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GRANULATION PLANT REVAMPS – METHODOLOGY AND DESIGN OPTIONS (a)

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1. Introduction

There are many and varied reasons operating companies decide to increase the capacity of their plants. Whether it is to improve economies of scale for a small plant or to take advantage of a market opportunity, Jacobs follow a common process to ensure our clients end up with a plant that is capable of producing a consistent, quality product.

This paper will describe the process Jacobs uses to identify capacity limitations in existing plants and discuss some of the common solutions available to overcome equipment bottlenecks.

In addition to de-bottlenecking projects, scrubber revamp projects to enable more stringent emissions levels to be met are occurring more regularly. Jacobs have undertaken several projects where scrubbers have been converted to dual mole scrubbers and/or tail gas scrubbers have been installed and these will be discussed.

2. Debottlenecking the Plant

A granulation plant can be conveniently split into five distinct areas that are studied consecutively to determine the maximum capacity of the plant.
They are as follows;

- Recycle Loop – granulator, dryer, elevators, screens and crushers
- Product Handling – cooler, elevators, screens and conveyors
- Reaction System – preneutralizer, slurry pumps and pipe reactors
- Scrubbing – scrubbers, fans and pumps
- Raw Materials – acid, filler, solid raw material, ammonia supply and vaporization

Each equipment item in each area is studied in detail to determine, firstly, its maximum capacity and, secondly, what changes? if any? are possible to eliminate it as a bottleneck.

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2.1 Recycle Loop

The recycle loop in most granulation plants incorporates the granulator, dryer, dryer and recycle elevators, oversize screens, oversize mills and recycle conveyor (Figure 2.1).

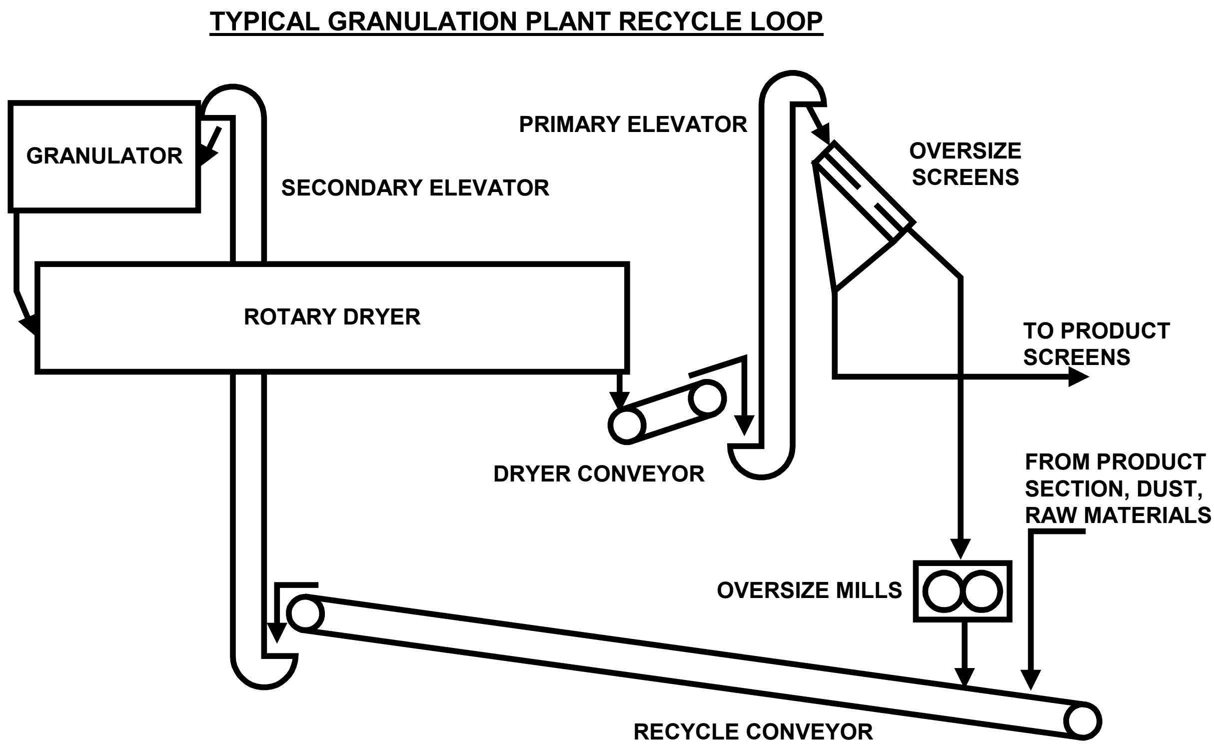

Figure 2.1

In de-bottlenecking projects, Jacobs will typically start with the granulator and dryer to determine the maximum handling capacity of the recycle system. Since both of these items of equipment have a large capital value it is unlikely that replacing them, except in the case of where the drums are approaching the end of their operating life, would be justified. Fortunately both these items of equipment are often over designed when originally installed. Several options exist to increase the throughput of the granulator and dryer while maintaining the original drum. These include changes to the speed, slope and discharge weirs.

2.1.1 Granulator

The granulator is arguably the most critical item of equipment in the plant as this is where the granules are formed. No other item of equipment in a granulation plant can compensate for an inappropriately designed granulator. Therefore, any modifications to increase capacity must be made with the impact on product quality in mind.

The granulator can be conveniently thought of as consisting of three zones:

- Mixing region

- Wetting and partial granulation region
- Granulation and shaping region

The mixing region is relatively short, normally about 1.2 m and is dictated by the need to get the recycle and solid raw materials into the drum and away from the inlet chute before any liquid is added.
The wetting zone is the area in which the liquids are added. This is where the liquid phase necessary for granulation is formed and partial granulation occurs. The length of this zone is determined by the amount of liquid that is being added; the upper limit for liquid addition is expressed in tph/m2.
Particle rolling distance is the most important variable that can be identified in determining the required length of the granulation and shaping region. For a fixed drum loading and speed, rolling distance is proportional to residence time. Residence time is, in turn determined by the speed and slope of the drum and the height of the discharge weir.

For an existing drum, the original speed, slope and discharge weir height are evaluated against Jacobs' design parameters and adjusted so as to maximize the throughput of the drum without compromising the minimum requirements for each of the three granulator zones.

Slope: Jacobs experience has been that many granulators, particularly those designed by European vendors, tend to be specified with very low slopes. This limits the extent to which the throughput of the granulator can be increased as excessive solids hold up will result in poor mixing of the liquid with the recycle and will also result in back-spillage problems. We have therefore often found it necessary to increase the slope as part of the de-bottlenecking exercise. Jacobs prefer to maximize the slope (typically 3.5°) and control the residence time (solids hold up) by the height of the discharge weir.

A change in the granulator slope allows a higher throughput without necessarily requiring the drive train to be modified. Having increased the slope it may be necessary to increase the height of the recycle elevator in order to maintain an acceptable angle of the elevator discharge chute.

Speed: The rotational speed of the granulator performs a very important role in distributing the liquid evenly over the rolling bed. Low speeds tend to result in a higher level of oversize formation and a less round product granule. Jacobs experience is that many older plants were originally designed with relatively low speeds – of the order 30-35% of the critical speed. Useful gains in drum throughput, as well as improvements in granulation can be obtained by increasing the speed to at least 40% of critical. An increase in speed and throughput increases the power draw. Whether it is then necessary to modify the drive train is evaluated on a case-by-case basis

Weir Height: having fixed the new slope and speed of the drum the residence time in the drum is now controlled by the height of the discharge weir. Jacobs would normally allow for an adjustable weir to allow granulation conditions to be fine-tuned on a grade- by-grade basis.

2.1.2 Dryer

The main dryer design parameter is the residence time required to dry the fertilizer product. The necessary residence time is both grade and production method dependent. In general ammonium phosphates and TSP produced by the slurry route require a low residence time, in the order of 5-7 minutes. This is primarily due to the way in which the granules are formed, which is predominantly by layering. The moisture is thus mostly on the surface of the granules and is therefore relatively easy to remove. Granulation of NPK's involving a number of raw materials supplied in the solid form involves more of an agglomeration mechanism. In this case most of the moisture has to diffuse from the inside the solid, through the pores, to the surface. Residence times required for such materials are generally much higher ranging from 15 to 30 minutes.

In Jacobs' experience many plants producing MAP/DAP were designed with residence times more in line with NPK dryers, thus leaving scope to reduce the residence time and increase the throughput in the case of a revamp. Many of these dryers are designed with slopes of 1.5° or less. We have also often found that older dryers were originally designed with lower solids hold-ups than is the current Jacobs standard.

Jacobs normally aim for a volumetric hold up of 18-20%. Having determined the residence time required for drying the products to be made on the plant, this then fixes the maximum throughput of the dryer. The speed and / or slope are adjusted in order to provide for the residence time required.

<u>Speed</u>: In order to dry the fertilizer efficiently each granule should have as much of its surface area as possible, for as long as possible, exposed to the hot air. This is achieved by operating with a high cascade rate. The cascade rate is maximized by careful flight design and the correct choice of speed and slope. For optimum cascading the speed of rotation should be in the range 15-25% of critical.

<u>Slope:</u> Jacobs generally avoid specifying dryers with low slopes unless the fertilizer to be dried requires a particularly long residence time. Generally slopes in the range 2.5°- 3.5° are used. Several DAP plants that we have studied recently were specified with much lower slopes than this.
Jacobs also design flight arrangements for rotary dryers. The objective in flight design is to obtain as many curtains of cascading material as possible across the full diameter of the dryer and to ensure that the cascade density is uniform in each falling curtain. This is achieved by appropriate selection of the number of flights, the size of the radial and lip sections of the lifting flights and the angle formed by the two sections. These parameters are selected based on the diameter of dryer, the solids hold-up and the drum speed.

Jacobs experience is that the flights in dryers are often designed with too few flights and with insufficient carrying capacity. In addition the design of the flights is often such that the flights empty too early resulting in large part of the drum cross-sectional area where the hot air can pass straight through the dryer with minimal contact with the wet solids. These deficiencies are particularly important in the back half of the dryer where the driving force for drying is much less.

The design of the inlet feed scrolls is also important to prevent back-spillage and a careful review of the existing design for suitability is necessary, particularly if the solids hold-up is to be increased as part of the revamp.

In summary, where fairly large increases in capacity are desired (say up to 50%) it is often necessary to increase the throughput of both the granulator and dryer. This is usually obtained by an increase in speed and/or slope of both drums. It is often also necessary to modify or replace the feed scrolls and/or lifting flights within the dryer to increase drying efficiency.

Having determined the maximum capacity of the granulator and dryer the capacity of the remaining equipment within the recycle loop is matched to the new recycle rate.

2.1.3 Conveyors

Short of replacing a conveyor belt, there are two adjustments that can be made to belt conveyors to increase their capacity. They are belt speed and trough angle. These can be changed in unison or independently to obtain the desired capacity increase.

Increasing the speed: This can usually be accomplished by either replacing a pulley or sprocket of belt and chain driven belts respectively or by replacing the reducer for direct drive belt. However, regardless of the method by which the speed increase is achieved, it is critical to ensure both the head chute and feed chute designs will accommodate the increased belt speed. Trajectory of the material discharging from the belt is directly related to the speed of the belt. As the belt speed increases the material trajectory will lengthen. If no changes are made this may result in poor loading of downstream equipment. Altering the position of the head pulley (i.e. shortening the conveyor) to cater for the increased speed or in some cases replacing the head chute may be necessary.

The maximum capacity of a conveyor belt is limited by the maximum recommended speed. Maximum speeds are a function of the material being conveyed, belt width, inclination and trough angle. There are numerous sources that can be used to determine these speeds. A good example is the CEMA publication “Belt Conveyors for Bulk Materials”. However, for the specific case of the recycle conveyor which is discussed later, Jacobs recommend the speed should not exceed 1.0m/s due to the very dusty nature of the material on this belt.

Increasing the trough angle: This will result in an increased carrying capacity per meter of belt. It will impact on the absorbed power of the belt and this should be reviewed when undertaking such changes. The cost of increasing trough angle is, as expected, closely related to the length of the belt. The longer the belt, the more idlers to change. One item that is often overlooked when changing trough idlers is the need to install transition idlers at the tail and head pulleys and the possible effect this may have on loading points.

In any case where a change is being made to a belt conveyor the designer should review the mechanical, electrical and structural design to ensure the conveyor will handle the increased loads.

In the event that modifying the existing conveyor will not achieve the desired capacity increase the alternative is to replace the conveyor in its entirety. While the cost of a new conveyor may account for a small part of the entire cost of a revamp, quite often it is not the cost that impedes replacing a conveyor. Actually fitting a wider belt into the space occupied by a smaller one plus accommodating the additional width to the down stream equipment can be a challenge.

In a recent design undertaken by Jacobs it was exactly this problem that had to be overcome: where the new conveyor would not fit in the available space. Consequently a trade off had to be made that resulted in a narrower conveyor operating at speeds near the high end of the preferred operating range.

In plants where the recycle conveyor is in fact drag flight conveyor Jacobs often recommend it be replaced with a belt conveyor. The ability to measure and control the quantity of material recycled back to the granulator is very important. A wide, slow moving belt conveyor with a specially designed double-skirted, well ventilated cover is recommended to reduce the dust generation. Drag flight conveyors are notoriously high maintenance items with high operating costs when compared to a belt conveyor. The recycle conveyor system was implemented successfully at the WMC Fertilizers plant in Australia and the Oswal Fertilizers plant in India.

2.1.4 Bucket Elevators

Bucket elevators can account for a large portion of the capital cost of a plant. In addition, complete replacement of an elevator with a new larger casing is often not a practical proposition because of space restrictions. Consequently replacing these items is avoided where possible. Often elevators are designed based on a 75% water level in the bucket at the minimum bulk density. The motor and drive train are sized based on a 100% water level in the bucket at the maximum bulk density. This infers that a 25% increase in capacity is available without the need to modify the elevators. Claiming the full 25% and not making any other changes may not be recommended as doing so would leave no design margin in the elevators at all.

Like conveyors, bucket elevators are fairly restricted in what changes can be made to increase the capacity. Primarily two avenues exist to increase the capacity, either increase the chain speed or change the buckets design for a larger bucket. A combination of both can be used if the magnitude of change exceeds what is possible by either or option.

Speed: Continuous discharge bucket elevators are normally specified at about the maximum speed, which is generally considered to be in the order of 0.68 m/s (135 fpm). Modest increases in speed up to 0.76 m/s (150 fpm) are a possibility. If higher speeds are necessary to obtain the desired capacity, conversion of the elevator to a centrifugal discharge is required. This significantly alters the bucket design, loading chute and discharge chute but nevertheless this can be achieved within the same continuous discharge casing. Centrifugal discharge elevators run at speeds of up to 1.52 m/s (300 fpm).

Bucket Design: Specially designed buckets with greater capacity and better unloading characteristics have been developed and can often be retrofitted into existing elevators.

Depending on the magnitude of the capacity increase that is desired a combination of increased speed and new bucket design may be used.

Regardless of the path taken to increase the capacity of the elevator it is imperative that close attention be paid to the following components to ensure new loads exerted do not exceed the existing design:

- Drive shaft and bearing size
- Drive sprockets
- Chain size and tensile strength

- Rollback devices
- Gravity take up system
- Casing

In many cases increasing the capacity will require one or more of these components to be either changed or reinforced.

2.1.5 Screens

Due to the large footprint of screens it is often difficult to install additional screens into existing plant structures. Conversion of regular single deck screens to “riffle” decks is an option for increasing capacity without increasing the footprint. The screens are essentially two single deck screens in one housing with a feed chute splitting the feed onto the upper and lower decks.

Alternatively improving the efficiency of the existing screens can result in capacity increases. Screens wider than 4ft can often be inefficient due primarily to the poor distribution of the feed across the width of the screen. Installation of vibrating pan feeders has greatly improved the performance and capacity of screens.

When limitations exclude the use of the existing screens several vendors offer screen designs such as double width screens with matching feeders, which have a smaller footprint per screening area than the conventional two parallel screens.

Where single deck screens are employed in the existing design, it is possible to increase screening capacity by conversion of the oversize screens to double deck machines. In this case the opportunity can be taken to install a larger than normal mesh size on the lower deck. A flap operating in the under hopper can then be used to divert what amounts to small sized product into the recycle stream. This is superior to the normal arrangement where the product that is recycled is anything within the upper and lower range of product size. Recycling product in the lower size range enables recycle ratio to be reduced due to the higher surface area per tonne that results while at the same time improving product quality – increased median product size (SGN) and “tighter” product sizing (UI).

2.1.6 Oversize Crushers

Jacobs experience with crushers is that they have limited scope for capacity expansion without replacing the machines. In recent projects where crushers have needed to be replaced Jacobs have preferred to install chain mills for crushing oversize. They generally have lower cleaning and maintenance requirements are capable of much larger capacities than alternative types.

2.2 Product Handling

Once the recycle loop has been de-bottlenecked the product rate that can be obtained is determined by the recycle ratio. The lower the recycle ratio, the higher the product rate. Options to reduce the recycle ratio are discussed later in Section 2.3.

Once the throughput has been determined each piece of equipment is de-bottled neck to suit. The principles for de-bottlenecking the conveyors, elevators and screens used in the recycle loop are applicable here.

2.2.1 Product Cooling

Increasing the product capacity generally means an increase in cooling capacity is required. The cooler, regardless of type, must be capable of handling both the increased materials handling and heat transfer requirements. Installation of air chillers upstream of the cooler or supplemental cooling capacity are the two most likely solutions to increasing the cooling capacity.

Air chiller: Installation of an air chiller upstream of the cooler, if one is not installed in the original design, may be sufficient to cool the extra product. This assumes that the cooler, whether it be a rotary cooler or a fluidized bed cooler is actually capable of transporting the material. Increasing the transport capacity of a rotary cooler is a somewhat similar exercise as described for rotary dryers.

Air chillers can operate either in closed or open loop. Open loop chillers can be used when vapor ammonia is used in the downstream process. Liquid ammonia is vaporized in a finned tube heat exchanger by the ambient air. The air can be nominally cooled to within 5°C of the equilibrium vaporization temperature of the ammonia. The vaporized ammonia is then used in the process as necessary with any liquid carryover being piped to the existing vaporizer units. The air leaving the chiller is saturated with water so it is recommended that a reheat coil be installed to dehumidify the air when it is used in a fluidized bed, at least during shutdowns, or with very hydroscopic products.

Supplemental or replacement cooling capacity: This is necessary if the existing cooler can't physically handle the extra product or if air chilling is already practiced. Two possible alternatives are column coolers or fluidized bed coolers, both of which are relatively small and lightweight, which better enables them to be retrofitted into an existing plant.

Column coolers use cooling water to remove the heat via radiators or tubes installed in a vertical vessel that the product flows down at a controlled rate. This type of cooler has the advantage of requiring very little if any additional airflow. The disadvantage appears to be that it is subject to blockages caused by moisture condensation within the unit as the product cools. This effect is however much more pronounced when this type of cooler is used as the primary cooler.

Jacobs generally prefer to use fluidized bed coolers and the installations in Nigeria, China, India and Australia have all utilized fluidized beds. In circumstances where the fluidized bed is installed as a supplementary cooler, the air exhaust from the cooler can be safely used as dilution air in the dryer air heater, as the product has already been substantially dedusted in the primary cooler, thus saving some fuel for drying.

2.2.2 Product Coating

For plants with coating drums adjustment to throughput can be made by changing a combination of the speed, slope and weirs. Maintaining sufficient residence time and rolling length in the coating drum is critical to ensuring consistent coating of the granules.

An alternative to coating drums is a paddle mixer which has an order of magnitude smaller footprint and lower operating costs. Jacobs have successfully installed paddle mixers in coating applications for both NPK and ammonium phosphate granulation plants. It is now considered to be our standard design.

2.3 Reaction System

Minimizing recycle rate goes hand in hand with maximizing production rate so it is common sense when undertaking any de-bottlenecking exercise to look at ways to reduce the recycle ratio. Pipe Reactors have been successfully retro fitted into plants where a conventional tank reactor has been in use. The traditional method of producing ammonium phosphates involves reaction of phosphoric acid with ammonia in a tank reactor to produce a slurry which is then pumped to the granulator. In order to be able to successfully pump the slurry a relatively high water content is required.

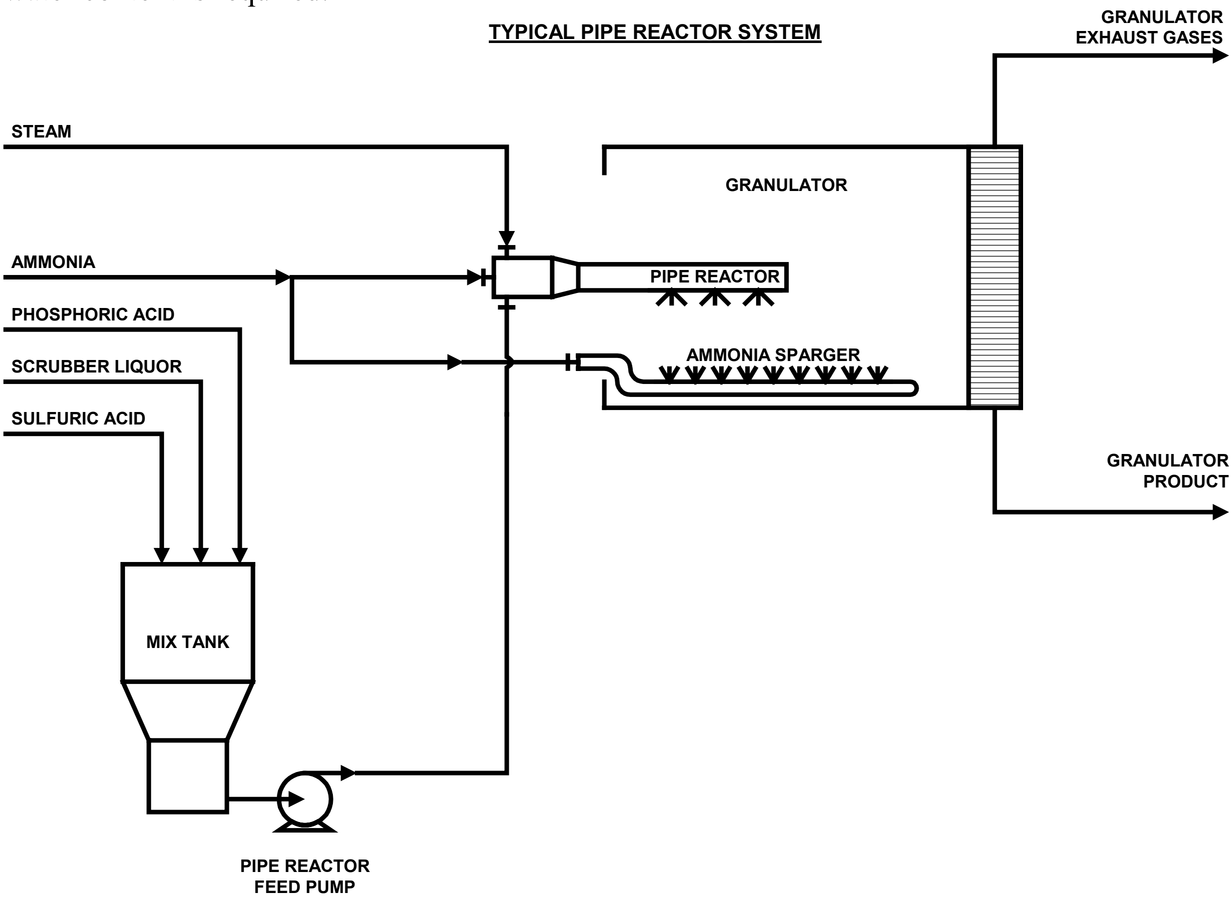

Figure 2.2

A pipe reactor on the other hand is installed directly inside the granulator and so there is no need to pump the slurry (Figure 2.2 depicts a typical pipe reactor agreement). Therefore, in principle, provided stronger acid is supplied, a lower water content slurry can be made which can result in a decrease in recycle requirements and therefore an increase in production rate. It must be stressed however, that this is dependent completely on the concentration of the acid being fed. If the acid concentration is maintained the same, there will be no increase in production rate, and of course, if lower strength acid is supplied then production rate will fall.

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 automatically ratio the feed of ammonia to the acid and also to automatically control of the acid feed SG.

Depending on the type of acid being processed, pipe scaling can be a problem. Jacobs use an automatic on-line steam purge arrangement that has proved to be very successful at keeping the pipe clean. The purge is controlled by a series of timers which flush the pipe with a large volume of steam for a very short period. The system is completely automatic and requires no operator input.

In retro fitting a pipe reactor into an existing plant it is very important to have an adequate ventilation rate through the granulator. Since the vast majority of the reaction is taking place in the pipe reactor the steam generated must be exhausted from the granulator. If the steam is allowed to condense the recycle ratio may actually increase rather than decrease compared to the tank reactor operation.

An alternative arrangement is the combination pipe reactor and preneutralizer. This is a particularly interesting arrangement in a revamp situation where the preneutralizer is already in place.

One alternative is to operate the pipe reactor and the preneutralizer in parallel. However, this arrangement is somewhat complicated with independent slurry flows to the granulator. It is further complicated by having to split the scrubber liquor return between the two reactors. A further disadvantage is that the preneutralizer is still operated at exactly the same condition that it is in the conventional process – the slurry is close to solidification in order to minimize the water input to the granulator. Lastly, the overall water input to the granulator is higher than it would be with a pipe reactor alone because part of the slurry is being sprayed directly from the preneutralizer with its relatively high water content.

The arrangement that Jacobs prefer involves the preneutralizer and pipe reactor operating in series. The scrubber liquor and part of the fresh acid feed is ammoniated in the preneutralizer and the resultant slurry is pumped to the pipe reactor where further ammonia and concentrated phosphoric acid is reacted. This system allows the preneutralizer to be operated at a higher water content than the normal as excess water is driven off in the pipe reactor. In addition, as the only slurry being sprayed into the granulator comes from the pipe reactor, the final slurry water content is lower than in the parallel arrangement described above. Figure 2.3 shows a typical flow sheet for this arrangement.

The advantage with both these combination flow sheets is that because part of the reaction is occurring in the preneutralizer not all of the steam generated needs to be vented through the granulator. This is particularly useful with retrofits where the granulator diameter may be a limiting factor in the airflow that can be realistically drawn through it.

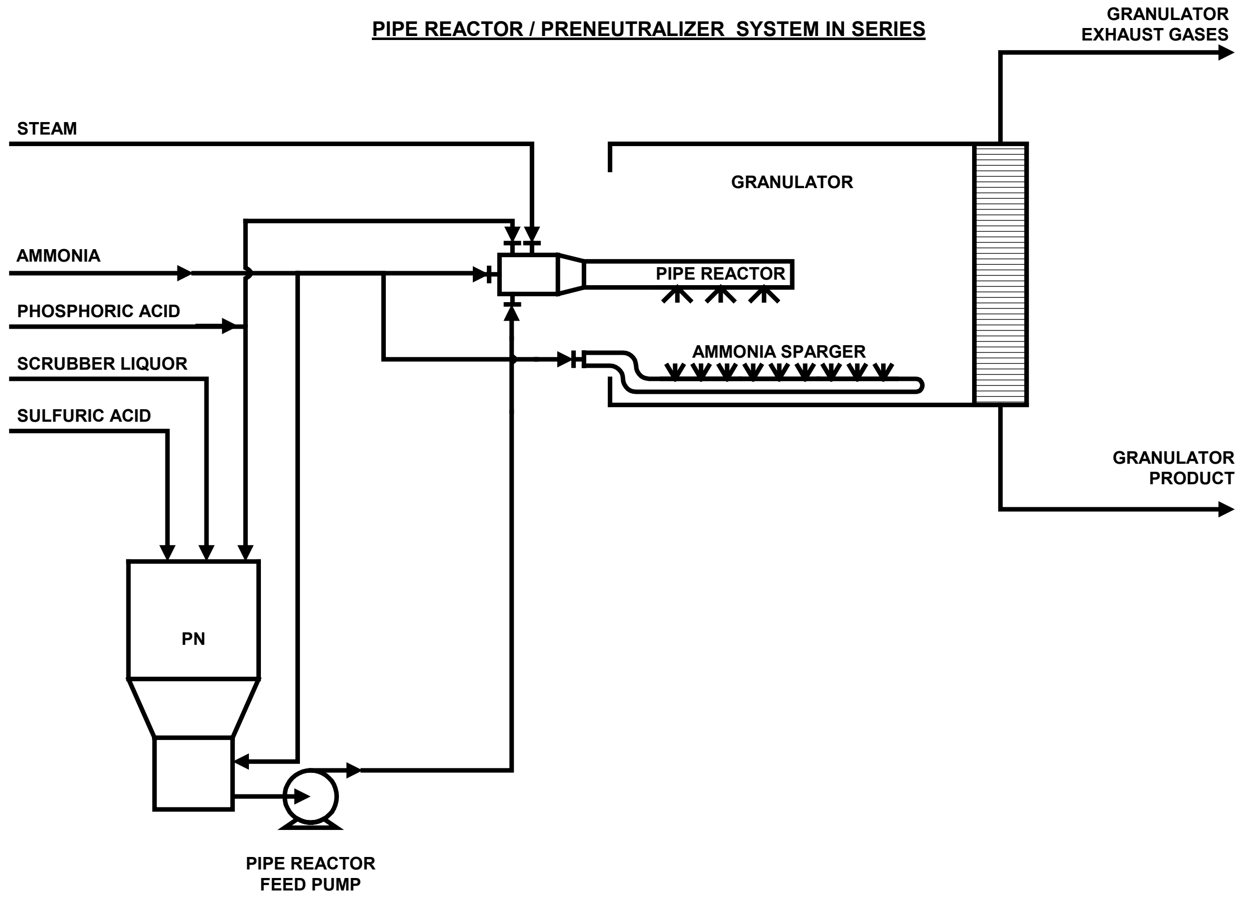

Figure 2.3

To fit a pipe reactor into a conventional tank reactor plant Jacobs would recommend that the existing tank reactor, if it is in good condition, be reused as the mix tank for the scrubber liquor and phosphoric acid. In the case of a combination pipe reactor/preneutralizer arrangement the preneutralizer would remain as the first stage reactor. In projects undertaken by Jacobs it has been found that the existing slurry pumps need significant modification if not replacement to cater for the new duty. The pressure generated in a pipe reactor can be in the order of 500-600 kPag, which needs to be overcome by the pipe reactor feed pump.

If ammonia is sparged into the granulator it is often preferable to use liquid ammonia to reduce the solids temperature leaving the granulator. This minimizes ammonia losses to the scrubbing system.

In the case of the pipe reactor/preneutralizer system, installation of a variable speed booster pump to control the feed of phosphoric acid to the pipe reactor is preferred.

Jacobs have installed pipe reactors making various product grades and have experience in their design and operation. Some examples are listed below;

Client	Type	Product	Status
PCS, USA	Pipe Reactor	MAP/DAP	Operating
NAFCON, Nigeria	Preneutralizer/Pipe Reactor	Urea Based NPK	Idled
Huangmailing, China	Preneutralizer/Pipe Reactor	DAP/MAP	Operating
Oswal, India	Preneutralizer/Pipe Reactor	DAP/NPK	Operating
OCP, Morocco	Preneutralizer/Pipe Reactor	DAP	Under Construction

3. Scrubbing Modifications

In any plant upgrade it is crucial to ascertain the effects of changes in the reaction, recycle and product systems on the scrubbing system. However, as scrubbing systems are wide and varied in their design it is difficult to discuss them in terms of specific changes that can be made to alter their performance with regard to increased capacities.

It does, however, lead us into the second driving force behind plant upgrades. That is to improve scrubber performance so as to meet the changing requirements for emissions from chemical plants. Nearly every, if not all, countries regulate emissions from granulation plants and in general these are getting more stringent. For example, it is only recently that new fluoride emissions standards came into effect for fertilizer plants in the United States that required some producers to make changes to their granulation plant scrubbing systems. Jacobs, in fact, designed modifications for two plants that enabled them to pass the new fluoride emission standards.

Emission requirements will not be relaxed and more than likely they will become more stringent with time. Consequently, operators need to look at ways to modify their plants so as to meet these ever changing requirements. One option is for plants to upgrade to a dual mole scrubbing system. Plants designed by Jacobs in Saudi Arabia, China, Korea, India, Australia and Morocco all feature the dual mole concept.

In the dual mole concept the gases that are most heavily laden with ammonia, namely the exhaust from the granulator (and preneutralizer if one is present) are scrubbed twice (Figure 3.1 gives a simplified dual mole scrubbing flow sheet).

Dual Mole Ratio Scrubbing System

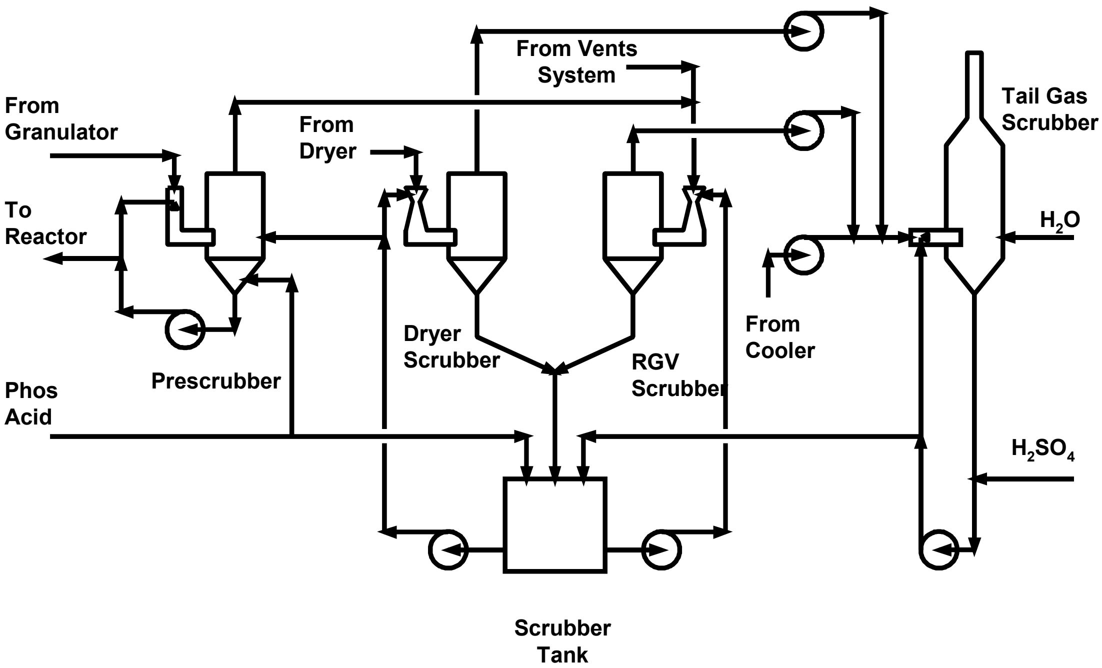

Figure 3.1

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 ft3 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 ft3.

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.

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

In the majority of cases the standard Jacobs flow sheet would also include a tail gas 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 ft3. Provided the plant water balance will stand it, we generally prefer to use circulated 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 circulated 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. This arrangement was used in the WMC Fertilizers MAP/DAP in Australia which was commissioned in 2000 and successfully passed its emissions test.

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

Depending on the product grade it may only be necessary to install a tail gas scrubber and to operate at different conditions in the upstream scrubbers to enable existing plants pass emission requirements. The tail gas scrubbers Jacobs have installed in these cases are similar to those discussed earlier.

Jacobs recent experience with scrubber revamps is detailed below;

Client	Modification
Namhae, S.Korea	Installed a pre-scrubber and a tail gas scrubber
Pequiven, Venezuela	Installed a tail gas scrubber
PCS, USA	Installed a tail gas scrubber
Agrium, Canada	Installed a tail gas scrubber
Luling, USA	Installed a tail gas scrubber
Cominco, Canada	Installed a dryer/granulator venturi-cyclonic scrubber
Agrico, USA	Installed a pre-scrubber and modified the tail gas scrubber

4. Summary

While Jacobs would enjoy designing new plants every time a client wanted to increase their production capacity it is not always the most economical approach. Therefore, the revamping of existing plants will continue to be a source of new capacity. To revamp any plant successfully you must follow a logical and technically sound approach.

The Jacobs approach is to;
De-bottleneck the recycle loop
Determine the product capacity and de-bottleneck the product handling
Modify the reaction system to improve the recycle ratio
Check the scrubbing system
Match the raw materials input to the production requirements

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