Syngas | Ammonia | Urea | Nitrates | Methanol | GTL | Hydrogen
CRU Nitrogen + Syngas 2016
29th International Conference & Exhibition

The Snamprogetti™ SuperCups Solution

ELMAR LADSTÄTTER, ALEXANDER GUSENBAUER
Borealis Agrolinz Melamine Int. GmbH
Linz, Austria

MUHAMMAD ASLAM, ASHRAF KHAN
Fauji Fertilizer Company Ltd.
Mirpur Mathelo, Pakistan

UGO AVAGLIANO, LINO CARLESSI
Saipem S.p.A.
Milan, Italy

The performance of urea reactors can be improved by the application of the latest generation of internals: the Snamprogetti™ SuperCups.

The proprietary design of such high efficiency trays is a further step ahead to approach the theoretical equilibrium conversion in the urea synthesis.

This paper presents the first world assessment of SuperCups performances achieved since 2014 with the installation and operation in the urea reactors of Borealis Agrolinz Melamine GmbH in Linz (Austria) and Fauji Fertilizer Company Ltd in Mirpur Mathelo (Pakistan).

The increase in the efficiency has permitted direct benefits to the overall day-by-day performances of the units, thus allowing a lower energy consumption and a reduced environmental impact.

THE SNAMPROGETTI™ *SUPERCUPS*

The fluid-dynamics of a urea reactor can be significantly improved by the introduction of the latest generation of internals recently invented and patented by Saipem.

The driving force for innovation has come from the continuous trend toward higher and higher plant efficiency with the aim to optimize the capital investment of the high pressure equipment, decrease the energy consumption and so reduce the environmental impact of plant operation.

The proprietary Snamprogetti™ ***SuperCups*** drastically increase the mixing of the reactants phases, respectively ammonia / ammonium carbamate and carbon dioxide, thus optimizing the product conversion rate in the reactor. The immediate benefit is the lower specific steam consumption requirement to decompose carbamate to CO_2 and NH_3 in downstream sections. Taking into consideration the necessity to minimize the pressure drop across the reactor, the improved mixing is obtained without any increase of compression energy for carbon dioxide.

This represents a further step ahead to get closer to the theoretical equilibrium conversion in the reactor.

DESIGN FEATURES AND WORKING PRINCIPLES

Urea reactors are non-ideal multi-phase plug-flow reactors ("PFR") type equipped with dedicated distributors for the reagents and a number of sieve type trays which consist of perforated plates that prevent back-flow of the heavier solution from the upper part downwards and favour the gas absorption in the liquid phase.

The innovative concept of the Snamprogetti™ ***SuperCups*** lies in the realization of a confined reaction space within the reactor tray geometry, namely the cups. They perform as a number of mixing units where ammonia is contacted with the gaseous CO_2 in small bubbles.

Once the reactants have swirled inside the cups, the mixed solution of product and non-reacted components is uniformly distributed on the upper part of the tray by means of the upper cup distributor. The outlet flow pattern ensures a further mixing of the solution coming from all the cups.

The peculiar behaviour of the ***SuperCups*** is characterized by a triple fluid-dynamic effect – Gas Equalizer, Mixer Reactor and Gas Distributor – which are described here below.

Gas Equalizer

The first effect of ***SuperCups*** is to uniformly distribute the concentration of the light phase reagent on the entire section of the tray. In this way, the gas-like bubbles moving upward "lose the memory" of the non-uniformity of the previous reaction stage and the non-reacted CO_2 can be evenly fed to each cup of the tray.

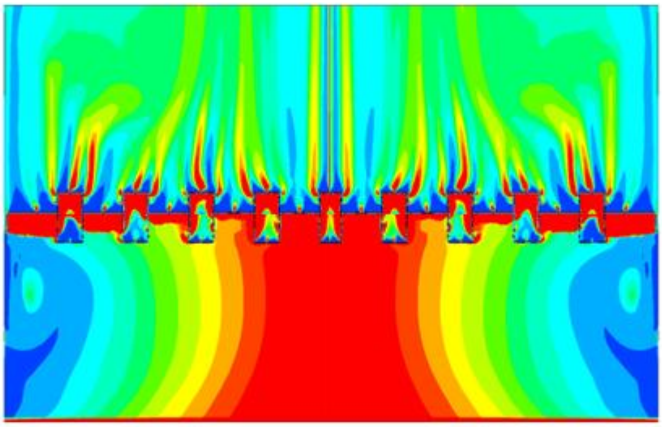

Fig. 1: CFD of *SuperCups* tray showing CO_2 volume fraction

Mixer Reactor

The cups behave as a number of confined reaction volumes in which the multi-phase reagents – carbon dioxide and ammonia/carbamate – heavily swirl inside, thus reaching a high mixing degree. Each cup performs as a static mixer where the phases are strongly contacted (see Fig. 2).

In this way the ***SuperCups*** trays do not simply behave as gas distributors – like the existing commercial high efficiency trays – but perform as additional **active reaction stages** which can be modelled as a Continuous-Stirred-Tank Reactor ("CSTR") in series with the PFR of the stage.

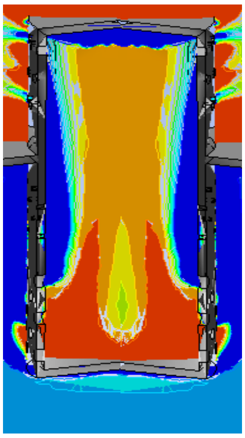

Fig. 2: Mixing reactor effect

Gas Distributor

The CO_2 phase forming the gas-cushion below the tray can be partially streamed inside the cups to create a mixer-reactor and partially distributed on the upper stage by means of dedicated holes. This split range is one of the most critical design parameters since it allows to customize the residence time distribution (RTD) curve of each reactor stage and to increase (or decrease) the CSTR (perfect mixing) or PFR (plug flow) behaviour according to the composition of each stage.

Fig. 3 plots, for several geometries, the RTD curves obtained by simulating a pulse injection of tracer at the inlet boundary and detecting the outlet concentration as function of time.

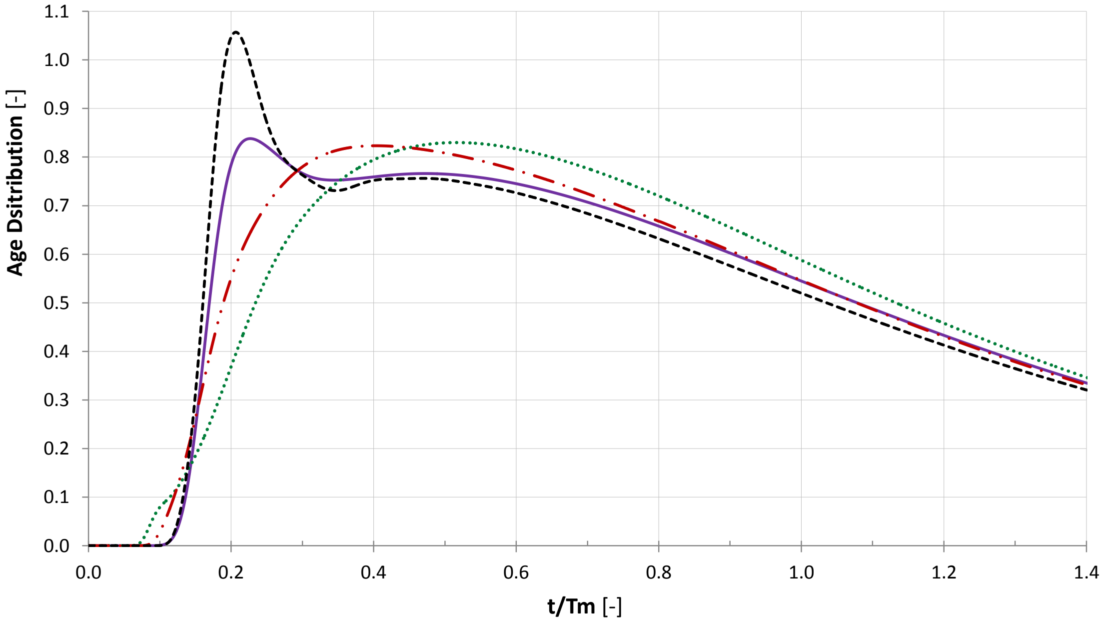

Fig. 3: RTD curves for several types of tray design

PERFORMANCE ASSESSMENT

After development of the innovative design, thanks also to the support of a comprehensive CFD study and of a mechanical assessment for constructability review, Saipem has decided to directly test on field the new technology before the commercial launch. Therefore, a joint collaboration agreement was set with two of its historical partners, Borealis Agrolinz Melamime International GmbH (Borealis) and Fauji Fertiliser Company Ltd (FFC).

The first performance assessments of the new ***SuperCups*** trays have been carried out in the year 2014 with a twin test in the urea plants, respectively, of Borealis located in Linz (Austria) and Fauji sited in Mirpur Mathelo (Pakistan).

This paper presents the results found along one year of operation after adoption of the new technology.

Operation and Results in Borealis

Borealis is a Vienna-based leading provider of innovative solutions in the fields of polyolefin, base chemicals and fertilizers, operating production plants in 10 countries and employing 6,500 employees all over the world.

In Linz (Austria), Borealis operates production facilities for melamine with a capacity of 50,000 metric ton per year (MTPY), fertilizers like urea, complex fertilizers (NPK) and calcium ammonium nitrate (CAN) as well as technical nitrogen products like technical grade ammonium nitrate and guanidine carbonate (1,500 MTPY in total), making Borealis the second-largest producer of melamine and market leader in fertilizers in the Danube region.

The urea plant in Linz is based on Snamprogetti™ process and currently produces approximately a total of 400,000 MTPY of urea.

The urea unit is supplied with ammonia and carbon dioxide produced on site and feeds two melamine plants (one high pressure and one low pressure process), thus forming a highly integrated plant network.

Installation of SuperCups during 2014

During plant shut-down in April 2014 (SD-2014), two ***SuperCups*** trays have been installed in the urea reactor as additional items.

The new trays have been designed keeping the same sector assembly of the original ones with a central man hole cover and have been positioned between the existing trays 10 – 11 and 11 – 12 where spacing was higher than the upper trays, resulting in an evenly spaced tray alignment as shown in Fig. 4.

No other modification relevant to the synthesis section of the urea plant was carried out during the plant shut-down.

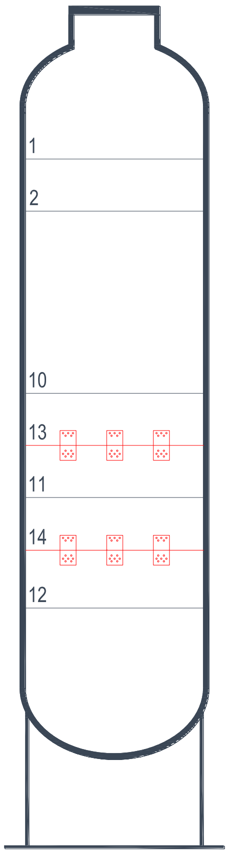

Fig. 4: Sketch of modifications implemented during SD-2014

Plant Performance after Installation of SuperCups

The performance assessment has been carried out by monitoring the high pressure loop and medium pressure steam network of the urea plant in a wide time frame before and after the installation of the trays.

The first remarkable point in the evaluation of the plant performance after the installation of the new trays comes from the evidence of increased maximum achieved plant capacity.

Table 1 shows the capacity increase after SD-2014 calculated from maximum plant load for an increasing number of subsequent days.

Table 1
Plant Capacity Increase after installation of two SuperCups during SD-2014

	5 day average	21 day average
Capacity Increase [%]	**2.2**	1.9

Urea Reactor Performance

Another part of the performance assessment consisted in the analysis of the urea reactor outlet stream composition before and after the trays installation.

Analytical data of the reactor outlet composition shows that the installation of two ***SuperCups*** has moved the average operating area of the urea reactor toward higher conversion rates at increased plant loads.

In addition, in order to provide a quantitative indication of the reactor performance at different plant loads, the analytical data relevant to operation before and after the trays installation has been rearranged to obtain the mean residence time (MRT) of the reactor.

The MRT in the reactor has been calculated as ratio between the overall reactor outlet flow rate and the reactor volume; the reactor outlet flow rate has been calculated from plant load and urea mass fraction resulting from reactor outlet analysis. In this way, two sets of data of mean residence time were obtained, describing the reactor performance as a function of plant load before and after the trays installation.

Fig. 5 plots, for each plant load, the difference between the mean residence time before and after the installation, defined as follows:

$$(1) \quad MRT\ Increase\ [\%] = \frac{MRT_{After} - MRT_{Before}}{MRT_{Before}} \times 100$$

It is remarkable that the MRT Increase is higher for higher plant loads, thus showing that, when the reactor is operated in the limiting conditions of very high capacity, the improvement of fluid-mechanics permits to effectively enhance the performance of the reactor.

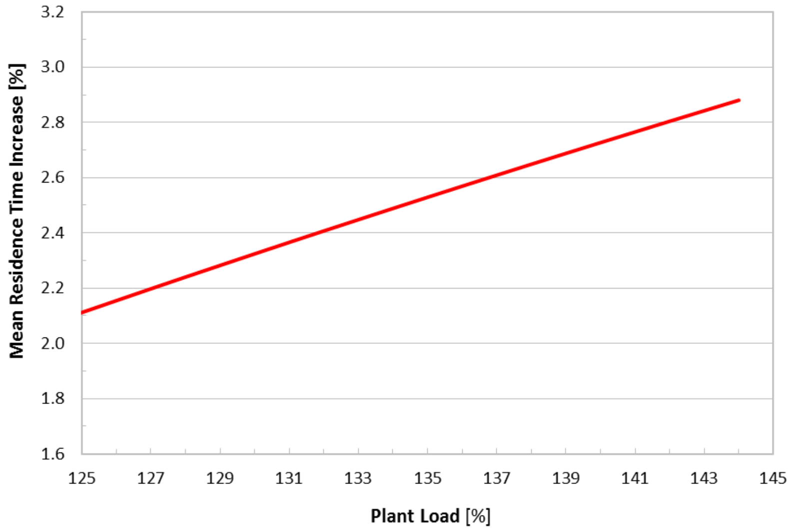

Fig. 5: Increase of MRT after SuperCups installation vs. plant load

Steam Balance

The evaluation of the overall steam duties and consumption figures is based on plant data collected in several series before and after the plant shut-down.

Noticeably, the plant load was increasing after the installation of the ***SuperCups***, while the overall medium pressure steam consumption stayed the same, resulting in a decrease of the specific heat duty by 2.3 % after SD-2014 at the plant capacity of 142 %.

Compared to the energy consumption prior to installation, this lower specific energy consumption results in a net saving of 1.3 t/h of medium pressure steam at maximum plant load.

Based on the specific steam saving found in the assessment, it was also calculated that the theoretical CO_2 conversion increase at reactor outlet is + 0.74 % after the installation of two ***SuperCups***.

OPERATION AND RESULTS IN FFC

Fauji Fertilizer Company Limited (FFC) is one of the largest urea manufacturers of Pakistan. FFC operates three large scale ammonia-urea complexes with aggregate annual urea production capacity of over 2.4 million metric tons.

FFC has vast experience of Snamprogetti urea synthesis technology operation. FFC has been part of the technology evolution process through collaboration in testing and development of Omegabond Stripper technology and testing of ***SuperCups*** urea reactor trays. FFC Plant-III has been one of the earliest testing grounds of both these technologies.

The plant of Mirpur Mathelo was commissioned in 1981 with design urea production capacity of 574,000 MTPY. FFC acquired this plant from Government of Pakistan through privatization program in 2002, and carried out a major capacity revamp in 2008 to increase plant capacity up to 718,000 MTPY (125% of the original nameplate capacity).

The urea reactor originally contained 10 sieve trays of old design. During the capacity revamp, 05 more sieve trays of the latest design were added below the original trays.

Installation of SuperCups during 2014

During last plant turnaround in September 2014 (TA-2014), two of the lowest bottom sieve trays were dismantled and replaced with ***SuperCups*** trays (see Fig. 6). In order to install these trays on the existing support system, a modified design consisting of a C-shaped ring (installed at site) was employed to position, adjust and fix the new trays. Installation time of the new trays was somewhat higher than the sieve trays primarily due to relatively higher weight of the system (ring and tray) and for constraint in cradle movement inside the reactor. The activities were anyhow performed on time.

No other modification was implemented during the plant turnaround – that was mainly dedicated to ordinary maintenance.

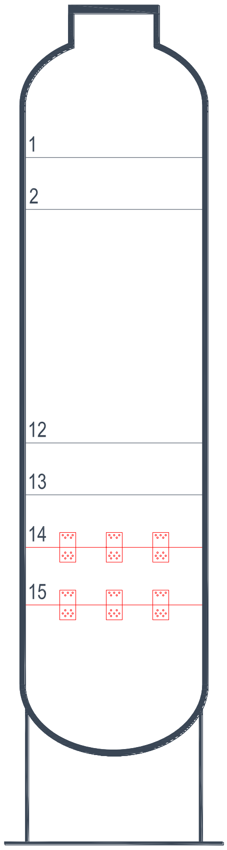

Fig. 6: Sketch of modifications implemented during TA-2014

Plant Performance after Installation of SuperCups

Detailed evaluations have indicated improvements in the reactor performance and HP stripper steam consumption after the installation of ***SuperCups*** trays. Urea reactor conversion has in fact increased with consequent decrease in the HP stripper steam consumption. It is expected that installation of a complete set of ***SuperCups*** in place of the sieve trays shall yield significant benefit in stripper steam consumption.

The first important remark is given by the fact that, after the installation of two new trays, the urea plant has been operated at higher loads. Fig. 7 shows the plant capacity along the whole 2014 up to August 2015 as percentage of original design capacity. The average load after ***SuperCups*** installation has increased by about 4 % with respect to the period before TA-2014, reaching peaks higher than 140%, thanks to the availability of additional natural gas.

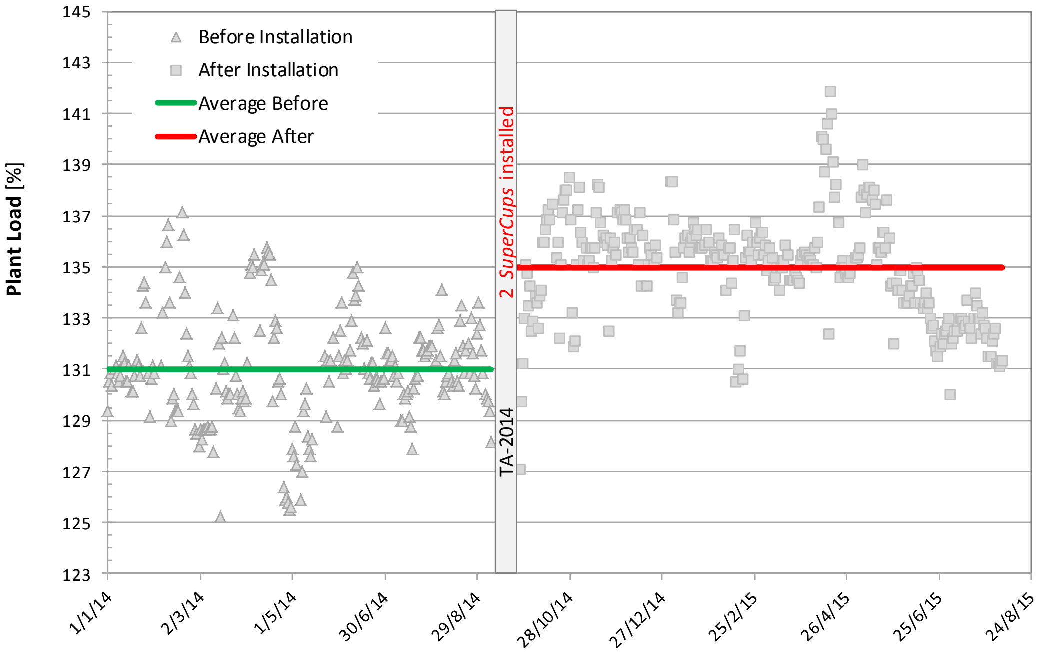

Fig. 7: Plant load before and after SuperCups installation

Urea Reactor Performance

The starting point of the performance assessment consisted in the evaluation of urea reactor outlet stream composition throughout the entire 2014 and up to August 2015, before and after the trays installation.

The map of urea reactor analyses show that the replacement of two sieve trays with two ***SuperCups*** has mostly shifted the operating condition of the reactor toward higher conversion rates at increased plant loads.

In addition, based on the reactor analyses collected at different plant capacities before and after TA-2014, the mean residence time has been calculated as the ratio between the reactor outlet flow rate (depending on analyses) and the reactor volume (as per equation 1). The MRT Increase after the installation of ***SuperCups*** trays has been plotted versus the plant load in Fig. 8.

The MRT Increase grows steadily with the plant capacity and becomes more significant at high loads. In other words, for high capacities, the reactor volume tends to be limiting for the conversion and the improvement of fluid-dynamic patterns through the ***SuperCups*** allows to overcome this limitation and to operate the reactor at increased capacity with enhanced conversion.

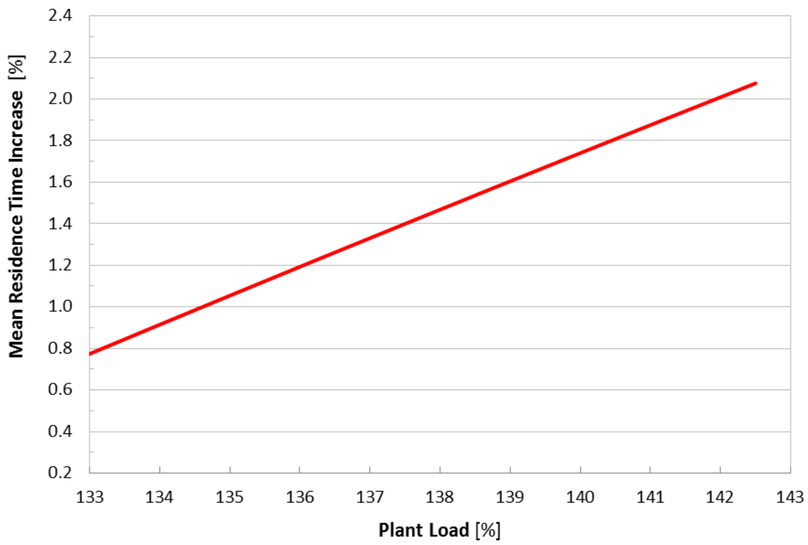

Fig. 8: Increase of MRT after SuperCups installation vs. plant load

Steam Balance

The evaluation of the overall steam duties and consumption figures is based on the plant data collected on a number of dates before and after the plant turnaround of 2014.

Results show that the specific heat duty of each steam user is lower after the installation of the ***SuperCups*** trays and, in particular, the reduction of overall specific duty of medium pressure steam (MS) users is ranging between 1.1 ÷ 1.9 %, corresponding to a direct saving of MS steam from 0.9 t/h to 1.6 t/h.

Obviously the greatest contribution is to be attributed to the urea stripper, however, the reduction of MS consumption in the M.P. Decomposer (via booster ejector) is anyway significant.

Based on the specific steam saving mentioned above, it has been calculated that the theoretical CO_2 conversion increase in the urea reactor ranges between 0.30 % and 0.54 %.

CONCLUSIONS

As of today, the ***SuperCups*** have been comprehensively tested in two industrial facilities before the commercial launch.

The performance of these innovative trays has been assessed by monitoring the plant operation over a wide time frame. The laboratory analyses, the steam balance and the process evaluation of High and Medium Pressure sections all lead to the evidence of an enhancement in the performance of the units that, after the installation of ***SuperCups***, have been operated at increased plant loads with higher reactor yield and lower specific energy consumption.

In addition, at maximum plant capacities, the reactor volume starts to be limiting and the improvement of fluid-dynamic patterns given by ***SuperCups*** allows to push the reactor conversion upwards thanks to the higher mixing efficiency of reactants and to the increased mean residence time.

These operational finding results are even more significant considering that the extent of modifications was limited to two trays only for each unit.

In conclusion, based on its proven features, the ***SuperCups*** represent a completely innovative **reaction device** for urea synthesis that can be advantageously applied to design a new generation of urea reactors as well as to improve the performance of existing equipment in retrofit design.