An Inside Job

Vorobiev Alexander and Anderzhanov Rinat, NIIK, Russia, explain how internal urea reactor devices can help to improve efficiency in urea plants.

The installation of internal devices in a urea reactor results in increased CO_2 conversion into urea due to improved flow hydrodynamics. In turn, this leads to the reduction in recycling to the urea reactor and therefore lower energy consumption for decomposition and recycling of unreacted components. Primarily, it is indicated by the reduction of steam consumption at the stripping and decomposition stages.

The most important criteria of urea process efficiency is conversion of CO_2 into urea. The CO_2 conversion rate is subject to several factors; namely pressure, temperature, N:C ratio, water content, W/L, residence time and hydrodynamic regime of solution inside of the urea reactor. However, kinetic and hydrodynamic factors are the key forces influencing CO_2 conversion, and these factors are connected to each other.

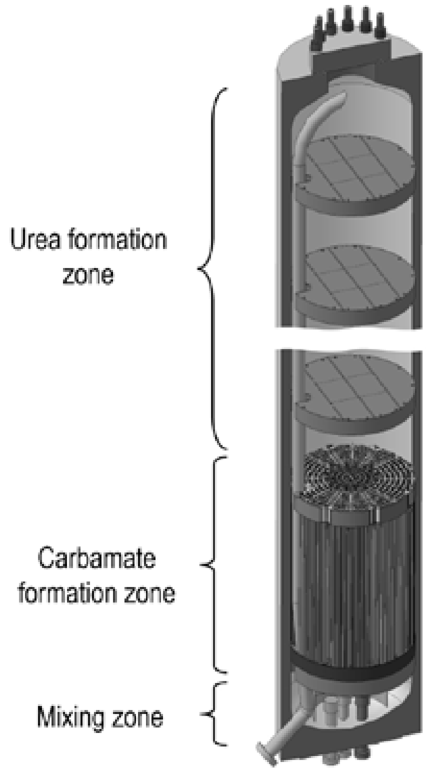

Figure 1. Sectioning of a urea reactor.

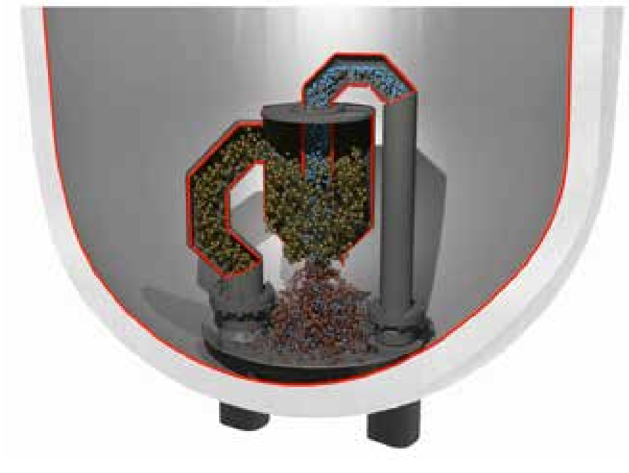

Figure 2. Vortex mixer.

Inside the reactor

NIIK has been studying the flow hydrodynamics of urea reactors for a number of years. Numerous lab studies, field tests and vast operating experience have resulted in the creation of a concept of optimal hydrodynamic regimes in the urea reactor. In these reactors, there are three operating zones with diverse hydrodynamic conditions:

- Mixing zone.
- Ammonium carbamate formation zone.
- Urea formation zone.

Mixing zone

In the mixing zone, gas and liquid are mixed together for a more efficient ammonium carbamate formation reaction. There are different types of mixing devices used for this purpose. A mixing device must meet the following key requirements:

- Ensuring the most efficient media contact at the urea reactor inlet to enhance mixing and exclude formation of stagnant zones.
- Providing intensive gas dispersion to create uniform fine-bubble gas flow and an extended interphase surface.

NIIK conducted simulation tests on different types of mixing devices used in urea reactors. The results of these test revealed the fact that all conventional mixing devices in urea reactors demonstrate insufficient mixing efficiency, relatively poor gas dispersion and have a low utilisation factor of the mixing zone and, ultimately, have a low specific surface of gas-liquid contact.

In order to provide efficient mixing of the feeding components, NIIK designed a Vortex mixer, which operates on the principle of a swirl chamber.

The main features of this mixer are as follows:

- Wide expansion angle for the outcoming flow.
- Intensive gas dispersion.
- No erosive wear of the device since the gas is located near the swirling flow axe. Also a special baffle plate is installed at the bottom of the reactor to protect it from erosion.

Due to the unique design of the Vortex mixer, dispersion of gas into liquid is done more efficiently – the bubbles are much smaller than the ones produced in conventional mixers. In this case, the specific surface of the media contact generated by the Vortex mixer is two times higher.

Formation of ammonium carbamate

The ammonium carbamate formation zone is located in the bottom part of the urea reactor above the mixing zone. This zone is designed for maximum bonding of feedstock into liquid ammonium carbamate.

In a hollow urea reactor, ammonium carbamate formation is performed in a complete mixing regime, which results in back mixing of reaction products with feeding components and ultimately in the reduction of ammonium carbamate speed formation. This is facilitated by the dispersion of feeding components in the reactor by bubbles floating up in the melt.

For this reason, it is important to limit the bubble floating height in the urea reactor and the ammonium carbamate formation zone, bringing it to the plug-flow regime.

The specific capacity of a urea reactor operating in a plug-flow regime is two times higher than the same urea reactor operating in a complete mixing regime.

In order to ensure efficient conditions for ammonium carbamate formation reaction, after efficient mixing of feeding components, it is important that the gas-liquid mix moves in plug-flow conditions, i.e. there should be no axial and cross sectional mixing in this zone.

For this reason, NIIK designed a device that removes axial and cross sectional mixing in the bottom part of the urea reactor and creates plug-flow conditions for reaction products.

This device is the conversion booster, and consists of vertical tubes assembled in the solid structure, which is installed in the bottom part of the urea reactor. The vertical tubes serve as channels. The gas-liquid mix moves up inside the channels in plug-flow conditions, avoiding axial and radial mixing.

Despite efficient mixing of feeding components by the Vortex mixer, gas bubbles may be larger in size at the conversion booster inlet. As a result, the gas will be moving in piston mode, which could impede the reaction. To break down the gas bubbles, there are additional turbulisers installed at the tube inlet.

The operating principle of the turbuliser is based on superposition of acoustic vibrations caused by resonance on gas-liquid flow passing through it. Passing through the turbuliser, the gas bubbles in the flow are broken up into smaller bubbles, which increase the media contact surface and therefore intensify the reaction.

Formation of urea

Since ammonium carbamate dehydration is a slow reaction, the entire volume of the urea reactor above the conversion booster is devoted to this particular reaction. Reverse mixing of reaction products (urea and water) with ammonium carbamate reduces the conversion rate into urea. In order to minimise this reverse mixing, sieve trays are installed above the conversion booster. Since the amount of gas media is reduced throughout the reactor height, the quantity of tray holes is reduced as well to equalise melt velocity profile in the cross section of the urea reactor.

The sieve trays designed by NIIK provide the following advantages:

- Eliminate longitudinal mixing.
- Equalise velocity profiles of ascending movement of phases.
- Increase interphase surface.

Related effect

Internal devices facilitate the efficient operation of the urea reactor even when its specific load is increased.

Installation of the internal devices in the synthesis reactor ensures efficient operation of the synthesis section with an increase in CO_2 conversion. In the case of reactor load increase and preservation of the conversion rate, the internal devices enable the reduction of specific energy consumption in distillation sections due to recycle reduction.

The maintenance of internal devices includes the following activities:

- Visual check during annual turnaround – no special maintenance required.
- Wedge fixed assembled structure – easy and fast pull out/pull back of each part.

Case study

The RCF Trombay urea plant in India was commissioned in 1981. The design capacity of the plant is 1000 tpd. In 2011, 10 original trays in the urea reactor were replaced with new trays. Maximum achieved capacity of the urea plant is 1300 tpd.

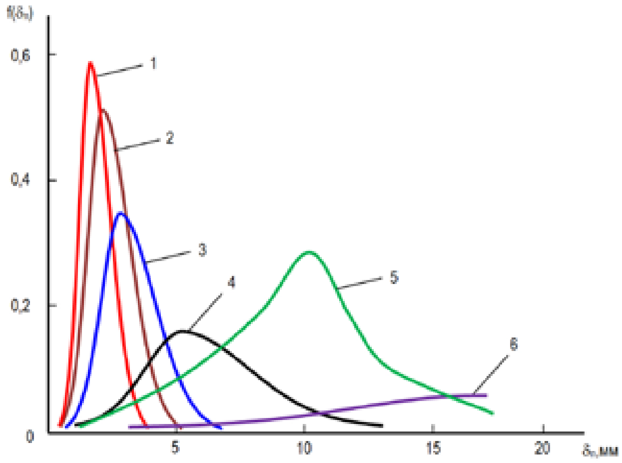

Figure 3. Bubbles size distribution in a mixing zone.

Figure 4. Conversion booster.

Figure 5. Mass transfer trays.

In order to improve the energy efficiency of the urea unit, NIIK proposed to install a Vortex mixer and conversion booster in the urea reactor.

For this particular urea plant, NIIK guaranteed 75 kg/mt of urea 26.8 bar steam saving. As a first step, the parties approved the procedures for a test run and guarantee figure calculation.

Before the internal devices were installed, the parties conducted basic data collection to freeze key operating

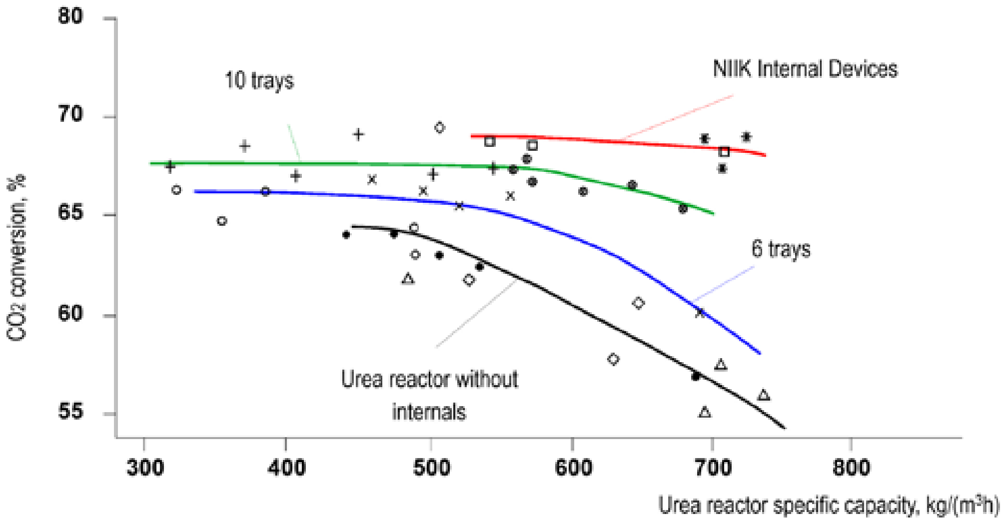

Figure 6. Efficiency of urea reactor when increasing unit load.

Table 1. Schedule of installation works

Number	Works	Working days								
		1	2	3	4	5	6	7	8	9
1	Removal of tray parts; removal of the old mixer	✓								
2	Installation of Vortex mixer; quality control of the welding joints		✓	✓	✓					
3	Installation of the conversion booster				✓	✓	✓	✓	✓	✓
4	Assembly of the trays									✓

parameters of the urea plant, namely consumption of MS steam.

The internal devices were manufactured by a Russian equipment manufacturer. Acceptance of equipment after manufacture was performed in the presence of the third-party inspection authority, Lloyds, which confirmed that the equipment was manufactured in accordance with all quality requirements. Inspection on site did not reveal any deviations.

Before installation of the internal devices, the NIIK maintenance team conducted a corrosion inspection of the bottom of the urea reactor. Permission to start installation works was granted after the parties confirmed that the base metal and welding joints of the reactor liner had no defects.

Erection works of the internal devices were carried out by an Indian vendor under NIIK technical supervision. Before erection, the contractor checked the actual location of the inlet nozzles at the bottom of the urea reactor to exclude any deviations from the reactor drawing and completed mock-up assembly of internal devices on site near the urea reactor.

All welders passed a welding qualification test, after which they received a permit to perform welding work.

Visual inspection and dye penetrant testing of the welding joints were carried out at all stages of erection works.

For installation of the internal devices, the bottom most tray in urea reactor was shifted up and fixed at a higher elevation. This change impacts neither the reaction process nor the maximum load achievement.

The erection of the internal devices was completed in accordance with the schedule, taking just nine days.

One of the key conditions of this project was to maintain the same process parameters and conditions of the urea plant before and after installation of internal devices to the maximum possible extent; namely plant load, steam consumption parameters and cooling water (CW) temperature.

During the guarantee test running (GTR), the urea plant was maintained at a stable condition for 72 hr. During this period, the engineers collected required process parameters of the plant as per the procedure.

Based on 72 hr GTR, the steam saving was 78.4 kg/mt of urea.

The following positive changes were observed during the guarantee test:

- Increased CO_2 conversion rate in the urea reactor.
- Increased urea content in the solution from the urea reactor.
- Reduced load on the carbamate pumps .
- Reduced opening of the valve (low pressure steam to low pressure decomposer).

NIIK has recently installed internal devices at two other facilities in India.

In June 2014, the company successfully completed the modernisation of a urea reactor (Urea Unit-II) at Nagarjuna Fertilizers and Chemicals Ltd with the installation of a vortex mixer within five days.

The following changes were observed during the guarantee test:

- CO_2 conversion rate in urea reactor increased by 0.6% (from 57.2% to 57.8%).
- Urea content in the solution from the urea reactor increased by 0.8%.
- CO_2 conversion rate approached equilibrium state by 0.9%.
- Achieved an average value of medium pressure steam saving of 39 kg/t of urea, and a guaranteed value of 35 kg/t of urea.
- Ammonia pressure before the ejector decreased by 1.0 bar.

- Valve opening at high pressure carbamate pumps was reduced by 1.3%.

In July 2017, NIIK successfully completed the modernisation of the urea reactor at Gujarat Narmada Valley Fertilizers & Chemicals Co. (India) (GNFC) with the installation of Vortex mixer.

The following changes were observed during the guarantee test:

- CO_2 conversion rate in urea reactor increased by 3.3% (from 55.2% to 58.5%).
- Urea content in the solution from the urea reactor increased by 1.8%.
- Achieved an average value of medium pressure steam saving of 31.6 kg/t of urea, and a guaranteed value of 25 kg/t of urea.
- Load on the carbamate pumps decreased from 97.4 to 89.9 rpm.

Presently, 10 Vortex mixers, 16 conversion boosters and 12 sieve trays have been installed into urea reactors belonging to Saipem, Stamicarbon (stripping, total liquid recycle) and Tecnimont.

Conclusion

There is always scope for increasing energy efficiency of urea production units, and this can be achieved by implementing simple but effective technical solutions with relatively low capital investments.

The installation of NIIK's internal devices in a urea synthesis reactor increases the efficiency of the operation. It enables the conversion of carbon dioxide into urea to be increased, the amount of unreacted components at the outlet of the reactor to be reduced, and results in decreasing energy consumption to separate these components from the finished product and recycle them to the synthesis section. WF