Table 2: **CO_2 emissions before and after Toyo ACES21® urea revamp**

	Before revamp	After revamp
Capacity (t/d)	1,620	2,460
Urea production (000 t/a)	558.9	848.7
CO_2 consumption (000 t/a)	413.6	628.0
Energy consumption in boiler and power plant for urea production:		
Gcal/t	1.269	709.2
000 Gcal/a	0.913	774.9
Energy consumption in boiler and power plant for CO_2 capture from flue gas (Gcal/a)	None	94,118
Total energy consumption (000 Gcal/a)	709.2	869.0
Crude oil equivalent (t/a) (10,000 kcal/g)	70,924	86,898
Equivalent CO_2 emission-based oncrude oil (000 t/a)	219.4	268.9
Net CO_2 emission (000 t/a)	219.4	168.9
Specific CO_2 emission (t CO_2/t urea)	0.393	0.199

Table 3: **Comparison of UFT's ammonia abatement and acidic scrubbing technologies**

Reduction	UFT ammonia abatement system	Acidic scrubbing	Ideal
Emission reduction	25-40%	80% min.	80% min.
Waste stream	None	c.2 kg AS/t urea as 40% solution	none
Operations	Easy	easy	easy
Additional investment	Low	moderate	low
Operating cost	Low	moderate	low

(AS = ammonium sulphate)

cooling system. The high-pressure loop may also require a limited upgrade. Particular attention has to be paid to the condensation and recycle steps of each section. Saipem also offers revamps that combine debottlenecking with energy savings, incorporating a predecomposer or pre-vacuum concentration. An additional or replacement exchanger may also be required, as well as modifications, replacements or additions to the high- pressure pumps. The vacuum systems may also require upgrading to cope with the increased load conditions. For extensive revamps involving capacity increases above 35%, Saipem will typically specify a new rotor for the CO_2 compressor or else a new parallel compressor. The latter may be a reciprocating type, in order to cope with the additional load.

Saipem's revamps can significantly reduce a urea plant's variable costs. The main revamp opportunities to achieve such savings are via:

- Ammonia preheating
- Carbamate preheating
- Heat recovery from MP off-gases in the auxiliary boiler or reforming furnace
- Reuse of process condensate as boiler feed water
- Use of variable frequency motors as drivers of HP pumps.

Saipem has a long history of improvements to the urea process scheme to comply with stringent environmental requirements. Its process technology is designed for zero discharge of liquid effluents, since all the produced process water can be reused as feed to the polishing section of the boiler feed water preparation system. For gaseous effluents, the main schemes introduced are aimed at either reusing the continuous off-gases by their heat valorisation (in the auxiliary boiler or in the reforming furnace) or at obtaining a very low ammonia emission level through scrubbing systems.

For cases where absolutely no emissions are permitted, Saipem has developed the Zero Tolerance concept, whereby flares are installed on both the continuous and discontinuous vents. To abate emissions from the air in the finishing section, Saipem can install a urea dust ammonia/dust acid and urea dust scrubbing systems.

Uhde Fertilizer Technology

Uhde Fertilizer Technology (UFT) has undertaken numerous innovations that reduce ammonia emissions from urea granulation plants that can be retrofitted to existing plants. UFT accounts for over 80% of the fluid bed granulation capacity, and the company offers customers several options, including UFT's proprietary ammonia abatement system and acidic scrubbing. The performance of each system is compared in Table 3.

While moderate reduction of ammonia emissions by 25-40% can be achieved by UFT's ammonia abatement system, further reductions (up to 90%) can be attained via an acidic scrubbing system. The latter generates an ammonium salt, such as ammonium sulphate if sulphuric acid is employed. This system has the drawback of producing a waste stream that cannot be handled in a normal urea facility. As a result, UFT has developed a "zero effluent" scheme that reduces ammonia emissions to low levels without generating waste liquid that requires additional treatment. UFT also recommends the addition of the by-product ammonium sulphate into the urea granules.

UFT has developed its proprietary Ammonia Convert Technology that uses a combined dust and acidic scrubber. The ammonia is absorbed in the acid scrubbing section and is converted into AS solution. This in turn is added to the recycle flow going back to the evaporation section. The additional investment required for the Ammonia Convert Technology is an additional scrubbing stage, a sulphuric acid dosing system and some modifications in the evaporation and condensation/vacuum section. The system can be easily implemented in existing plants and promises a quick payback.

NIIK

JSC NIIK (Research and Design Institute of Urea), Russia has over 55 years of expertise in designing and revamping urea plants. One of the basic elements in NIIK's revamping concept is the modernisation of the synthesis unit. This is the most important part of the urea plant as its efficiency determines the recycle ratio of unconverted feedstock and hence the energy consumption of the facility. (*Revamping urea plants for increased production and efficiency*, **Nitrogen+Syngas** [p61, January-

February 2009].) Enhancing the efficiency of the synthesis unit improves operating parameters and also increases final product output.

Among its many services, NIIK offers revamping of the synthesis section without significant capital investments, focusing on a revamped urea synthesis reactor, the HP stripper, HP carbamate condenser, HP scrubber and HP ejector. With the goal of increasing urea synthesis and enhancing the conversation rate of CO_2 into urea, a NIIK revamp increases the efficiency of the reaction volume by optimising the hydrodynamic flows inside the reactor. The increased CO_2 conversion rate reduces the amount of unconverted NH_3 and CO_2 in the synthesis melt. The NIIK revamping concept is via the sectioning of the synthesis reactor. Depending on the process, the synthesis reactor can be divided into three operating areas:

- Mixing area of the original reagents
- 1st stage urea synthesis
- 2nd stage urea synthesis.

The initial dispersion of the gas occurs in the mixing phase, as well as the formation of the liquid/gas mixture. To ensure maximum efficiency, NIIK offers a high-performance vortex mixer with a design based on intensive gas distribution. The area where the first stage of the urea synthesis reaction occurs is aimed at ensuring the maximum bounding of the components into ammonium carbamate. In a revamp, this area is fitted with NIIK's proprietary design of longitudinal sectioning element, which achieves the full bounding of the feedstock into ammonium carbamate with optimum hydrodynamics in the reactor.

NIIK has recently offered a modified sectioning element which offers several advantages over the original design, including:

- More efficient contact of feedstock and therefore a higher rate of local conversion
- Stable efficiency regardless of operating loads
- Reduced hydraulic resistance
- Fast drainage of the reactor.

The second stage of the urea synthesis is aimed at ammonium carbamate dehydration in the formation of the urea. To achieve maximum efficiency of the reactor, this area is equipped with sieve trays designed to eliminate longitudinal mixing, equalise the velocity profiles of the ascending movement of phases and to increase the interface surface. NIIK's overall scheme for revamping the urea synthesis reactor includes equipping the bottom part of the reactor with a vortex mixer and improved longitudinal sectioning element, while the remaining internal space of the reactor is sectioned with sieve trays.

NIIK has retrofitted some 15 units in Russia and the CIS with this equipment. In one case, the introduction of the internal devices on two units with a capacity of 1,500 t/d each has resulted in an improved conversion rate in the synthesis reactor of 3%, raising capacity up to 1,650 t/d. The steam saving was also improved by a minimum of 0.4 Gcal/t.

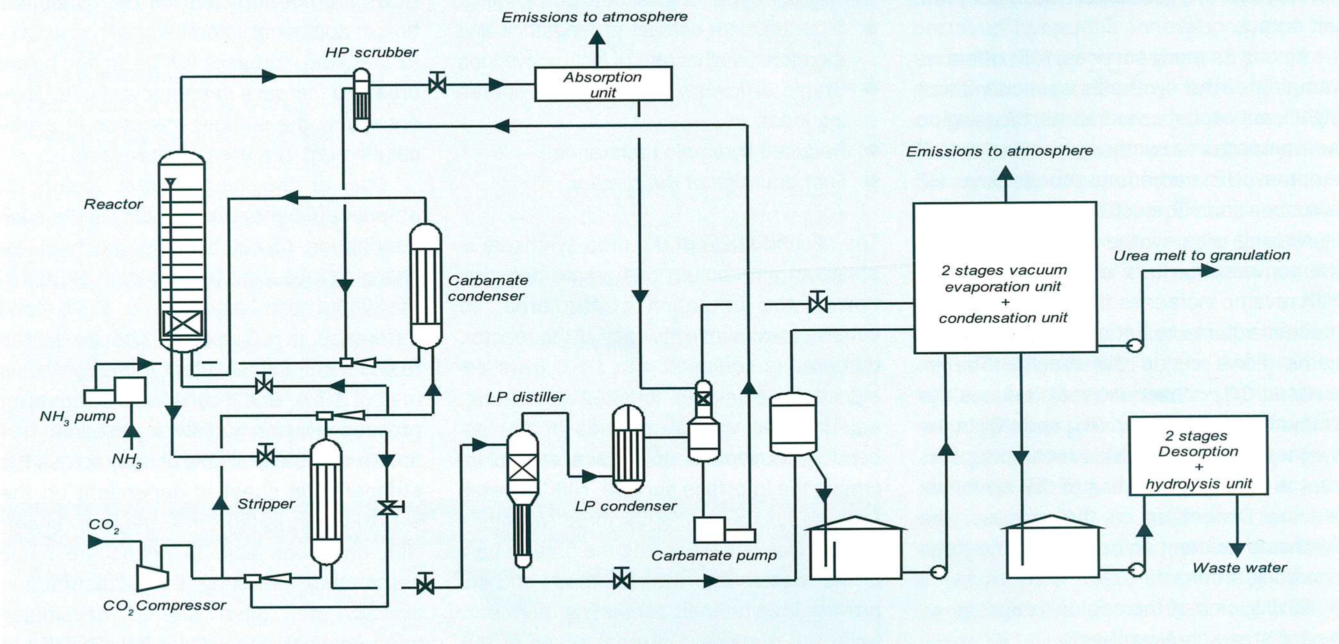
NIIK offers revamping of the HP stripper. The stripper is designed for the removal of unreacted NH_3 and CO_2 and their recycling into the synthesis unit. If the load increases with any corresponding intensification of the removal process, a large amount of unreacted NH_3 and CO_2 will appear in the distillation and recycle units. Since the existing heat exchanging surfaces are not sufficient for the condensation of additional volumes of NH_3 and CO_2, further load increases will be limited by the pressure increase in the recycle unit. Thus enhancing the stripper operation is a critical element in a urea plant revamp.

One of the fundamental factors in stripper efficiency and capacity is the even distribution of liquid along the heat exchanging tubes: a 10% deviation of load in the liquid can result in a 2.5% load difference in CO_2 and a change in the residual ammonia content in the synthesis melt of 1.5%, with a consequent impact on process efficiency. NIIK's research has shown that the real flow of melt across the stripper tube sheet is dependent on the way the melt is fed on to the tube sheet. NIIK has been able to define the basic parameters affecting liquid distribution across the tube sheet, developing mathematical models that have helped to develop an improved distributor for the melt liquid in the stripper that ensures the more even feeding of all tubes. (Fig. 3)

The new NIIK design improves the variation in distribution of liquid across the tubes from 8-10% to 1-2%. Additional advantages are the elimination of corrosive conditions connected with connected with the melt distribution along the tubes. Several revamps incorporating the modified distribution unit have already been undertaken. They have typically achieved a 3-8% increase in the rate of ammonia removal.

NIIK has also undertaken revamps of the HP carbamate condenser in various urea plants. The carbamate condenser is designed for the preliminary reacting of

Fig 3: **NIIK improved distributor for the melt liquid in the stripper**



feedstock into ammonium carbamate for its further conversion into urea in the synthesis reactor. The vessel also operates as a boiler, converting the heat of ammonium carbamate formation into steam. Distribution devices located at the top of the carbamate condenser have been designed to:

- Separate the feed of gas and liquid phases on to the tube sheet to ensure the fall of the feed mode on the heat exchanger tubes
- Ensure an even distribution of liquid and gas phases across the vessel section and along the heat exchanger tubes.

The new design of carbamate condenser ensures the stable operation of the unit with increased loads and eliminates overheating in the top part of the tube bundle.

The HP scrubber is a key vessel in the synthesis section as it ensures that the ammonia and CO_2 condensation exiting the urea synthesis reactor. Increased loads on the scrubber can lead to significant temperature deviations as a result of higher gas volumes at the reactor outlet: the existing heat exchanging surface is insufficient for the complete transfer of the heat load. To overcome this, NIIK recommend extending the heat exchanging surface of the HP scrubber by replacing the heat exchanging section with extra cooling water piping. Revamping of the HP scrubber ensures operation at increased loads without limiting the synthesis unit or production unit. NIIK also recommends the replacement of the HP ejector with a higher capacity unit in order to cope with the increased flows of ammonium and ammonia salts.

An alternative to the HP synthesis unit is a revamp conversion of the carbamate condenser to submerged operation mode. This eliminates some of the drawbacks of the vertical carbamate condenser design (such as insufficient contact surface between the large amount of gas and small amount of liquid). Thus, when the gas is bubbled into a liquid phase with a submerged carbamate condenser, gas condensation is very effective and the temperature and pressure of the gas increase. This enhances the contact between the liquid and gas phases in the unit and increases the time the process fluids spend in the unit. The pressure of the steam produced in the carbamate condenser increases.

NIIK's *URECON-2007* revamp scheme offers several advantages, including:

- Maximum use of the active volume of the unit
- Good conditions for ammonium carbamate production
- Good conditions for urea production in the condenser due to media movements which are close to perfect displacement
- The entire amount of fresh CO_2 and distillation gases is fed to the synthesis reactor, ensuring a higher conversion rate
- Ease of operation.
- More economical use of steam fed to the stripper due to the use of part of the hot distillation gases as the stripping agent.

The measures offered by JSC NIIK have been implemented successfully at several urea plants in the Russia and the CIS, enabling capacity to be increased by up to 30-40%.

All measures which achieve energy savings in ammonia and urea production translate into lower fuel consumption. This in turn means burning less fossil fuel, with a corresponding reduction in greenhouse gas CO_2 emissions. Revamp projects in India and other less developed countries qualify for Certified Emission Reduction (CER) credits. An emission reduction of one tonne of CO_2 qualifies for one CER. These CER credits are tradable and can be used to contribute to the emission reduction commitments of industrialised counties. All these projects should satisfy additionality criteria under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Indian fertilizer producers have become particularly aware that the financial benefits from CDM can improve the viability of the project, thereby stimulating energy-saving measures in ammonia and urea plants via revamps. ■

A new generation of prilling towers

The most recently constructed urea plants have mainly adopted granulation technology, and the older established prilling technology appeared to have been superseded. However, the Russian technology company JSC NIIK has given prilling a fresh shot in the arm, having modernised the design of the prilling tower to enables urea producers to meet the highest standards of energy efficiency and low emissions and supply a product that meets the needs of today's markets.

Solid urea is marketed as prills or granules. Prills offer the advantage of generally being cheaper to produce than granules, but the latter have a narrower particle size distribution, giving granules an advantage over prills when applied mechanically to the soil. Other properties such as impact strength, crushing strength and free-flowing behaviour need also be taken into account, being particularly important in product handling, storage and bulk transportation, and these in turn can be a function of the chosen manufacturing process.

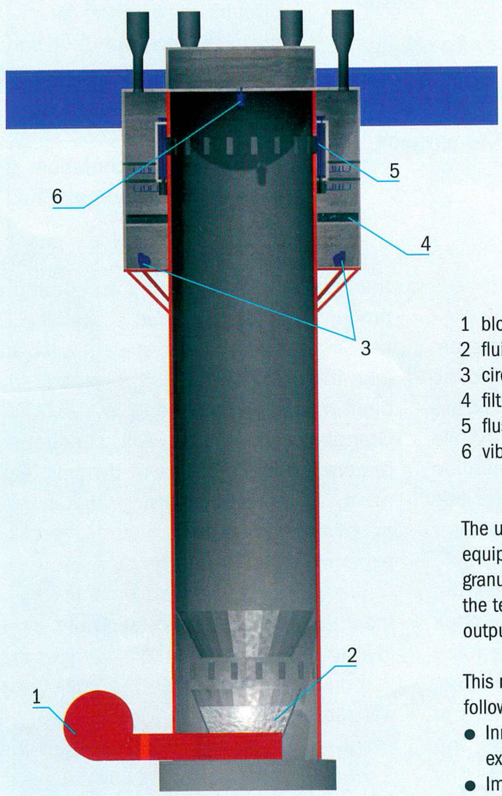
In its essential physical and chemical form, urea is a crystalline colourless substance formed as thin needles or rhombic prisms, with a melting point of 132.7°C. Like most nitrogen products, urea absorbs moisture from the atmosphere. It should therefore be stored in closed/sealed bags on pallets, and if stored in bulk, under cover with a tarpaulin. As with most solid fertilizers, urea should also be stored in a cool, dry, well-ventilated area.

Crystalline urea can cake very heavily during storage – a factor which granulation appeared better able to tackle because of the more uniform size range during the granular production process. Whereas prilling technology is essentially the formation of spherical drops of urea melt while in free fall (and their subsequent crystallisation in the cooling air counter current), granulation comprises the spraying and multiple layering of urea melt across the surface of pre-solidified particles. This in turn leads to the formation of spherically-shaped granules, followed by their cooling.

Despite the inroads made by granulation technology, prilling technology has continued to advance, with a particular focus on enhancing prill size and strength as well as reducing atmospheric emissions. JSC NIIK has been in the forefront of developments in this respect, paying particular attention to the design and performance of prilling towers. Older generation prilling towers were constructed from concrete and had a typical height of around 40 m. These towers were equipped with a urea melt dispergator, a scraping conveyor for loading product, and fans for supplying cooling air into and from the tower.

The modern design of prilling tower that NIIK has developed is a composite struc-

Fig 1: JSC NIIK's modernised prilling tower



1 blowing fan
2 fluidised bed cooling unit
3 circulation pumps
4 filtration
5 flushing jets
6 vibrogranulator

The underbody of the granulating tower is equipped with a fitted unit to cool the granules in a fluidised bed. As a result, the temperature of the granules at the output does not exceed 45°C.

This method of modernisation has the following advantages:

- Innovative design easily integrates into the existing granulating tower building structure
- Improved emissions rate and final product.

ture 114 m high and 16 m wide with a throughput capacity of between 600-2,100 t/d and more. (Fig. 1) The barrel of the tower can be made from either reinforced concrete or metal structures. The capacity limit for a new generation single line prilling tower is just below 3,000 t/d, but NIIK believes that this figure can be exceeded.

The key features of NIIK's enhanced performance prilling tower are:

- A centrifugal sprayer with vibration mode located at the top of the tower permits the production of mono-dispersed urea with increased granule size.
- An injection-type scrubber with two in-line blocks that minimise ammonia and urea emissions.
- An integrated granule fluidised bed unit that ensures product cooling to 50°C with minimal cracking or dusting.

Granulation technology gathered pace in the 1970s as such licensors as Stamicarbon and Toyo Engineering Co. developed fluidised bed urea granulation. The fluidised bed granulation sections licensed by different companies have similar process stages and differ mainly in the design of nozzles spraying the urea melt on to a fluidised bed of pre-solidified (or seed) particles.

After the evaporation unit, urea melt with urea-formaldehyde additive is pumped to the granulation unit. The granulator has two sections: the granulation section and the cooling section. The seed particles are fed to the granulation section along with off-spec product from the sorting stage, urea melt from the evaporation unit and cooling air. In this section, the seed particles are fattened with urea melt drops which are sprayed through the spray nozzles. While the granules are moving in the granulation section, they gradually become larger due to fattening until the granules' diameter reaches the intended level.

This granulated product is forwarded from the granulation section to the cooling section, where the granules are cooled to ambient temperature by cooling atmospheric air fed by the fans. After this, the granulator bucket elevator delivers the urea granules to the sorting stage. At this stage, screen sizing of the partially cooled product takes place. There is an upper and lower limit on particle size: small-sized particles are forwarded to the granulator as recycle after sorting, while the large-sized granules are ground by rollers and then sent back to the granulator. The finished product, with granules of the correct size, is delivered to the final product cooling stage.

Table 1: Comparison of prilling and granulation process stages

Stage	Prilling	Granulation
Evaporation section	Yes	Yes
Melt dispersion	Yes	Yes
Cooling	Yes	Yes
Purification	Yes	Yes
Sorting	No	Yes
Grinding	No	Yes
Recycle return	No	Yes
Final cooling	No	Yes

At this stage, the granules are cooled by a cooling agent which has a temperature of 7-10°C. After the product is cooled to around 40-50°C, commercial-grade urea is transported to the warehouse or dispatch area. Two scrubbers are employed for exhaust air purification. The air from the granulator is purified in the first scrubber, while the second scrubber treats the air in the preliminary and tail fridge. The air in the scrubbers is purified by washing with a recirculating urea solution.

> **The lower capital cost of a prilling tower promises an earlier payback.**

The main process stages in prilling and granulation technologies are summarised in Table 1.

Prilled urea plants are more compact than granulation units, and have four fewer process stages. Whereas a typical 2,000 t/d single-line prilling urea plant will occupy less than 500 m^2 of land area, a granular plant will require between 1,500-2,000 m^2. Granular urea plants will consequently require additional items of dynamic equipment, as well as incurring higher operational, maintenance and servicing expenses. While a granular urea plant requires frequent shutdowns (every 1-2 months) for the process equipment and utilities to be cleaned (due to blockages in the gas ducts and equipment), a prilling tower will require cleaning only once every 1-2 years – work that can be undertaken during a scheduled overhaul. The capital cost of a prilling unit remains significantly lower, at around \$15-20 million, compared with \$35-42 million for a granular urea plant.

Off-spec product is a fundamental aspect of the granular urea production process: the narrower the granular size range, the more that must be recycled. Circulating off-spec product through the system requires additional equipment and energy. Product manufactured in the prilling process does not have off-spec particles. As a result, energy consumption in a granulation unit may be up to three times higher than in a prilling tower.

To produce granulated urea, a formaldehyde additive is required to be fed before granulation, while high-quality prilled urea can be produced without this additive. The formaldehyde additive is also a carcinogenic substance, which leads to complications in the discharge unit, storage and feed of the additive, as well as limiting urea application.

Emissions to the atmosphere from a granulation unit can be high, especially with ammonia emissions (around 135 mg/Nm^3 for ammonia and around 30 mg/Nm^3 for urea). Ammonia and urea emissions from a prilling tower are much lower, at around 40 mg/Nm^3 for ammonia and 25 mg/Nm^3 for urea.

Demand assessments

Both prilled and granular urea are in substantial demand in the global market. Both enjoy comparable physical and mechanical properties, the main difference being the greater strength of the granular product. However, in the Middle East, Asia and Africa, there is stronger tendency among buyers to prefer prilled urea. The main advantages claimed by prilled urea are:

- Smaller size of the production facilities
- Less waste during production, with no agglomerates or off-spec products to be recycled
- The production process is simpler and requires less equipment or maintenance
- Minimal power costs for the process needs for steam. Cooling agents and formaldehyde additive are not required to feed the urea melt
- Minimal harmful emissions to the atmosphere
- Consistent product quality.

The lower capital cost of a prilling unit promises an earlier payback on the investment. The cost of production of prilled urea was estimated (in early 2008) to be about €7-10/t lower than that of granular urea. ■