Hydro
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THE DESIGN AND START-UP OF A 1 M TPY GREENFIELD NPK GRANULATION PLANT

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1 Historical Development of Project

The National Fertilizer Public Company Limited (NFC) plant is located on the eastern seaboard industrial area of Thailand near the city of Rayong some three hours drive south of Bangkok. The project has a long history dating back to the mid 80 's when commercial quantities of natural gas were located offshore in this area. Thailand has always imported a wide variety of NPK fertlizer grades and import substitution formed the key basis for the project. The design basis in 1985 was for a flexible plant to make 1.2 million tonnes per annum of ammonium phosphate based NPK's - typically 15:15:15. Hydro Fertilizer Technology was selected for both the phosphoric acid and granulation plants. The phosphoric acid plant utilised the Hydro two stage hemi-dihydrate (HDH) technology as phosphate rock has to be imported and therefore high process efficiency is essential. By operating at 50% P2O5 in the reactor the evaporation stage can be eliminated thus saving steam. The ex filter acid is strong enough to be used directly in the granulation plant ammonium phosphate reaction system. The Hydro solids granulation route was selected based on the production of powder mono-ammonium phosphate, combined with imported prilled urea and powder potassium chloride to produce a full range of NPK grades. The project proceeded through the design stage to a point where site levelling and construction work had commenced. At this point financing difficulties caused the project to be suspended.

It took a number of efforts and several years before the project was re-established in 1994. Of course during this period the Thai fertilizer market had expanded and market requirements had changed. A thorough review of the design basis was undertaken before the project recommenced. Imported phosphate rock and imported sulphuric acid naturally meant that the Hydro hemi-dihydrate phosphoric acid route remained the only logical choice. However, the decision to build a 2000 tonnes per day sulphuric acid plant on site was taken the following year. The design basis for the NPK granulation plant was changed from the solids feed route to the Hydro Fertilizer Technology pipe reactor process with a capacity of one million tonnes per annum. A consortium headed by Hyundai and Mitsui Engineering and Shipbuilding were awarded the contract to build the plant consisting of a dedicated quay, intake system, raw materials storage, product storage, bagging and dispatch, utilities and effluent treatment, as well as the process units, on a lump sum turnkey basis.

Flexibility in the design of both the phosphoric acid and granulation plants was essential. NFC have no captive sources of raw materials and therefore both processes were required to accept a wide range of raw materials so that production economics could be optimised. At the same time the granulation plant was designed to produce a wide range of NPK and NP products to suit the diverse agriculture of Thailand. The HDH phosphoric acid plant was designed to produce 50% P2O5 acid directly from the filter using Florida, Morocco, Jordan or Phalabora rocks. For the granulation plant there were a total of ten design grades based on either urea or ammonium sulphate such as 13:13:21, 16:20:0 and 15:15:15.

The following sections of this paper concentrate on the design and performance of the Hydro Pipe Reactor Granulation process.

2 Process Features and Design

2.1 Granulation Plant Arrangement

Even with today's ability to manufacture large scale equipment for solids material transport it was necessary to have two streams each of 1590 tonnes per day capacity to generate the required production of one million tonnes per year. The next question was two identical streams in parallel or mirror image plants. The two identical streams option certainly has advantages in cost terms as the engineering, equipment design and plant layout are the same for both units. However, there are additional costs in the conveying of raw materials to the plants and taking finished product to the store building. Also, as NPK production usually requires close and continuous monitoring to achieve the maximum plant output two control rooms are almost essential. The mirror image option allows raw material feed and product off takes to be centralised into one gantry system, and a single central control room simplifies plant supervision. The wet scrubbing sections can occupy a common bunded area. This option was selected for the NFC plant.

2.2 Raw Material Intake

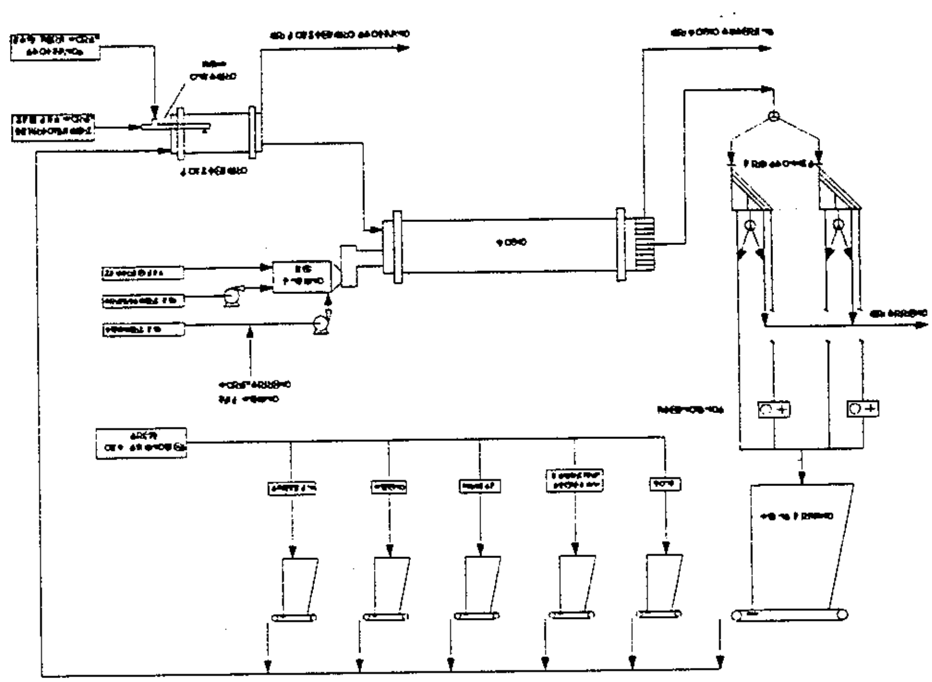
The solid raw materials - urea, ammonium sulphate, and potash arrive by sea and are conveyed to 30,000 tonne bulk stores. The urea/ ammonium sulphate building is air conditioned to minimise moisture pick-up. Automatic portal reclaimers are used to recover material for feed into dedicated raw material hoppers in the granulation plant. Locally available beach sand is utilised as filler in the formulations, and this store is also used for recycling any off-specification material. Front end loaders are used for recovery of these materials and the potash. A diverter at the end of each raw material conveyor system automatically splits the feed to either granulation line A or B depending on the hopper level. The hoppers are fitted with variable speed extractor weighbelts to accurately meter each feed material. These discharge onto a common collector conveyor with the recycle fines and are fed via an elevator to the rotary drum granulator.

2.3 Granulation Section

A simplified flowsheet of the Granulation Section is shown in two parts below in Figures 1 and 2. Figure 1 shows the raw materials intake and recycle loop and Figure 2 shows the product section

In many respects the granulator is the heart of the process where the finished product is formed. For a plant designed to produce a wide range of product analyses the operating conditions in the granulator have to be very flexible. In the case of NFC grades such as 13:13:21 are very much at the granulation efficiency controlled end of the scale, and grades such as 16:20:0 and 20:20:0 are at the liquid phase end. The Hydro pipe reactor provides this degree of flexibility without the need for auxiliary pipe work for steam sparging or ammonia addition under the granulation bed. As the pipe reactor is the only piece of pipe work in the granulator the need for a support beam running the length of the drum is eliminated. The pipe reactor is robust enough to be supported by an external frame at the granulator inlet. This has eliminated the traditional problem of material build-up and lump formation found in most granulators fitted with internal pipe work. The reactor feeds are gaseous ammonia and phosphoric acid suitably diluted in the scrubbing section of the process. The design range of 1.2 to 1.9 for the N : P mole ratio is very large and in practice values from 1.3 to 1.85 have been used. The feeds are ratio controlled to ensure the mole ratio is accurately maintained at the selected value. The granulation moisture balance is achieved by adjusting the amount of water added to the phosphoric acid - high for the granulation efficiency controlled grades and low for the liquid phase grades. The operating characteristics of the pipe reactor are particularly advantageous for minimising the water input to the granulator on liquid phase grades such as DAP. A large proportion of the water flashes off at the slurry spray nozzle, and this is removed by an appropriate air flow through the drum.

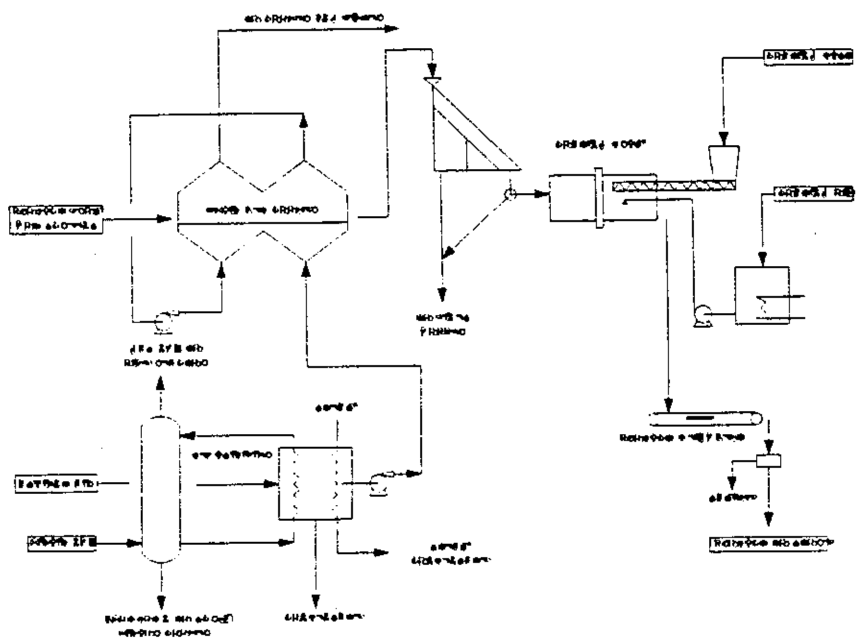
Figure 1
Flowsheet of Granulation Section - Recycle Loop



The granules are discharged directly from the granulator to the rotary drum drier. This is the largest and most expensive item in the flow sheet. Each NPK formulation has its own drying characteristics and the low product moistures required to avoid caking in storage usually mean long retention times. All NPK's are temperature sensitive, and the inclusion of urea and potash in the formulation puts severe constraints on the inlet air temperature and solids temperature in order to avoid unacceptable solids build-up on the drum shell. The drier design for a flexible NPK plant is therefore always somewhat of a compromise. This is achieved by independent automatic control of the inlet and outlet air temperatures and the air flow through the drum. The outlet temperature controls the fuel rate to the air heater, and the inlet temperature controls the amount of dilution air. For the NFC design the inlet temperature ranges from 110° C for the urea based grades to 350° C for the ammonium sulphate grades. This means that the air heater has to have a wider than normal operating and turndown range. Fortunately with a natural gas fired burner this is quite feasible. As an energy saving measure the air from the cooler circuit can be recycled to the air heater as dilution air, thus reducing fuel consumption by around 20%.

The granules are discharged from the drier through an integral 150 mm grizzly to ensure no large lumps of build-up can reach the screens. For this size of plant two double deck screens are sufficient. Vibratory feeders are necessary to ensure an even feed of material across the entire width of the screen cloth. Oversize (+ 4 mm) is removed on the top deck and fed to hammer and drum crushers which are mounted directly on top of the fines bin to eliminate the possibility of dust emission into the plant. Undersize fines from the bottom deck fall by chute into the fines bin. The fines cloth is split in two sections - the second section giving a coarser cut than the first. A divertor flap is placed beneath this second section to allow the choice of placing small product (typically between 1.5 and 2 mm) either into the product or fines streams; This provides a useful tool for fine tuning the optimum amount of recycle fines fed back to the granulator. The use of high efficiency vibrating cloth machines in this duty enables a product stream of generally more than 90% in the range 2 to 4 mm to be fed to the product cooler.

Figure 2
Flowsheet of Granulation Section - Product Treatment



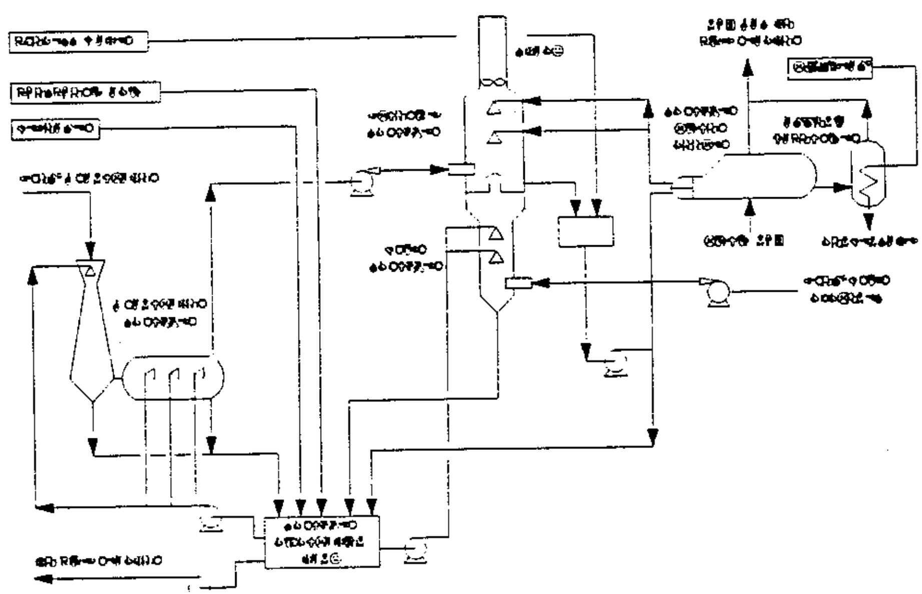
As the material ex drier is 75 to 85° C product cooling is necessary to avoid problems with heat set caking in storage. A two stage fluid bed cooler with a conditioned air feed provides the most economic design solution. Liquid ammonia is stored in a 20,000 tonne atmospheric tank at -33° C. An outflow heater raises the temperature to around 0° C prior to pumping across to the NPK plant. A part of the ammonia feed is vapourised by in the atmospheric airflow to the cooler. This cools the air from a typical 35° C ambient temperature to 10° C, condensing out a significant proportion of the moisture in the air. A small steam exchanger raises the temperature so that the air to the cooler is below its saturation point, which prevents condensation and build-up on the fluidising plate. Thus product cooling into the range 40 to 50° C is achieved with a relatively modest air flow.

- After cooling a single deck polishing screen is used to remove residual fines to give a final product of 95% in the range 2 to 4 mm. NPK's based on urea require coating to prevent caking in storage. A conventional rotary drum is used for this purpose. The anti-caking coating agent and coating oil are fed to the drum under ratio control from the product weigh belt. The product is then conveyed to the 60,000 tonne bulk storage. This building is air conditioned to prevent moisture pick-up by the product. Automatic portal reclaimers feed the four 50 kg bagging and palletising lines.

2.4 Process Air Treatment

A flow diagram of the gas scrubbing section is given in Figure 2 below
An extensive dust extraction system is fitted to minimise the generation of dust from material transfer points within the granulation plant. This air is vented through a high efficiency bag filter to atmosphere. The air from the fluid bed cooler being warm and dry is also treated with a bag filter for dust recovery.

Figure 3
Flowsheet of Gas Scrubbing Section



The high recovery efficiency (99.9% plus) means that this stream is considered to be clean enough for direct recycle to the air heater as dilution air. Surplus air is discharged directly to atmosphere. The drier exhaust air is first fed to a bank of cyclones to remove the majority of the dust content, and then to a void tower scrubber to recover the remaining dust and the small amount of ammonia slippage.

The exhaust from the granulator is vented to a sophisticated multiple venturi scrubber to recover the ammonia slippage. The air from the granulator and drier scrubbers is fed to the fluorine scrubber before discharge to the atmosphere. Phosphoric acid at a nominal 49% P2O5 is fed to the gas scrubber tank. A common scrubbing liquor is used in both granulator and drier scrubbers. In order to minimise the fluorine scrubbing duty this liquor is controlled at an N : P mole ratio in the range 0.4 to 0.5 by automatic analysis and regulation of the phosphoric acid flow to this part of the scrubber tank. Operation in this range fixes most of the fluorine content of the acid in the liquid phase as fluorophosphates. The remaining part of the phosphoric acid flows to the pipe reactor feed section of the tank. The partially neutralised acid is then fed under flow control to the pipe reactor. The fluorine scrubber is a void tower fitted with a packed section. Process water is used as the scrubbing medium. As a means of energy recovery and also to improve the fluorine scrubbing efficiency the scrubbing liquor is used to complete the evaporation of the liquid ammonia, the first part having been carried out in the fluid bed cooler air conditioning unit. The liquor has an operating temperature of 45 to 50 C which is quite satisfactory for evaporation in a conventional shell and tube exchanger. A small steam vaporiser is provided to evaporate any small quantity of residual water in the liquid ammonia feed, if required. The liquid blow down from the fluorine scrubber is regulated to provide the required quantity of water for the phosphoric acid dilution duty for the pipe reactor feed. This ensures that the plant operates in a liquid effluent free manner.

2.5 Process Control

The granulation plants have a high level of instrumentation allowing both trains to be operated from a single centrally located control room at the granulator floor level. A DCS control system provides accurate on-line control and extensive production data processing capabilities. A data highway means that plant performance can be monitored from more remote locations such as the plant management office block and the central laboratory.

3 Process Performance

The design basis covers the five major tonnage NPK grades for the Thai market. These are:- 15:15:15, 16:16:8, 16:20:0, 13:13:21 and 20:20:0. The first two grades were made during the initial commissioning period and the second two subsequently. Other NP grades, in particular DAP, have also been manufactured.

Commissioning of both granulation lines started in late 1997 and was completed during early 1998; during this period 15:15:15, 16:16:8 and 16:20:0 were produced. Design rates were achieved for all grades and a 72 hour performance test run was made on 15:15:15 during which all test parameters were passed.

From both a design and performance point of view the most critical operation is that of the Granulator. The performance of the Granulator cannot be separated from that of the Pipe Reactor. The Pipe Reactor/Granulator is the heart of the process and represents the interface between the wet and dry sections. If conditions in the Granulator are not correct then the process will not achieve performance expectations; the Pipe Reactor plays the major role in establishing desired Granulator operating conditions.

The main function of the Pipe Reactor is to react phosphoric acid (from the gas scrubbing section) with ammonia to produce a slurry of ammonium phosphate. The heat of reaction is dissipated by evaporating water from the incoming phosphoric acid feed and a mixture of ammonium phosphate solution and steam is discharged into the Granulator. In order to maintain control of the Pipe Reactor it is necessary to contain the Pipe Reactor back pressure in the range 2.5-3.5 kg/cm2 over a wide range of different operating conditions which are required to give operating flexibility. Table 1 below illustrates the wide variability in the Pipe Reactor design operating range. In addition to the to the conditions given in Table 1 the Pipe Reactor was also required to operate at a turndown of 50%. To accommodate the wide range of operating conditions the reactor was supplied with a number of discharge nozzles of different sizes. The nozzles were simple bolt on devices which could be changed in a matter of minutes.

Table 1
Pipe Reactor Operating Range

Grade	Acid to Pipe Reactor m^3/hour	Reaction Steam tonnes per hour
16:20:0	20.80	7.80
16:16:8	16.00	6.30
15:15:15	14.70	5.90
13:13:21	12.90	5.00

A mixture of ammonium phosphate and steam, typically at about 150°C, is discharged onto the bed of rolling solids in the Granulator. A stream of ambient air is drawn through the Granulator to remove the reaction steam and any ammonia slippage from the Pipe Reactor. It is most important that the reaction steam disengages from the ammonium phosphate slurry and is carried away in the air stream. If steam condenses in the rolling bed of solids over-heating accompanied by over-granulation occurs and design performance cannot be achieved.

The general performance of the Pipe Reactor and Granulator were excellent under a wide range of operating conditions for example the N:P mole ratio of the Pipe Reactor was varied from 1.3 to 1.85 during optimisation. During the commissioning period there was not a single blockage of the Pipe Reactor due to the automatic on-line steam purging system. The efficiency of the reactor was much higher than expected; the original design assumed that 10% of the ammonia fed to the reactor would be lost in the Granulator air stream. However the actual performance indicated that only about 5% was lost.

3.1 Process Performance - 15:15:15

Analysis of the actual operating conditions from the performance test run on 15:15:15 indicated that across the whole process and particularly the Granulator and Pipe Reactor the process performed in accordance with the design heat and materials balance. A summary of the performance test results are given in Table 2 below.

Table 2
Summary of 15:15:15 Test Results

Guarantee Parameter		Guarantee	Achieved
Aggregate Capacity		4,76	5,35
Size % 2-4 mm		85	85.9
Analysis	%N	14.6 - 16.2	15.6
	%P2O5	14.6 - 16.2	15.1
	%K2O	14.6 - 16.2	15.5
%N+%P2O5+%K2O		46.9 maxm	46.3
Water Content %		1.5	0.96
Hardness		2	2.6
Efficiency	% N	99.2	99.81
	% P2O5	99.7	99.97
	% K2O	99.7	99.98
Utilities	Steam kg	35	5.5
	Gas Kcal	65	33,75
	Water m3	0.17	0.05
Effluents	F mg/Nm3	5	<1
	Dust mg/Nm3	75	54

3.2 Process Performance - 16:20:0

Despite the excellent performance of the plant on 15:15:15 the operation on 16:20:0 was more problematic. Major problems occurred in the Granulator;

granulation temperatures were much higher than expected from the design (95°C+ compared with 80°C). As production rates were pushed to 85-90% of design the granulation temperature increased beyond 95°C and formation of oversize granules was excessive. Normal granulation could only be restored by increasing the recycle ratio and design production rates could not be achieved.

Data collected during the operation was analysed and compared with the design heat and materials balance. The study indicated that the excessive temperatures were caused by condensation of Pipe Reactor steam in the Granulator rolling bed. The reaction steam was not disengaging from the ammonium phosphate slurry. A number of modifications were made to improve disengagement :-

The design of the Pipe Reactor nozzles was modified to improve the dispersion of the ammonium phosphate slurry.
The air flow through the Granulator was maximised.
The Pipe Reactor was moved an additional 150mm away from the rolling bed.

After the modifications the plant achieved design production rates for 16:20:0. All three actions improved the steam disengagement but by far the most effective was the modifications to the discharge nozzles. The performance of the Granulator/Pipe Reactor before and after modifications is given in Table 3.

Table 3
Pipe Reactor Performance

	Pipe Reactor Steam tonnes/hour	Granulator Exhaust Steam tonnes/hour	Net Steam Evaporated tonnes/hour
Design Case	7.76	8.18	0.42
Original Performance	7.21	6.11	-1.10
Modified Performance	8.52	8.78	0.26

The first column indicates steam produced in the Pipe Reactor from a heat and materials balance calculation. The second column gives the steam which is carried away with the Granulator exhaust gases and is obtained from the exhaust temperature and humidity. The last column indicates the net effect; the original design assumed a net evaporation of 0.4 tph. However the actual performance indicates that in fact 1.1 tph of steam was condensing and causing the over-heating problem. After modification, and despite the larger quantity of steam generated the Granulator still achieved a net evaporative effect. One of the side benefits of the higher Granulation temperature was that the process was operated in an almost autothermal condition; the Air Heater for drying was only operated intermittently at minimum firing.

As described above the Pipe Reactor was designed to operate on gaseous ammonia. A potential way to reduce the steam generated by the reactor would be to operate with liquid ammonia feed. The current experience indicates that grades containing greater than 20 - 25% P_2O_5 be based on liquid ammonia feed to the Pipe Reactor.

4 Conclusions

The NFC plant start-up could not have happened at a worse possible time. During the latter part of 1997 and beginning of 1998 the Asian economic crisis was at its height, particularly in Thailand. There were cash flow problems and market prices were depressed. Despite these difficulties the NFC management and staff, all of whom were young and generally inexperienced in fertilizer factory operation, brought into production a world scale, greenfield, fertilizer factory in a very short time. The performance of the NFC personnel was very creditable and they deserve congratulations for their dedication and professionalism.

The flexibility of the Hydro Fertilizer technology NPK granulation process was demonstrated. In future NFC will probably need to expand their raw material sources and product range to account for of changing economic conditions and the demands of the market place. The flexibility built into the Hydro process will allow these changes to take place with minimum disruption to the overall production plan

The performance of the Pipe Reactor was demonstrated despite some teething problems with high P2O5 grades. However these problems were overcome with a some simple modifications. The wide operating flexibility was proven over a range of P2O5 capacities and N:P mole ratios. The nitrogen efficiency of the Pipe Reactor itself was significantly higher than predicted in the design, even at higher N:P mole ratios.

As for the future, Hydro are currently designing a combined NPK/DAP plant, based on Pipe Reactor technology, with a capacity of 1.2 million tonnes per year. The plant will be located in Jordan and constructed in two identical lines each line with a design capacity of either 80 tph NPK or 66 tph DAP.