NIIK's approach to energy efficiency

Technology developed by NIIK has extended the operating lives of many urea plants in the Former Soviet Union and enhanced their efficiency and competitiveness.

As a leading provider of urea technology to the Russian fertilizer industry, NIIK is offering continuous improvements in energy efficiency, feedstock consumption, environmental performance and safety parameters. NIIK has three proprietary urea technologies and offers its customers state-of-the-art concepts and solutions, both for the construction of new urea plants and for revamps. These technologies are *URECON 2006®*, *URECON 2007®* and *90 bar stripping*.

All three technologies use internal heat recovery as the main method for raising energy efficiency in urea plants. *URECON 2006®* is an improved TLR technology which proved its efficiency during numerous revamps of older urea plants, reducing specific energy consumption. This was achieved by applying the following technical solutions:

- Improving the synthesis process efficiency and reducing the unreacted components rate by the installation of proprietary internals in the reactor, resulting in hydrodynamics optimisation.
- Heat utilisation of medium-pressure (MP) distillation gases for the distillation of unreacted components in the low-pressure (LP) distillation section and concentration of urea solution in the pre-evaporation section.

For the *90 bar* stripping process, NIIK used high-efficiency synthesis and heat utilisation of distillation gases under 90 bar pressure to generate low steam together with the stage separation of liquid from gas for heat loss reduction during the solution throttling.

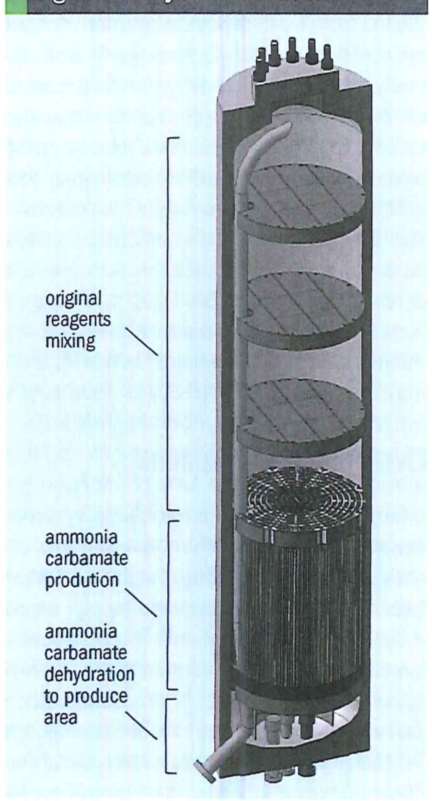
In addition to the above energy efficiency solutions, the following methods can be used: heat recovery of the process flows in the wastewater desorption and hydrolysis section; heat utilisation of CO_2 compression in the compressor to activate the catalytic oxidation of flammable impurities contained in the original gas; and cold utilisation of fresh ammonia for cooling the air supplied to the prilling tower. Another advanced solution is urea melt supercooling to generate low steam which is used for cold generation in the absorption cooler.

The main technical solutions used by NIIK for improving energy efficiency in urea plants are discussed further in the following paragraphs.

Three-zone synthesis reactor

NIIK designed the internals for this section. NIIK had been researching the hydrodynamics of the urea synthesis reactor for some time. Urea reaction comprises a two-stage process, via the production of ammonia carbamate in the first stage and its further dehydration in the second process stage. To obtain maximum efficiency in the urea reactor, the mode of operation in the reactor should be approximated to the plug flow. This is achieved by using urea sectioning. The common sectioning method is through the installation of mass-exchange trays in the reactor. After a long analysis of urea reactor hydrodynamics, NIIK specialists concluded that the processes could be intensified by installing additional internals.

Fig 1: Urea synthesis reactor



The reactor comprises three zones (Fig. 1):

- Original reagents mixing zone
- Ammonia carbamate production
- Ammonia carbamate dehydration to produce urea,

As each zone is critical to the process, NIIK introduced a special internal for all three zones. Each innovation was trialled in laboratory-scale and commercial-scale tests. For the original reagents mixing zone, NIIK developed a high-efficiency Vortex Mixer. This is aimed at the full mixing of the original reagents supplied to the urea reactor. The further reactions depend on the mixing rate of the original reagents. Unlike conventional mixers, the NIIK Vortex Mixer uses the full space of the reactor lower zone for mixing (90% for the Vortex Mixers, versus 30% for conventional mixers). The Vortex Mixer ensures maximum contact of gas with liquid due to high dispersion rates that are 1.5-2 times higher than conventional mixers.

A Conversion Booster is used in the second zone, for ammonia carbamate production. The numerous tubes of the conversion booster approximate the flows' hydrodynamics to the plug flow, which is very significant for ammonia carbamate production.

The rest of the reactor volume is sectioned by mass-exchange trays. These eliminate longitudinal mixing, balancing the flow velocity profiles and expanding the surface between the phases. The trays are designed specifically for each particular case to balance the velocities' profile along cross- and longitudinal sections of the reactor. They are consequently designed with a variable section, according to the height of the reactor.

Installation of the internals in the synthesis reactor ensures the efficient operation of the synthesis section, with an increased conversion rate. In the case of increased reactor yield while maintaining the conversion rate, the internals reduce specific energy consumption in the distillation and evaporation sections as a result of the higher conversion rate and reduced recycle.

NIIK internals have been installed in 19 urea plants in FSU countries, leading to the following benefits:

- Reduction in energy consumption (steam) of 0.04 Gcal/t and more
- The CO_2 conversion is increased by 2-4%
- The capacity of the urea plant can be increased by 30-40% with minimal modifications in the other sections.

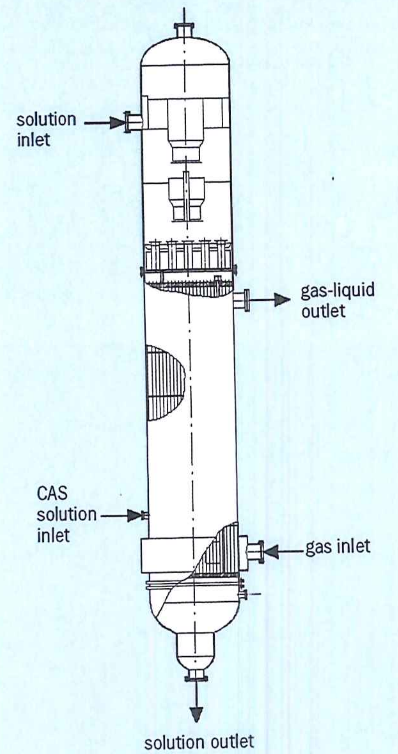
Distillation gas recovery

Energy-efficient technology enabling the direct transfer of process media heat is part of the *URECON 2006* concept developed by NIIK for revamps of urea plants with TLR.

MP distillation gases have high energy potential. Their heat as well as the heat from the stripping gases can be utilised in the process. Their temperature reaches 140°C, thus enabling their heat to be utilised in the LP distillation and pre-evaporation sections. Heating the urea solution in these sections reduces water consumption (or energy consumption) for distillation gases condensation and the steam consumption used for heating the urea solution. Because the process is relatively inefficient in typical heat exchangers, NIIK devised special vessels – an LP distiller and a heat recovery unit in the heat exchanger – for the pre-evaporation section.

Fig. 2 shows the LP distiller. The distillation phase is performed in a single vessel, in a distiller which combines a distillation column with a falling film heater. The falling film mode of solution flow ensures a high heat transfer rate. The design of the LP distiller ensures its highly efficient operation and a high distillation rate for unreacted components in the LP distillation unit.

Fig 2: NIIK low-pressure distiller



For the heat transfer, distillation gases from the MP distiller are used. The utilisation of MP distillation gas heat saves heating steam and cooling water consumed in the LP condenser. In addition, trays are installed in a mass-exchange section of the LP distiller, which generate two contact areas between the phases. The tray design is patented. The trays ensure a more efficient mass exchange between liquid and gas.

The LP distiller is a small unit, which significantly reduces the number of pipes in the LP distillation section. The proprietary design of the mass-exchange unit ensures highly efficient heat and mass exchange and reduces the urea carry-over to the LP carbamate solution.

The following results were achieved after installing the LP distiller:

- Energy saving of up to 0.05-0.07 Gcal/t
- Reduction of urea content in the LP CAS solution to 0.1% maximum
- Urea content in the urea solution after LP distillation reaches 68%.

The urea solution is delivered from the LP distillation section to the pre-evaporation recovery unit, where under low vacuum the residual ammonia is removed by heat from the MP distillation gases. The recuperative heat exchanger designed by NIIK combines an absorber-condenser and a film-type evaporator in a single vessel. The condensation heat from the first-stage distillation gases in used as an energy source for concentrating the urea solution.

The urea solution is supplied to the recuperator tube-side beyond the existing separator, while MP distillation gases and carbamate solution from the LP condensation section are supplied to the shell-side. A gas-liquid mixture from the recuperator shell-side is delivered to the absorber. Installing the recuperative heat exchanger in the pre-evaporation section results in the following beneifts:

- A reduction of steam heating consumption by a minimum of 0.15 Gcal/t
- An increase in the ammonia stripping rate from the urea solution from 80-83% to 97%
- Ammonia content in the urea solution in the pre-evaporation section of 0.1%
- Reduced consumption of cooling water in the flushing column.

At present, four LP distillers designed by NIIK are in operation at two facilities in the FSU. The guarantee performance tests have been performed successfully. Recuperative heat exchangers were installed in the pre-evaporation section and are now operating in six urea plats. The estimated energy savings and other performance criteria have been achieved.

The use of the full *URECON 2006* concept in revamps of urea plants with TLR may result in an increase in capacity from 270-400 t/d to 500 t/d, at the same time reducing energy consumption by 25% and enhancing the reliability and safety of the plant operations.

Further advances

The *90 bar* stripping technology is an advanced approach to energy saving in urea plants. NIIK's activities are not limited to revamps of existing urea plants but embrace other advances in urea technology. The technology used in the *90 bar* stripping concept embraces several energy-efficient technologies, including the effective design of vessels (synthesis reactor, distiller, desorber, etc.) and the utilisation of process internal heat for process needs. The technology also incorporates a highly efficient 200 bar urea reactor, a partial 90 bar CO_2 stripping facility with further gas

Fig 3: **NIIK synthesis and distillation sections**

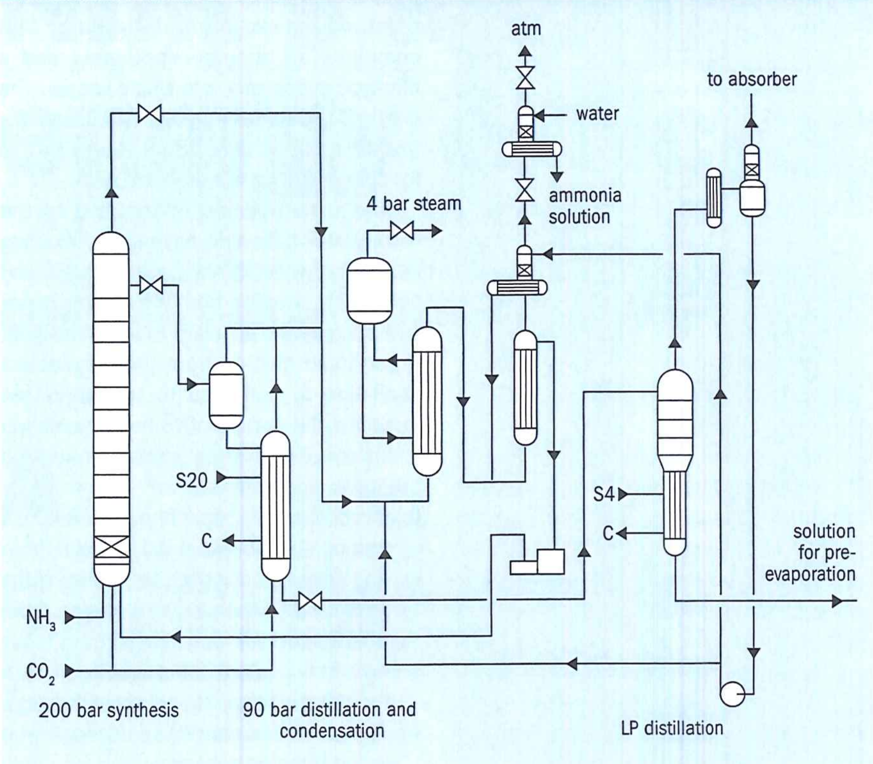


Table 1: **NIIK urea technology utilities consumption**

Utilities consumption	Unit of measurement	Values
Steam	Gcal/t	0.46-0.79*
Power	kWh/t	175/33*
Cooling water	m³/t	87/107*
General energy consumption in terms of natural gas	m³/t	184/195*
	GBTU	6.6/7.0*

** If compressor with steam drive is used*

Table 2: **Results achieved with NIIK revamp**

Parameter	Before modernisation	After modernisation	Improvement/saving
Capacity (t/d)	1,100	1,500	36%
Consumption:			
Steam (Gcal/t)	1.476	0.692	53%
Power (kW/t) 156.5	156.5	-	
Cooling water	116.5	77.5	34%

stripping in carbamate condensers and CAS recovery to the urea reactor. (Fig. 3)

One of the methods of reducing the load in the HP distillation section is multiple melt separation before its delivery to the stripper. The melt is primarily separated in the reactor. Because of the removal of surplus gaseous ammonia in the reactor, heat loss is reduced during throttling. As a result, the melt has a higher temperature when it is supplied to the distiller, thereby reducing steam consumption in the stripper.

The main criterion for estimating stripping process energy efficiency is the optimisation of the ratio between the efficiency of internal heat utilisation and the efficiency of stripping the unreacted components. One of the best methods for utilising the internal heat is to generate low steam for its further utilisation in the urea process.

A maximum 4-bar low steam used for the urea plant's internal needs seems efficient to meet the process and economics criteria. NIIK engineers calculated the optimal distillation for the process with 200 bar synthesis, based on the ratio between general steam consumption and the size of the heat exchanger, as being 90-95 bar.

The gas removed in the HP distillation section is condensed in two cascade carbamate condensers. Gas from the synthesis section is also delivered there. During the condensation process in the first condenser, low 4 bar steam is generated in the shell side. In the second condenser, the condensation heat is removed by the cooling condensate.

The efficient removal in the distillation section under 90 bar pressure means that a single LP distillation section (3.5 bar pressure) is quite sufficient and eliminates the need for MP distillation equipment and any associated energy consumption (steam, cooling water, power, etc.). Steam generated in the HP carbamate condenser is utilised in the LP distillation section, the first-stage evaporation section, desorber, etc., improving the energy efficiency of the process.

In addition, the NIIK process uses heat recovery of other process flows – for example, stream condensate heat for liquid ammonia heating and cooling, and water cooling supplied for flushing the tail absorbers. Table 1 shows the utilities consumption that can be achieved.

Depending on the energy source, its cost and other preferences, either a compressor with electric drive or one with a steam drive can be used. In terms of general energy consumption, the electric drive is more efficient, especially as NIIK's technology involves very low steam consumption.

90-bar stripping can furthermore be used in urea plants with TLR. In the case of two or four urea units, they can be incorporated in a 90-bar distillation section, providing a total capacity increase of up to 60% and a reduction in energy consumption of 50%. These results can be achieved because a significant part of the urea solution is processed in the HP stripping section, allowing the stripping gas heat to be utilised to generate low steam for use in the internal process. The load on the MP distillation section of each urea unit is significantly reduced. Table 2 shows the results achieved when a plant is revamped.

Most of the NIIK technologies described above have been successfully implemented and many existing urea plants in the FSU countries have been revamped based on NIIK's concepts. ■