GRANULATION PLANT DESIGN OPTIONS

D.M. Ivell
Jacobs Engineering Group Inc.
Lakeland, Florida

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By: D.M. Ivell, Jacobs Engineering Group

Introduction

It is probably true to say that the fluidized bed granulation concept for the production of straight nitrogen products, such as urea and ammonium nitrate, can be classed as a giant leap forward in technology. Its domination of the market over the last 10 years or more is a testament to its revolutionary nature. In contrast, progress in phosphatic fertilizer granulation technology has been evolutionary rather than revolutionary. Since the introduction of the rotary ammoniator-granulator, pioneered by TVA in the 1950's, the unit operations have remained very roughly the same in all designs.

However, it is often the detailed design of each unit operation, rather than the basic principle, that differentiates one company's design from another. Those details can make the difference between a rather poor design and a good design.

At Jacobs we are rather lucky in that our staff includes engineers who cut their teeth at other companies before coming to Jacobs. That wide and varied experience allows us to offer a design, which incorporates the best ideas from a variety of sources.

Jacobs have recently completed basic engineering for two large granulation projects – three lines each rated at 142 mtph DAP for Oswal Chemicals and Fertilizers in India and one line rated at 135 mtph DAP/MAP for WMC Fertilizers in Australia. To the best of our knowledge, the Oswal DAP plants have the largest nameplate capacity in the world.

This paper discusses some of the design options that can be considered for a modern granulation plant. Many of these features are incorporated in the Oswal and WMC plants. We will not try and pretend that all of the ideas are brand new - it is often the combination of ideas that makes for a successful design.

Pipe Reactors

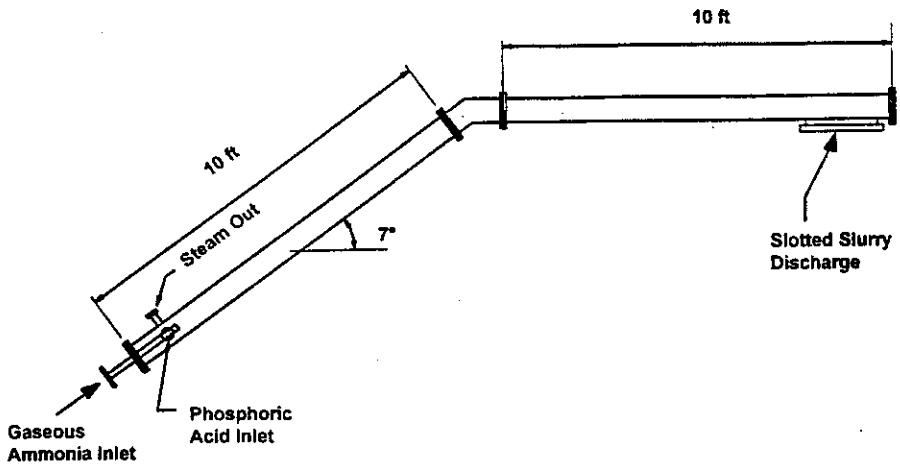
Pipe reactors have been around for a long time now and in the early days, back in the 1970's, were the subject of many papers. The concept has never really caught on the US - which is ironic since much of the pioneering work was done here. In fact Jacobs' predecessor, Dorr-Oliver held the original pipe reactor patent dating back to 1967. However, there are several European fertilizer licensors who have been very successful in licensing pipe reactor technology throughout the rest of the world. Indeed the vast majority of new plants that have been brought on-stream over the last 10 years or more have incorporated pipe reactor technology and it is for this reason that a section on pipe reactors is included in this paper.

Jacobs designed and installed the only pipe reactor currently producing DAP in the US. The pipe was installed at PCS, N. Carolina when their existing TSP plant was converted for ammonium phosphates in 1985(1). The plant has produced both MAP and DAP and currently produces exclusively DAP at a rate of about 65 tph. The plants licenced by Jacobs in Nigeria, China and now in India at Oswal - the worlds largest DAP granulation plant - have all included pipe reactors.

The author's personal experience with pipe reactors dates back to 1989 when he was responsible for the design and start up of a pipe reactor to make MAP in an existing NPK plant. At that time we had nothing better to go on than the information published by TVA and the design was based on those principles. Since that time a lot has been learnt through trial and error and we now have a very good handle on what is important and what is not.

That first pipe reactor was very long - about 24 ft overall - with about half its length installed on a 7° upward slope as per the TVA recommendations of the time. A sketch of the arrangement is shown in Figure 1.

Fig. 1 Old Pipe Reactor Design



The slurry discharged through a narrow slot of around $^3/_8$". The pipe operated on gaseous ammonia injected down the length of the pipe with the acid fed at 90° to it. Despite the long length, the ammonia losses from the pipe were disappointingly high - about 10% when operated at mole ratio 1.0. In addition, the slot discharge resulted in a very wet bed in the area of the discharge. It was this latter problem which eventually caused us to remove the ammonia sparger and do all the ammoniation in the pipe.

Since that time all kinds of pipe arrangements have been tried - ammonia and acid feed orientation reversed, static mixers of one sort or another in the pipe and slurry discharge through a series of holes to name but a few. We have concluded the following:

- A long pipe is not necessary provided the orientation of the feeds is optimized. Ammonia losses are only of the order of 15%, even when the pipe is operated at 1.8-1.9 mole ratio.
- Static mixers or other types of internal mixing devices are not necessary provided the orientation of the feeds is optimized.

- Control of the feeds to the pipe reactor is very much more important than with a tank preneutralizer because of the low residence time. Specifically the relative flow rates of acid and ammonia, as well as the concentration of the acid, need to be accurately controlled. Jacobs' philosophy is to use a pump tank to feed the total flow of P_2O_5 to the pipe. Ratio controls for the ammonia and feeds and automatic control of the acid feed SG are used.
- Slurry distribution is very important and, provided the correct type of nozzle is selected, large standard spray nozzles have been shown to give the best results. The nozzle sizes need to be selected to give a back pressure of not * less than 15 psig. At lower pressures experience has shown that the reaction becomes unstable and alternate wet - dry granulation results.

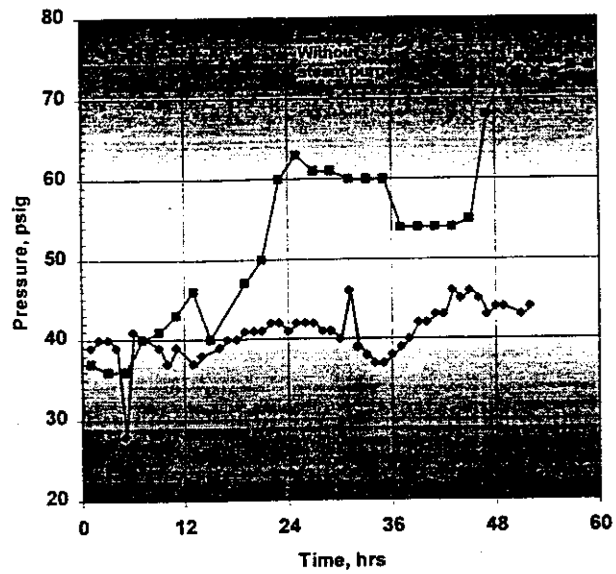
Wet Bed.

Pipe too close to Bed steam re-condenses and wets the bed.

- It is very important to have an adequate ventilation rate for the granulator. The ventilation rate, the slurry spray arrangement and the location of the pipe within the granulator are all important to ensure that the reaction steam does not recondense. If the reaction steam should recondense, excessive granulation temperatures and consequent difficulty in making grade can result.
- Depending on the type of acid being processed, pipe scaling can be a problem but the addition of sulfuric acid, as originally proposed by TVA, is not necessary. Instead a high pressure (preferably 250 psig) steam purge has proved to be very successful at keeping the pipe clean. The steam purge is controlled by a series of timers and is completely automatic.

Figure 2 below demonstrates the effectiveness of the steam purge system. The top line shows the typical build up in back presure that occurs with time when the steam purge system is not fitted. The bottom line shows how the steam purge keeps the rise in back pressure in check.

Fig.2 Effect of Pipe Reactor Steam Purge



There are many advantages to pipe reactor processing and below are a few that may be particularly interesting to the producers here in Florida:

- Almost zero Cl losses
- Lower product moisture content without fuel for drying
- Very responsive to process changes. Very quick and easy to start up and shutdown. The problems associated with pumping a viscous, foaming slurry close to its crystallization point are eliminated. No worries about preventing the slurry from salting out during shutdowns.

The first two obviously ease the problems associated with making grade, which many Florida producers are increasingly struggling with.

Some of the European licensors offer more complicated flowsheets with the aim of removing heat from the granulator. Jacobs use liquid rather than gaseous ammonia under the bed in the granulator and do not believe that these complications are necessary provided the precautions with regard to granulator ventilation and steam disengagement are taken.

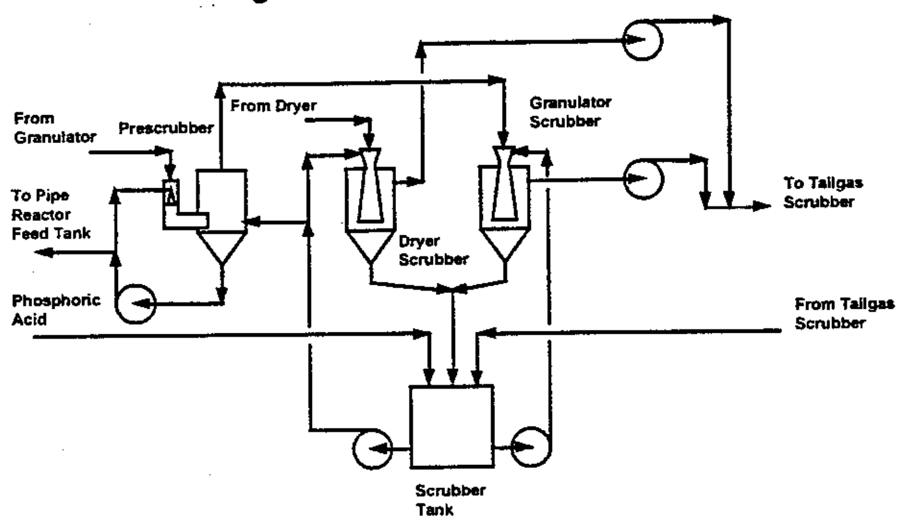
One process known as the "double pipe reactor" process uses two pipe reactors – one in the granulator and one in the dryer, each taking about half the P_2O_5 feed. The pipe in the dryer produces MAP powder, which is recycled to the granulator either as cyclone dust or fines. The main problem with the process is that this MAP now has to be ammoniated to DAP in the granulator, which is a very inefficient operation. Other problems that could be anticipated are blockages in the dryer cyclone circuit resulting from the higher dust loading as well as higher humidity in this airstream.

Another process uses a conventional tank preneutralizer operating in parallel with a pipe reactor. Obviously the process is more complicated with two independent flows of slurry to the granulator and having the necessity to split the scrubber liquor return between the two reactors. Furthermore the problems associated with operating a tank reactor mentioned above are not eliminated.

Scrubbing

Dual mole ratio scrubbing was first described by Dick McGinnis of US Agrichemicals at the DAP Quality Seminar conducted jointly by FIPR, TVA and TFI in 1986. In this concept the gases that are most heavily laden with ammonia, namely the exhaust from the granulator (and the preneutralizer if one is present), are scrubbed twice. A simplified flowsheet is shown in Figure 3.

Fig.3 Dual Mole Ratio Scrubbing



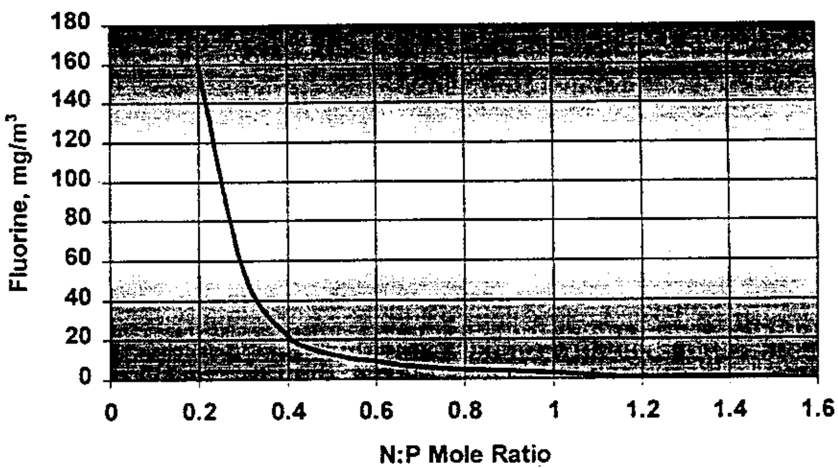
Jacobs design scrubbers and scrubbing systems in-house. The standard flowsheet for DAP or high mole ratio NPK grades would include dual mole scrubbing. Plants designed in Saudi Arabia, China, Korea, India and Australia have all featured the dual mole concept.

Because the gases are scrubbed twice, the "prescrubber" can be a simple, low pressure drop duct scrubber installed in conjunction with a cyclonic separator and can afford to be operated at relatively high mole ratios. Typical pressure drops are of the order of 3" water. Mole ratio is normally controlled in the range 1.3-1.4. The objective in this scrubber is to recover only 50-60% of the ammonia in the gases. A relatively high circulation rate of typically 25-30 galls/1000 ft^3 is used to prevent salting out.

The primary scrubbing system operates with a lower mole ratio - typically in the range 0.6-0.8. Jacobs use venturi-cyclonic scrubbers for this stage of scrubbing. Typical pressure drops would be 12" water with a circulation rate of around 15 galls/1000 ft^3.

This combination of high mole ratio in the prescrubber and lower mole ratio in the primary scrubber results in lower fluorine evolution, while at the same time providing for good ammonia efficiencies overall. The amount of fluorine stripped from the acid is heavily dependent upon mole ratio. This was reported by UKF in a paper given in 1983[(2)] and has been independently confirmed by laboratory tests. A typical relationship is shown in Figure 4, which shows that fluorine losses at mole ratios above 1.0 are very low but, at mole ratios much below 0.4, start to take off exponentially.

Fig. 4 Fluorine Losses from Scrubbers



However, it must be stressed that there are other factors which affect the actual amount of fluorine stripped - amongst them being the acid analysis, the amount of acid fed to the scrubbing system and the liquid:gas ratio.

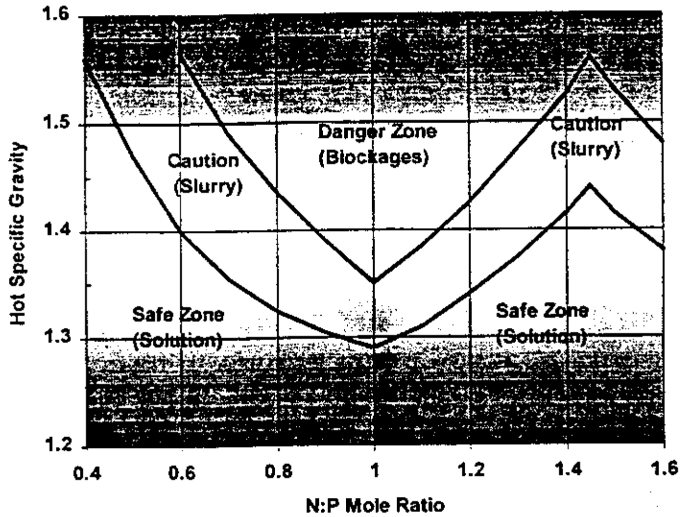
The dual mole system is very flexible in that the conditions at which each part of the system works can be selected to meet a specific objective. For example, we have found that when making low mole ratio grades of fertilizer, like MAP or ASP, depending on the level of fluoride emission that must be met, it is advisable to operate both the prescrubber and the primary scrubber system at high mole ratio. This is particularly true when the reactor (pipe or preneutralizer) is operated at a mole ratio of less than 1.0. In these cases ammonia losses are not a large issue but fluorine losses can be many times higher than in DAP operation.

A typical example was the scrubbing system that Jacobs installed at Namhae Chemical in Korea in 1995. This plant produced a variety of NPK grades, some of which required a mole ratio of 1.9 and some required much lower mole ratios. In all cases it was necessary to guarantee that fluorine emissions were below 3 ppm by volume and ammonia below 50 ppm. In practice we found that the best results were obtained while operating at the conditions described above for the DAP grades. However, when the low mole ratio grades were produced, it was advantageous to increase the mole ratio in the primary scrubbing system to the same high level as in the prescrubber. This was achieved by feeding less acid to the primary scrubber and more acid to the prescrubber. Even though the mole ratios were high, no ammonia was detected in the stack gases. A summary of the emission levels achieved are given below:

	DAP Grade	MAP Grade
Fluorine, ppm by vol.	2.0	2.9
Ammonia, ppm by vol.	5.1	None Detected
Particulate, mg/Nm^3	13.7	13.2

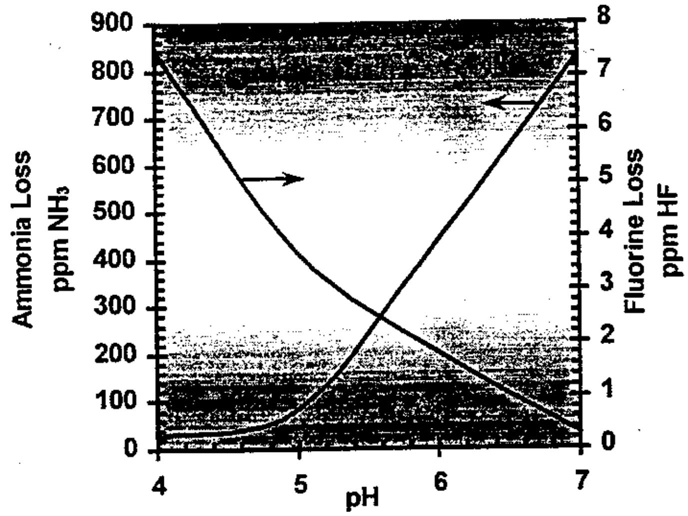
Of course, when selecting operating conditions for each section of the system, it is important to stay clear of the crystallization area. Figure 5 shows that, provided the SG in the scrubbing system stays below about 1.3, any mole ratio is safe. However, it is usually advisable to stay away from mole ratios approaching 1.0 to avoid problems with salting out.

Fig. 5 Operating Zones for Scrubber Liquor



In the vast majority of cases the standard Jacobs flowsheet would also include a tailgas scrubber. We have experience in designing packed towers, horizontal cross flow and cyclonic scrubbers. In most cases we prefer the latter on the grounds of less operating problems (plugging of the packing). A typical cyclonic scrubber would have a pressure drop of about 4" water and operate at a liquid:gas ratio of around 15 galls/1000 ft^3. Provided the plant water balance will stand it, we generally prefer to use recirculated fresh water and feed it forward to the primary scrubber, rather than once through pond or sea water. We have found that the use of pond water, even on a once through basis, results in higher fluorine losses. The use of recirculated fresh water allows the flexibility of acidifying the water to maximize ammonia recovery. This is best achieved with sulfuric acid to minimize the effect on fluorine emissions, although phosphoric acid can also be used. The operating pH for the tailgas scrubber is a trade off between ammonia and fluorine emissions as Figure 6 shows.

Fig. 6 Typical Stack Emissions



The three stages of scrubbing described above is often what it takes nowadays to meet increasingly strict environmental regulations, especially when making DAP.

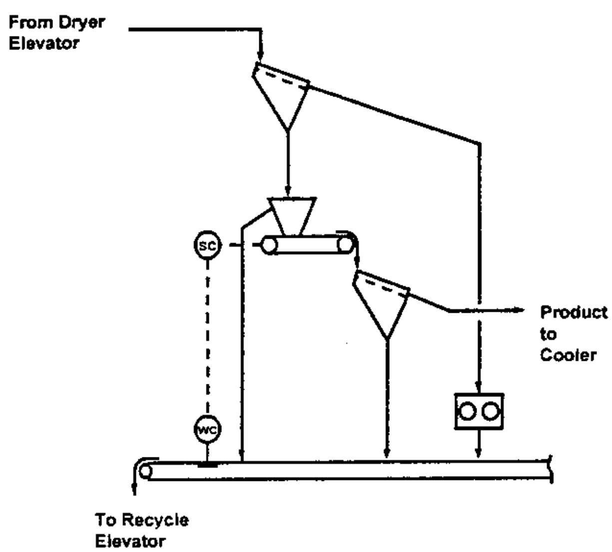
Screening

Jacobs prefer to use separate screens for oversize and fines separation duties, rather than double deck screens that some competitors specify. The main reason is that, since a relatively large amount of product sized material generally has to be recycled to give the optimum granulation conditions, there is little point in separating all of the product from the fines. By controlling the amount of material fed forward to the product screens the load on these screens is reduced.

Our philosophy is to accurately control the amount of recycle being fed to the granulator. We do not consider that elevator amp readings or watt meters are sufficiently accurate and this is borne out by failed attempts to use elevator watt meters for automatic control[3]. We therefore use a belt conveyor with a load cell to weigh the recycle and control it by adjusting the amount of product fed forward to the product screens. The system is shown in Figure 7.

Fig. 7

Recycle Control System



The use of a belt conveyor replaces the highly maintenance intensive use of a drag flight conveyor. The conveyor is oversized and runs at low speeds and is fitted with a specially designed double skin cover, which is vented to the dust collection system.

We prefer to use a small collection hopper or hoppers fitted with a variable speed extractor belt, rather than flaps in chutes, to control the recycle of product. The diverter flaps and their associated hydraulic or pneumatic actuators tend to be unreliable.

In the author's experience, problems with inefficient screening have usually resulted from poor distribution across the full width of the screening surface. This is especially true on machines wider than 4 ft, but even these narrow screens can suffer from this problem. Installation of baffles etc in the chutework have never proven to be really satisfactory and often lead to a scaling problem. A better solution is to fit the screens with vibrating trough distributors. This also allows screens wider than 5 ft to be considered thus reducing the number of units required on large modern plants.

It is gratifying to see that J&H Equipment, for example, have now developed and have available for sale, both vibrating trough distributors and screens in widths up to 6 ft.

J&H also have available for sale what they call a "riffle feed" screen. This is essentially a double deck machine but both decks have the same size mesh. The feed is divided equally between the top and bottom decks by a riffle fitted in the inlet chute. The major application for this device is probably as a retrofit to an existing plant where screening has become a limitation and there is no space available for either bigger units or additional units. At present Jacobs has no operating experience with this type of screen but it is certainly worth consideration by operators with a screening limitation.

Cooling

Unless the client has a strong preference for a rotary cooler, Jacobs believe that fluidized bed coolers are an attractive alternative. The Jacobs designed plants in Nigeria, China, India and Australia all have fluidized bed coolers as does the ammonium nitrate prill fattening plant designed for La Roche Industries in Alabama.

Fluidized bed coolers have acquired a rather bad reputation in Florida, based mainly it would seem on the poor performance of the old Buell coolers, which were erroneously referred to as fluidized bed coolers. A true fluidized bed cooler is a horizontal unit, which uses fluidization by air to transport the product down the length of the cooler. The fluidizing plate is normally made in stainless steel with fluidizing holes of around 2 mms. There are no moving parts except for the fans.

Because the granules are in a fluidized state, they behave like a liquid - as more product is poured in at the inlet end it displaces product at the outlet end, which overflows a retaining weir. Because the material is fluidized, each granule is entirely surrounded by the cooling air and the heat transfer is therefore very efficient - in other words the temperature of a granule at any point along the length of the cooler is practically the same as that of the air surrounding it.

The advantages of fluidized bed cooling are as follows:

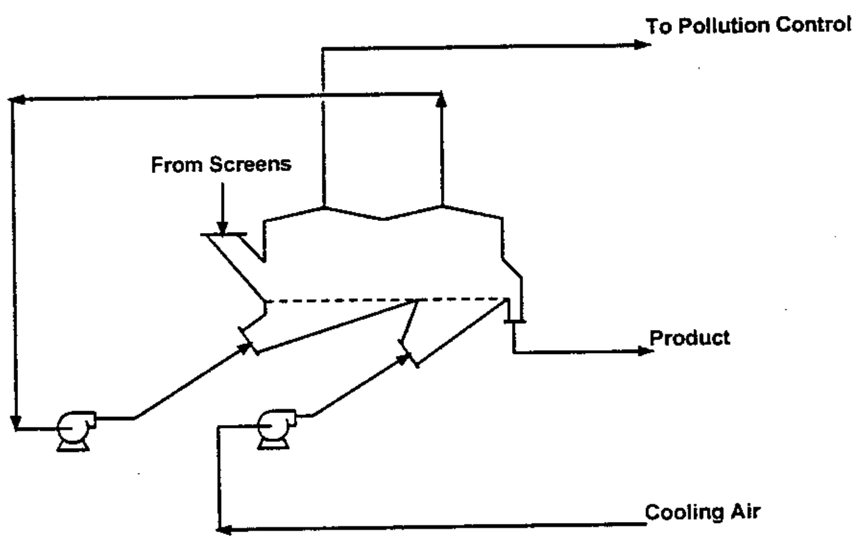
- Low capital cost
- Low weight and small physical size, which means that there is more flexibility with location of the cooler within the plant
- Gentle cooling action, which means little or no breakdown of product occurs

The main disadvantage is that the airflow requirements are generally about 50% higher than that required in a rotary cooler. This is because, unlike a rotary cooler, the fluidized bed does not have a truly countercurrent airflow. Instead of the air exhaust temperature approaching the solids inlet temperature relatively closely, it is closer to the mid point between the inlet and outlet solids temperatures. Of course the higher airflow means that all the anti-pollution equipment associated with it also has to be larger.

However it is possible to reduce the airflow to similar levels to that required by rotary coolers by using two stage cooling. The scheme is shown in Figure 8.

The incoming cooling air is used to cool the product in the second stage. As the product has already been dedusted in the first stage, the air exhaust from the second stage is clean and dust removal facilities are not required. The second stage exhaust is used as fluidizing air in the first stage. The air from the first stage is then passed through cyclones and scrubbed in the same way as the exhaust from a rotary cooler would be.

Fig. 8 Two-Stage Fluidized Bed Cooler



Summary

Until such time as a real breakthrough in technology is made Jacobs will continue to chip away at improving the detailed design of phosphatic granulation plants.

In the meantime we believe that the following trends will continue:

- The popularity of pipe reactors, not just in plant revamps but in new plants, will continue to grow. As the quality of the phosphate rock declines, the reduced Cl losses and product moisture available with pipe reactor processing will become more attractive to Florida producers.
- Environmental regulations will continue to get stricter and Jacobs will continue to meet those stricter regulations with its range of in-house designed scrubbers.
- As more new, modern plants are brought on-stream the pressure to improve product quality will continue to mount and new improved techniques, particularly for screening and cooling, will be required if the existing plans are to meet the challenge.

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