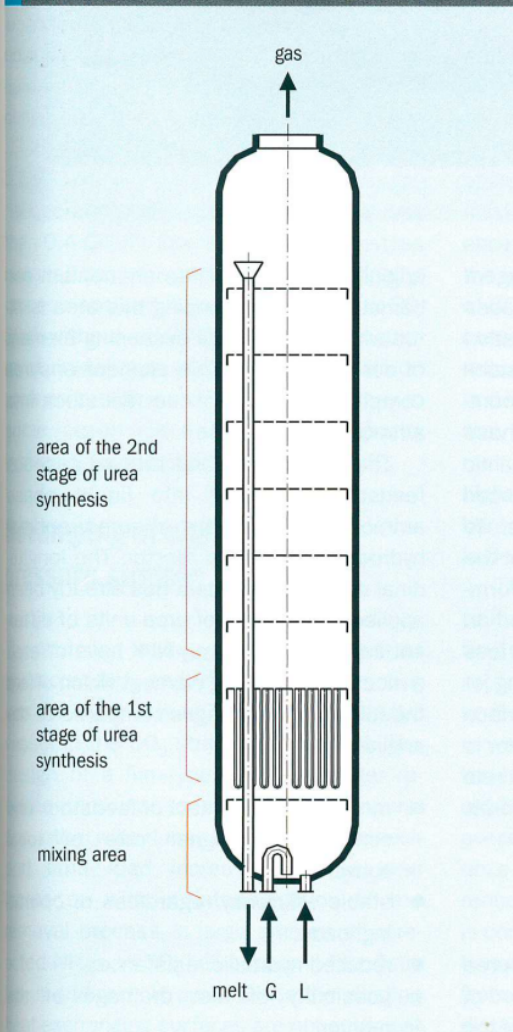


Changes to the urea synthesis section of a urea plant can improve output and plant efficiency with only relatively minor modifications to the vessel internals. JSC NIIK describes the results of laboratory and field studies.

Revamping urea plants for increased production and efficiency

Fig 1: Operating areas of a urea synthesis reactor



JSC NIIK (Research and Design Institute of Urea), with 55 years of experience in design of new and revamping of old urea production units, has a series of new developments aimed at increasing capacity and saving energy. One of the basic elements in the revamping concept developed by NIIK is the modernisation of the synthesis unit. This unit is the most important part of a urea plant, as its efficiency determines the recycle ratio of unconverted feedstock, and thus energy consumption of the production unit. Enhancing the efficiency of the synthesis unit not only improves operation parameters, but also increases final product output.

There are several possible urea production flow-charts, but in this article we will focus on high pressure synthesis via the CO_2 stripping process. For this type of plants NIIK offers revamping of the synthesis section without significant capital investments. Revamping does however require a short shut down of the production plant. The equipment revamped includes: the urea synthesis reactor; the high pressure stripper; the high pressure carbamate condenser; the high pressure scrubber, and the high pressure ejector.

Modernisation of urea synthesis reactor

This measure is aimed at increasing the urea synthesis and improvement of the conversion rate of CO_2 into urea. It 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 and this makes it possible to put more load on sections processing unconverted components.

The concept of revamping is via the sectioning of the synthesis reactor. This concept has been applied in numerous experimental trials in column-type reactors. Sectioning is one of the easiest to implement and the most efficient way of generating hydrodynamic conditions close to the ideal displacement mode.

Depending on the process, the synthesis reactor can be divided into three operating areas (Figure 1):

1. Mixing area of the original reagents.
2. 1st stage urea synthesis.
3. 2nd stage urea synthesis.

Figs 2 & 3: Simulated service tests on popular mixers

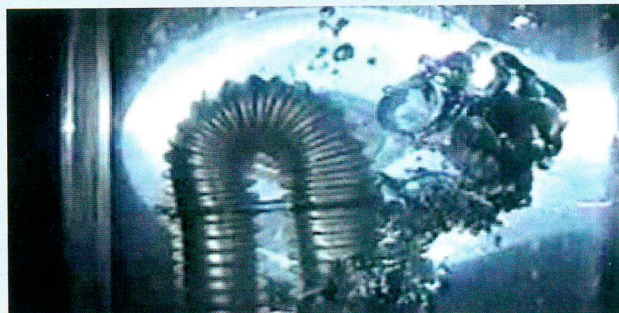
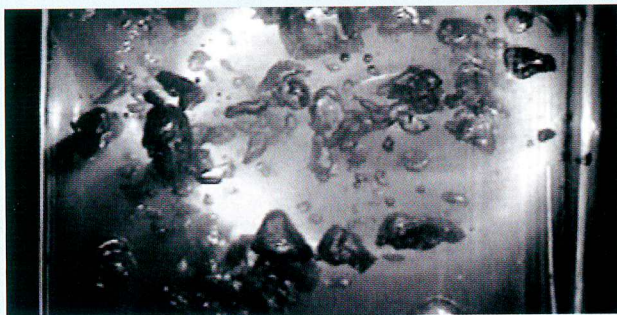
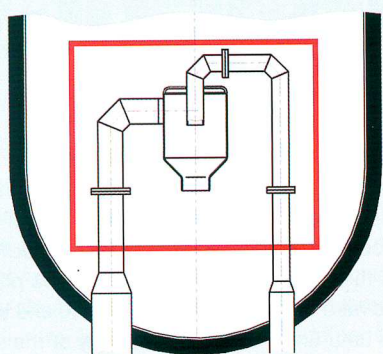


Fig 4: Improved mixing using high performance vortex



Mixing area

In the mixing area the initial dispersion of the gas takes place as well as formation of a liquid – gas mixture. This area includes the existing feeding nozzles and mixing device, the design and configuration of which is determined by original designer and manufacturer. It should be noted that the design of the mixer is very significant because its efficiency is decisive for conversion of the original feedstock into ammonium carbamate. In order to achieve this, the mixer should have the following features:

- to set conditions at the reactor inlet for efficient contact of phases so as to approach ideal mixing as closely as possible, excluding stagnant areas;
- to ensure intensive dispersion of the gases in order to form a homogenous small bubble structure in the liquid-gas flow and extended interphase surface.

Tests of different internal mixers applied in urea synthesis reactors led to the conclusion that not all of them

ensure the necessary degree of reagent mixing (Figures 2 and 3). In some cases the conditions result in increased duration of the first stage of reaction, and feedstock is dispersed in the reactor space amounting to a longitudinal mixing effect. These processes are the reason for hydrodynamic failure in the reactor and further reduced efficiency of the synthesis process. To ensure efficient mixing of feedstock at the reactor inlet NIIK offers a high performance vortex mixer with a design based on intensive gas dispersion due to the loss of hydrodynamic stability of the swirling jet (Figure 4). In this case the contact surface of phases generated by the vortex mixer is 1.5 – 2 times higher and the utilisation rate of the mixing column volume reaches 90% (against 30% for standard mixers.).

First stage of urea synthesis

The area where the first stage of the urea synthesis reaction takes place is aimed at ensuring maximum reliable bounding of the

original components into ammonium carbamate. During revamping this area is fitted with a longitudinal sectioning element of our own design. This element ensures complete bounding of the feedstock into ammonium carbamate.

The high speed and rate of gaseous feedstock bounding into liquid phase ammonium carbamate ensures optimal hydrodynamics in the reactor. The longitudinal sectioning element has already been applied in a number of urea units of different capacities. Recently NIIK have offered a modified sectioning element which offers the following advantages compared to the original:

- more efficient contact of feedstock and consequently higher rate of local conversion;
- stable efficiency regardless of operating loads;
- reduced hydraulic resistance;
- possibility of fast drainage of the reactor.

Second stage of urea synthesis

This area is aimed at ammonium carbamate dehydration, with formation of urea. To achieve the maximum efficiency of the reactor this area is equipped with sieve trays designed to eliminate longitudinal mixing, equalize velocity profiles of ascending movement of phases and to increase the interphase surface. In each particular case trays are calculated to achieve uniform velocity profiles in both longitudinal and horizontal sections of the reactor because these measures ensure that the hydrodynamics of the reactor are close to optimal.

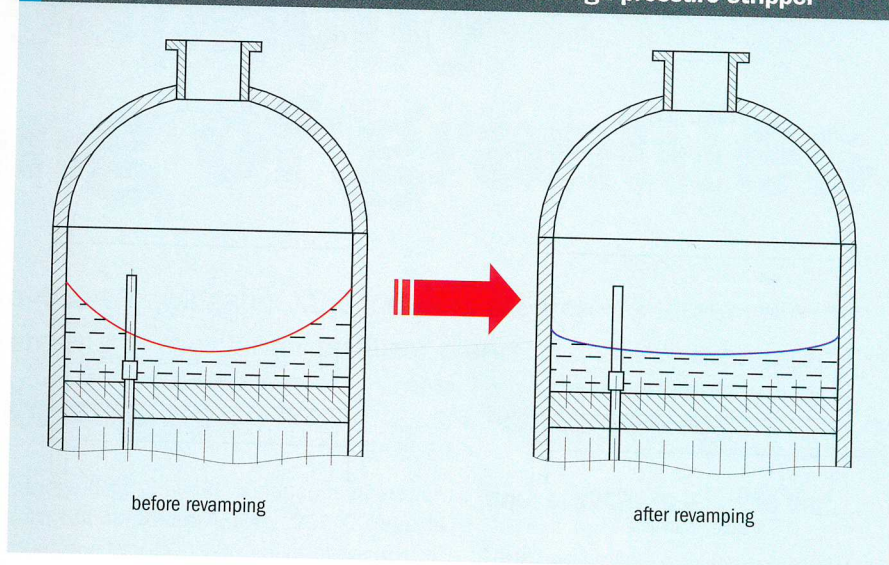
NIIK's overall scheme for revamping the urea synthesis reactor therefore includes equipping the bottom part with a vortex mixer and improved longitudinal sectioning element and the remaining internal space of the reactor is sectioned with sieve trays. These internal devices are protected by patents and have proved their efficiency in experimental trials and commercial applications, and are now installed on 15 urea units in Russia and the CIS of varying technologies.

In one case, introduction of the internal devices on two urea units with a capacity of 1,500 t/d each has ensured an improved conversion rate in the synthesis reactor of 3%. This increased unit capacity up to 1,650 t/d. The steam saving with a nominal operating load was improved by not less than 0.4 Gcal/t. The set of internal devices installed on urea units with a CO₂ stripping process ensures a capacity increase of 20-30% without additional expensive equipment. Installation of the same internals on urea units with a total liquid recycle may in some cases result in an 85% capacity increase, from e.g. 270 up to 500 t/d.

Revamping of high pressure stripper

The stripper is designed for removal of unreacted NH₃ and CO₂ and their recycling into the synthesis unit. It is the most vital vessel in the CO₂ stripping flow chart. The design of a film-type heat exchanger requires particular conditions while in operation, otherwise it may become a bottleneck and limit load increases. If the load increases without intensification of the removal process, a large amount of unreacted NH₃ and CO₂ will appear in the distillation and recycle units. Since the existing heat exchanging surfaces are not sufficient

Fig 5: Revamping of liquid distribution unit in high pressure stripper



for condensation of additional volumes of NH₃ and CO₂ it is evident that further load increases will be limited by the pressure increase in the recycle unit. That is why stripper operation improvement is one of the most critical tasks to be solved for capacity increase of the whole urea production unit.

One of the most influential factors in stripper efficiency and capacity and consequently the unit itself is even distribution of liquid along the heat exchanging tubes. According to the well known interdependence formula, a 10% deviation of load in the liquid results in a 2.5% load difference of CO₂ and a change of residual ammonia content in the synthesis melt by 1.5%. If refluxing in one third of tubes is 30% less and in another third is 30% higher than normal, the overall content of ammonia in the melt drained from the unit will be 1.5% higher. This means that an increased number of tubes with improper refluxing results in degradation of the process efficiency.

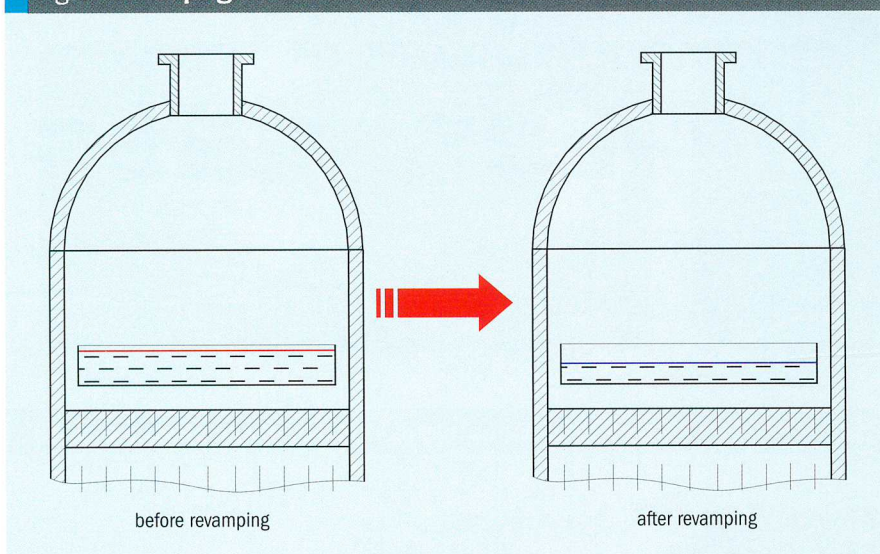
Theoretical and experimental results from NIIK's research showed that the real flow of melt across the stripper tube sheet is strongly dependant on the way the melt is fed onto the tube sheet. As the melt moves from the periphery to the centre of the tube sheet there is a liquid level gradient observable, caused by reduction in the overall impulse of the flow due to resistance from the cross flow of gas tubes and reduction in liquid mass flow as the liquid is consumed in refluxing of the tubes. Additional unevenness of the melt level results from feeding melt via a half-ring shaped distributor. At a urea unit with capacity of

1000 t/d height measurement of deposits on the wall of the top distribution chamber and on the gas pipe branches were made. After processing of the collected data it could be seen that the melt level on the tube sheet is significantly lower in the centre than on the periphery. A very sharp level increase is also observed at the wall opposite to the melt feeding nozzle. This is due to fusion of two melt counter-currents from the ends of the distributor. The difference in liquid level on the tube sheet results in uneven distribution of melt along the tubes, since the feed to each tube through the relevant holes depends on the liquid column above these holes.

Researches has allowed NIIK to define the basic parameters affecting liquid distribution across the tube sheet, and based on this they have developed mathematical models that have helped to develop an improved distributor for the melt liquid in the stripper, ensuring more even feeding of all tubes (Figure 5).

The new design will improve the variation in distribution of liquid across the tubes from 8-10% to 1-2%. Thus, without additional metal consumption it becomes possible to increase the vessel's reliability, to eliminate corrosion conditions connected with melt distribution along tubes and to increase the load on the unit. The modified distribution unit has been installed and is successfully operating at a number of urea plants in Russia and CIS. The result of such revamping is a 3-8% increase in rate of ammonia removal and the possibility to increase load on the unit up to 120-130%.

Fig 6: Revamping of distribution unit in HP carbamate condenser



Revamping of HP carbamate condenser

The carbamate condenser is designed for preliminary reacting of feedstock into ammonium carbamate for its further conversion into urea in the synthesis reactor. This vessel also operates as a boiler, converting the heat of ammonium carbamate formation into steam. Distribution devices located in the top part of the carbamate condenser are aimed at:

- separating the feed of gas and liquid phases onto the tube sheet to ensure falling film mode on the heat exchanging tubes;
- an even distribution of liquid and gas phases across the vessel section and along heat exchanging tubes.

Analysis of design peculiarities of existing distribution units showed that the vessel has an extended residence of the liquid phase on the distribution tray due to maintaining a high level. Calculations enabled NIIK to prove that extended liquid phase presence on the tray results in liquid phase temperatures increasing up to 150-160° in the top part of tube bundle before condensation which can lead to intensive corrosion of the underside of the tube sheet. NIIK suggests the installation of a new distribution unit as a substitute to the existing one (Figure 6). This new distribution unit is designed for a load of 1,500 t/d of final product.

The result of carbamate condenser revamping ensures the stable operation of unit with increased loads and elimination of overheating in the top part of tube bundle.

Revamping of HP scrubber

The high pressure scrubber is a very important vessel in the synthesis section as it ensures ammonia and carbon dioxide condensation exiting the urea synthesis reactor. Operational analysis of the scrubber at increased loads (120-130%) showed significant deviations of temperature. Excessive heat load leads to temperature bounds violation of carbon-ammonia salts and gases at the outlet of the unit. Significant heat load on the scrubber is caused by increase in the gas volume at the outlet of the reactor due to the overall capacity increase of the unit. It becomes evident that in this operating mode the existing heat exchanging surface is not sufficient for complete transfer of the heat load.

To overcome this, JSC NIIK suggests extending the heat exchanging surface of the high pressure scrubber by replacing the heat exchanging section with relevant cooling water piping. Revamping of the high pressure scrubber ensures operation at increased loads without limiting the synthesis unit and production unit itself, and hence capacity increase of final product.

Replacement of HP ejector

Due to capacity increases in the synthesis unit in particular and of the entire plant in general the design of the HP ejector does not allow for the passage of the increased flow. JSC NIIK proposes to replace the old HP ejector with a new one, designed for the required capacity of ammonium and carbon ammonia salts flows.

Submerged HP carbamate condenser

One of the alternatives to a HP synthesis unit is a revamp conversion of the carbamate condenser to submerged operation mode. The main design disadvantages of a vertical carbamate condenser are:

- insufficient contact surface between large amount of gas and small amount of liquid;
- process phases take little time in the unit;
- the process is in film mode.

All of these disadvantages are eliminated when the carbamate condenser is converted to the submerged mode. When the gas is bubbled into a liquid phase the gas condensation is very effective, and the temperature and pressure of the gas increase. This improves the contact between 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.

The revamp designated *URECON-2007* by JSC NIIK has several advantages including: maximum use of the active volume of the unit, and absence of circulation areas in 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 feed of the entire amount of fresh carbon dioxide and distillation gases to the synthesis reactor enables a lower W value and higher conversion rate; easy operation of synthesis unit; saving of steam fed to the stripper due to the use of part of the hot distillation gases as the stripping agent.

Conclusion

The measures offered by JSC NIIK are patented and have been successfully implemented at a number of urea units in Russia and CIS with very beneficial results, including final product capacity increasing by 30-40%.

JSC NIIK is ready to provide design and engineering services, package equipment delivery, field and contract supervision and the performance guarantee tests necessary for revamping of high pressure synthesis units of urea production plants operating with several different technologies.