- Within the granulation plant the DTR would normally be located one floor above the granulator. The height plus reactor pressure gives sufficient head to spray the solution, through flood jet nozzles, into the granulator. Slurry pumps and their associated problems, are therefore eliminated.

- When the slurry is let down to atmospheric pressure in the granulator additional steam flashes off thus lowering further the ammonium phosphate water content.

- The reactor operates with a residence time of around 20 minutes thus giving sufficient buffer capacity to smooth out feed or other fluctuations. In this way the reactor conditions can be easily controlled, independent of throughput, to ensure that the slurry condition is consistently maintained.

The foregoing discussion has tended to concentrate on DAP production. However, the pressure reactor is flexible and can handle mixtures of phosphoric acid, sulphuric acid and ammonia to produce ammonium sulphate/phosphate slurries. The operating principles for the pressure reactor are identical but obviously solubilities and therefore water contents and operating temperatures are different.

Additionally urea and/or potash can be added in the solid section to produce a wide range of NPK grades. Some further details of our operating experience are given below.

Grade	18-46-0	16-20-0	8-26-26	11-33-22
Reactor				
Temperature, °C	142	136	143	144
Pressure, kg/cm^{2}g	1.0	1.0	1.0	1.0
Moisture, %	14.5	21	15	13.5
pH (10% solution)	6.7	5.6	6.1	6.2
Granulator				
Recycle Ratio	3.9:1	3.3:1	2:1	4:1
Temperature, °C	80	98	77	80
Moisture, %	2.0	1.5	-	1.8
pH (10% solution)	7.4	4.0	6.1	7.1
Drier				
Air Inlet Temperature, °C	188	80	190	183
Air Outlet Temperature, °C	85	95	85	88
Solids Outlet Temperature, °C	82	82	75	82
Product				
% N	18.6	15.9	8.0	11.7
% P_2O_5	47.2	19.9	25.5	32.6
% K_2O	-	-	24.7	21.9
% H_2O	1.15	0.65	1.0	1.1
Size, % 1-4 mms	99	92	95	91

DRAUGHT TUBE REACTOR

The principle of pressure neutralisation of phosphoric acid is a well proven technique. The first commercial plant for Minifos MAP production was put into operation in 1965 and was based on a stirred tank reactor. Since that time well over thirty units have been built producing both Minifos MAP and slurry for direct granulation. The latest form of pressure neutraliser eliminates the need for mechanical agitation and is known as the Draught Tube Reactor (DTR).

Development of the DTR began at our Levington Research Station in 1974 with a pilot plant rated at about 180 kg/hr. The first commercial plant was erected in 1975 at Fison-UCB (now CNO) in Belgium and produced about 7.5 tonnes/hour.

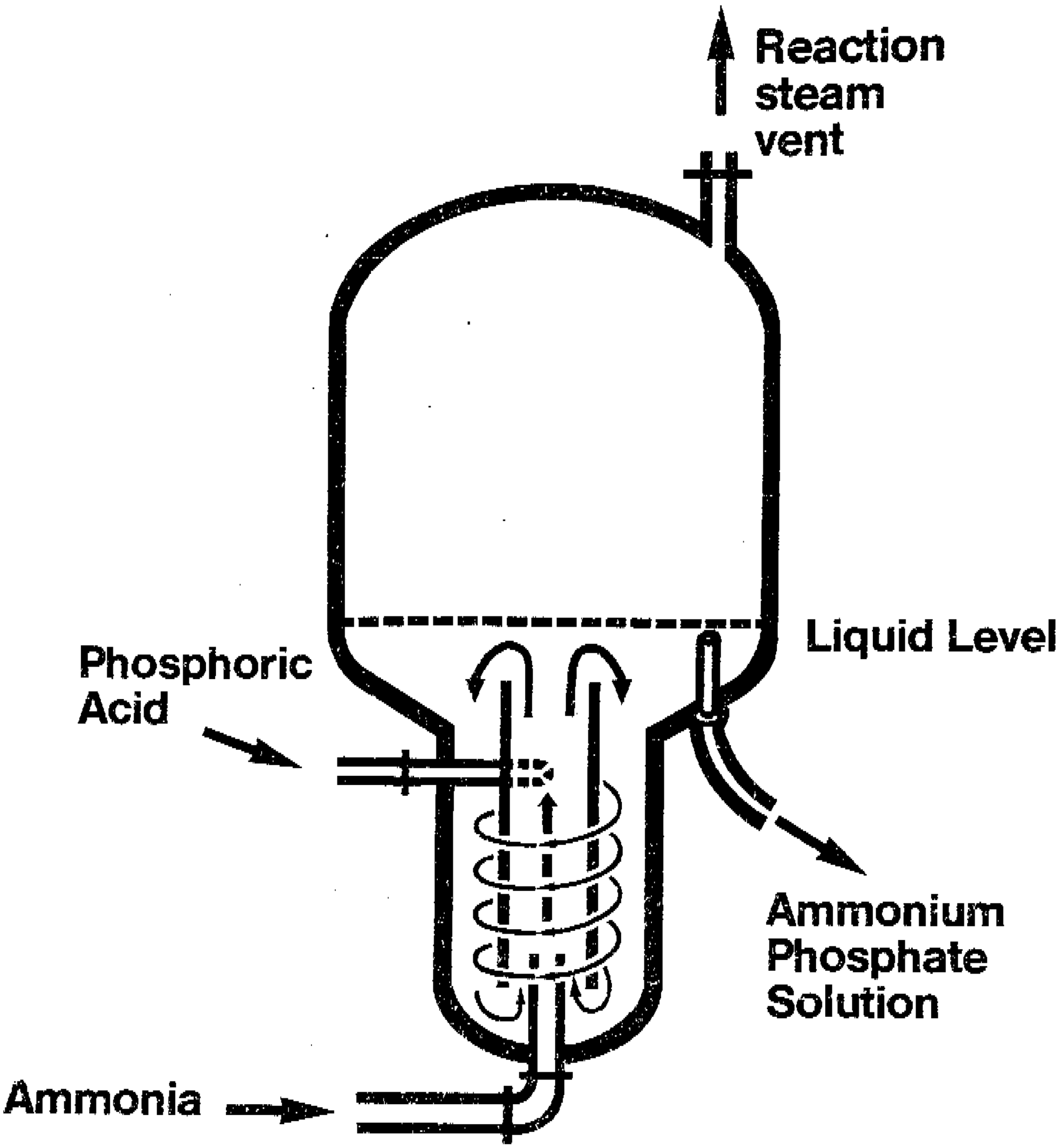


Figure 4.
Norsk Hydro Fertilizers Draught Tube Reactor

A second DTR with a 17 tph capacity was started up in 1981, the successful commissioning requiring only eleven days. A third DTR with a 27 tph capacity is currently under construction. More recently a contract has been signed for a 33 tph reactor which is now at the design stage. At this time in the development we are confident in offering DTR designs for capacities of up to 45 tph. Mechanically agitated pressure reactors have been commissioned with up to 60 tph capacity.

The main details of the DTR are shown in Figure 4.

Phosphoric acid is fed tangentially into the annulus of the lower section while ammonia is sparged into the lower part of the inner tube. The exothermic reaction causes steam to be formed which in turn causes a density reduction which results in an upward movement in the inner tube. As steam is released in the upper section of the reactor the density increases and the liquor falls through the annulus thus establishing a natural circulation.

In the upper section steam disengages from the liquor surface and discharges from the top of the reactor via a pressure control valve. The ammonium phosphate solution is discharged from the reactor through a standpipe. If it is necessary to feed sulphuric acid, e.g. to make ammonium sulphate/phosphate grades or adjust the analysis of DAP, this is fed into the upper section.

The draught tube section consists of two concentric tubes, the outer tube forming the wall of the reactor, whilst the inner tube creates an annular channel.

Exhaustive pilot plant tests were undertaken to determine the draught tube design parameters required to achieve maximum ammonia efficiency. The important conclusions were as follows:-

- A recirculation ratio of the reactants above a certain minimum is required to ensure a high ammonia efficiency. Very little improvement in efficiency is achieved at recirculation ratios above 20:1. The outer tube is sized to ensure that this ratio is attained.
- Provided that this recirculation ratio is attained the most important parameter is the velocity in the inner tube. The optimum velocity is that which promotes a "churn flow" regime. In this regime the steam bubbles which could trap ammonia are continually collapsing and reforming thus ensuring high absorption efficiency.
- No significant improvement in efficiency was found when the length of the inner tube was increased beyond 2m.

The diameter of the upper section of the reactor, or disengagement section, is determined by the maximum acceptable steam velocity without causing excessive liquid entrainment. Typical steam release rates of the order of 650-800 kg/m^2/hr are used for design - actual values depend on the product and operating conditions.

The DTR is generally constructed in 316L stainless steel, although 20 grade alloy is used for acids with high chloride levels. Reactor life is in excess of ten years.

RETRO-FITTING

With the ever increasing price of oil the fertilizer industry is acutely aware of the need to save energy. The DTR offers the opportunity to save energy, whilst at the same time boosting plant capacity, for a relatively modest outlay.

The DTR is located just above the granulator whereas an atmospheric reactor is often situated at ground level. It is therefore relatively easy to replace an atmospheric reactor without disrupting production. Existing equipment such as ammonia scrubbers, granulators, driers, fans etc. would be compatible with the DTR.

For a typical granulation plant we would expect at least a 20% increase in production and a decrease in fuel consumption of up to 50%.

NHF have recently been awarded a design contract to replace an atmospheric reaction system with a DTR pressure neutralisation system on an existing granulation plant. The new reactor will have a capacity of 33 tph. Within the solids section of the process recycle ratios will be reduced to the extent that production capacity will be increased by 30%.

CONCLUSION

The pressure neutraliser was originally developed for Minifos MAP production. Its simplicity of operation and reliability has led to thirty licences being granted in sixteen countries throughout the world, since its introduction almost twenty years ago. More recently, with the trend towards DAP, and high analysis NPKs based on DAP, the pressure neutraliser has been used on seven slurry granulation plants.

The design of the pressure neutraliser has been continuously refined and improved and in its latest form uses the draught tube principle to promote natural mixing of the reactants. Two commercial scale plants are currently operating using the DTR. A further unit will be put into operation in 1985 when the DAP plant for Hindustan Lever at Haldia, India is completed. A fourth DTR is currently being designed as a replacement for an atmospheric reactor on an existing granulation plant.

The use of the DTR pressure neutraliser on ammonium phosphate slurry granugranulation plants has many advantages over conventional atmospheric neutralisers. The low water content solution reduces recycle ratio and energy consumption. No agitation or pumping is required. The traditional virtues of conventional systems are, however, retained. The buffer capacity of the DTR gives a stable, efficient and easily controllable reaction for trouble-free granulation. The life of the reactor is in excess of ten years.

Boosting of existing conventional atmospheric plants using the DTR is possible with a considerable fuel saving being an additional benefit. In a recent contract a production capacity increase of 30% will be achieved simply by replacing an atmospheric reactor with a DTR.

TA/84/3 The use of a pressure neutralizer for slurry granulation by D.M. Ivell & N.D. Ward, Norsk Hydro Fertilizers Ltd, United Kingdom

DISCUSSION: Rapporteurs J. CARIOU, COFAZ SA, France and S. SWANSTROM, Kemira Oy, Finland

Q - Mr. K.L. PARKS, Agrico, USA

What is the composition of the acid stream used: a) to scrub the reactor and granulator exit gases and b) as the final gas scrubbing liquid (page 3, § 2 & 3 resp.)?

A - The scrubbing liquor is generally controlled at a mole ratio of 0.3 to 0.4:1. For DAP production, P2O5 concentration in the scrubbing liquor would be 40-45%.

Q - Mr. K. BELL, ICI PLC, United Kingdom

Do you experience any choking problems at the liquid outlet standpipe or ammonia inlet point and if so how do you clear the chokes? Do you experience any variations in flow due to foaming in the reactor?

A - There are certainly no significant problems with choking at either the liquid outlet or the ammonia inlet. We do however have automatic steam purges on all feed lines to and from the reactor. The feeds and steam purges are activated by multiposition switches. On the odd occasion the ammonia flow or the solution outlet flow can begin to drop off due to some small deposits. These deposits can be very easily cleared by selection of the appropriate steam purge for a few seconds. The plant would continue to run during this operation.

Q - Mr. G. BRUSASCO, Fertimont SpA, Italy

When you use phosphoric acid high in impurity, have you problems of building-up inside the reactor? If yes, how do you operate? What is the frequency of the reactor cleaning?

A - We have used sludge acid containing up to 15% solids in the pressure reactor without suffering from build-up problems or line blockages. We never have to drain the reactor for cleaning purposes.

Q - Mr. N. LOUIZOS, SAHPEC, Greece

What are the advantages/disadvantages of DTR compared to the pipe reactor? Could you convince a potential user to employ a DTR rather than a pipe reactor? What are normal ammonia losses with DTR?

A - We are happy to discuss the advantages of DTR compared to the pipe reactor and will leave others to discuss any perceived disadvantages.

The DTR has as its basis the same basic principle as a pipe reactor - that of operation at elevated pressure and temperature to produce a low water content solution and hence reduce recycle ratio and fuel consumption in the solids section of the process. As with a pipe reactor agitation and slurry pumping are dispensed with.

The main difference between the DTR and a pipe reactor relates to the buffer capacity of around 20 minutes which the DTR has. This enables changes in flow or composition of the feeds to be smoothed out before the ammonium phosphate is sprayed into the granulator. This ensures that the condition of the ammonium phosphate solution - mole ratio, temperature and water content - is consistently maintained. Problems of blockages in the reactor (well documented for pipe reactors) or in downstream equipment are avoided. A consistent slurry quality ensures that granulation is stable and easily controlled and results in minimum recycle ratio and therefore maximum production rates.

The buffer capacity in the reactor, in combination with the efficient mixing afforded by the draught tube, ensures a highly efficient reaction - ammonia loss closely approaches that due to the ammonia vapour pressure.

The vapour in the reactor is easily controlled so as to maintain slurry conditions of temperature and water content independent of throughput. The reaction steam is disengaged from the slurry in a controlled manner prior to spraying in the granulator. In this way the water and energy balance in the granulator is improved and controlled and the moisture carrying burden of the granulator is drastically reduced.

In summary, we believe that the DTR combines the advantages offered by pipe reactors with the traditional virtues of conventional atmospheric reaction processes. We believe that the inherent problems with pipe reactors are sufficiently serious, particularly for DAP production, to convince many potential users to employ a DTR in preference. The new plant in India and the revamped plant, referred to in the paper, are recent examples of this.

Q - Mr. A. SARKKA, Kemira Oy, Finland

Is a pressure neutraliser suitable for ammoniation of digestion liquor (calcium nitrate, phosphoric and nitric acid mixture)?

A - We have no direct experience of using the pressure neutraliser for ammoniation of nitrophosphate digestion liquor. We do have experience however of ammoniation of sulphuric/phosphoric acid mixtures as well as ammonium nitrate/phosphoric acid mixtures. In principle we see no problem with the use of the pressure neutraliser for this duty.

Q - Mr. N. KOLMEIJER, Windmill Holland, Netherlands

Why do you limit the pressure in the reactor to 1 kg/cm2 g? If you would go up in pressure the water content would be even lower and recycle further reduced.

A - We have used pressures of up to 2.1 kg/cm2 g for certain MAP based grades. The problem is, in general however, one of ammonia vapour pressure. Whilst increasing pressure above 1 kg/cm2 g certainly allows us to reduce water content, we can only do so by increasing the temperature.

Q - Mr. J. LE PAGE, ICS, Senegal

Is the NH3 used in the pressure reactor and in the granulator in liquid or gaseous form?

A - Liquid or gaseous ammonia can and have been used in both the reactor and the granulator. In general liquid ammonia is used in the granulator whilst in the reactor the decision would depend on acid strength: if acid of 48-49% or stronger is available for DAP production then liquid ammonia is used.

Q - Mr. E. SEUNA, Kemira Oy, Finland

How do you start the DTR? How long does it take? What is the minimum strength of H3PO4 to have any advantage of a pressurized neutralization? What is the difference of ammonia content in off-gases between atmosphere and pressurized reactor?

A - a) From cold the DTR is started by first filling the tube with phosphoric acid. The acid is then ammoniated to the required mole ratio depending on grade. Once this is accomplished spraying can begin and the reactor put into continuous operation. Start-up time depends on reactor mole ratio and characteristics of the acid but around 45 minutes is typical.

Note however that during short shut-downs (which can be up to several days) there is no need to empty the reactor. Shut-down is automatic and the reactor contents are maintained at the required temperature and pressure by closing all inlet and outlet valves. Small steam purges to the ammonia and phosphoric acid lines can be used if necessary to compensate for any leakage through the pressure control valve. Starting from this situation is achieved within five minutes.

b) Acid strength required depends on the grade being produced. For DAP production 40-42% P205 acid can be used although to take full advantage of pressure neutralisation 43-44% is preferred.

c) Reactor ammonia loss is only slightly in excess of that due to the vapour pressure of ammonia. Because the reactor operates at some 25°C higher than a conventional atmospheric reactor the ammonia partial pressure will be higher. One would expect therefore that the DTR would lose 1 or 2% more ammonia than an atmospheric reactor when producing DAP. This of course assumes that the atmospheric reactor and its agitator gives optimum mixing efficiency. However after scrubbing to recover ammonia the differences would not be detectable and therefore the overall ammonia efficiency of the atmospheric and pressure process would be the same, that is 99%.

Q - Mr. H.J. BOHTE, UKF, Netherlands

What is the recycle temperature to the granulator in DAP production when the recycle ratio is 3.9:1?

A - Recycle and granulation temperatures can vary depending on the layout of the plant. In the particular case referred to in the paper recycle temperature was around 60°C.

Q - Mr. S.K. MUKHERJEE, FAI, India

a) What is the experience of build-up of solids in pressure neutralizer?

b) How often do you need to clean the neutralizer? How much production time is lost due to cleaning?

A - a) We have used a wide range of acids in pressure reactor including sludge acid and have not experienced build-up or scaling problems within the reactor.

b) The reactor is only drained for long shut-downs (say in excess of 72 hours). The reactor is never drained for cleaning purposes.

Q - Mr. M. SIPILA, Kemira Oy, Finland

a) How much are the ammonia discharges leaving the draught tube reactor and the granulator to the ammonia scrubber and what is the efficiency of this type of scrubber?

b) What is the amount of gaseous ammonia leaving the drier?

c) What is the most preferable design of the rotary granulator?

d) Is it possible to use a blunger in this particular case?

A - a) The ammonia losses from the pressure reactor, granulator and drier depend on the grade of final product being produced. Losses are greatest during DAP production.

b) We have found that losses from the reactor are only slightly in excess of those due to the ammonia vapour pressure. In the case of DAP this is usually just over 5% of the ammonia fed to the reactor.

Losses from the granulator are of the order of 15% plus of the ammonia fed to the granulator.

Losses from the drier are of the order of 1-2% of the total ammonia fed.

The void tower scrubbers have an efficiency of around 90%. The gases from the reactor and granulator are scrubbed first in the ammonia scrubber and then in the gas scrubber thus ensuring an overall ammonia efficiency of 99%.

b) The detailed design of the rotary granulator has been developed over many years by Norsk Hydro Fertilizers and its predecessor Fisons Fertilizers.

For the production of DAP or related grades the most salient features of the design are:

- ammonium phosphate solution is sprayed under pressure through floodjet nozzles onto the bed of recycle solids.

- ammonia is added via an under-bed sparge pipe of special design.

- an outlet weir plate maintains a deep bed within the drum.

- the drum is air-swept to remove evaporated moisture, and ammonia for recovery in the scrubber system.

- flexible rubber panels are used to keep the inside of the drum free from build-up.

c) It is possible to use a blunger in combination with the DTR. We prefer however to use a rotary granulator as this enables recycle ratio to be minimised.

As the pressure is released through the spray nozzle to atmospheric pressure some flash evaporation takes place. The heat generated from the ammoniation in the granulator causes further evaporation. Efficient removal of evaporated water from the granulation device improves the water balance and thus minimises recycle ratio. This is best achieved in an air-swept rotary granulator where a large surface area of material is presented.

Additional questions put in writing

Q - Mr. M. LAURENS, Krebs, France

On the flowsheet of page 3-2, there are:

- a prescreening of fines before cooling: Why?
- a fluidized bed cooler. Is it not difficult to operate this equipment with a wide granule size range product?

A - The scheme in figure 1 shows the undersize and a proportion of product sized material recycled hot. Oversize and the remaining product is cooled. This arrangement is considered the optimum for absolute minimum recycle ratio. It is however not essential and, for example, both the new DAP plant for Hindustan Lever and the pressure reactor revamp, referred to in the paper, feature a total hot recycle.

The object of the screening arrangement shown - i.e. hot fines, cold oversize - is to give the optimum recycle temperature for minimum recycle ratio. (You should note that the secondary fines screening is a polishing screen only, the vast majority is removed hot).

A carefully designed fluidised bed cooler can cope with a combined product and oversize stream. Large lumps are crushed by a crusher situated in the drier outlet hood. Some further scalping is carried out in the screen feeder to remove any remaining lumps which then bypass the cooler.

Q - Mr. J. DEMEY, CNO, Belgium

1. How do you control the level?
2. How do you control the N-P ratio?

A - 1. The feeds to and from the reactor are both under flow control. The level is allowed to float, to a limited extent, although fluctuations are slow and small due to the buffer capacity of the reactor. The reactor is also fitted with a standpipe as a simple back-up level control.

2. The N-P ratio is controlled by making occasional fine adjustments to the ammonia flow as a result of periodic pH measurements on samples from the reactor. Once again fluctuations are slow and small due to the reactors'buffer capacity.

Q - Mr. M. BARLOY, OTP, Togo

Could you provide typical data for DAP production:
- P2O5 concentration of the phosacid
- Fuel consumption?

Which is governing the recycle ratio (or the production rate for a given plant); the amount of merchant product available in the dryer or the liquid phase absorption in the granulator?

In my opinion, the percent of final product between 1 and 4 mm is not representative of the size distribution quality since most of the product could be between 1 and 2 mm. It should be associated with the percent of products between 2 and 4. Do you agree?

A - For DAP production 43-44% P2O5 acid is required to realise the full benefit of pressure reaction. Fuel consumption is typically 3 kg/t.

For DAP production the liquid phase absorption in the granulator governs recycle ratio. For certain NPK grades which can be made at very low recycle ratios then the amount of product available ex dryer could determine recycle ratio.

Since generally recycle ratio is determined by liquid phase absorption rather than granulation efficiency, a very narrow size range can easily be obtained if required (e.g. 90-95% between 2 and 4 mm). The data reported on page 7 came from different places where local regulations allowed product of 1 to 4 mm and 1 to 5 mm respectively. No real attempt was therefore made to improve on the figures quoted.