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Successful replacement of an existing urea reactor in a Toyo plant

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SUCCESSFUL REPLACEMENT OF AN EXISTING UREA REACTOR IN A TOYO PLANT

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1. INTRODUCTION

In 2017, Southern Petrochemical Industries Corporation Ltd. (SPIC) in India requested Stamicarbon to replace their existing urea reactor with a new one in Safurex® material. The old reactor was already at the end of its lifetime, with some major repairs necessary due to excessive leakages during its operation time. The urea plant with a nameplate capacity of 1600 MTPD was licensed in 1974 and uses Toyo technology. With the old reactor, the plant could achieve a capacity of up to 2080 MTPD. There were a lot of process inefficiencies due to the aging of the equipment, which has reflected negatively on the production and overall performance of the plant.

2. REACTOR FEATURES

The old urea reactor was a plug flow reactor with no internals. Its outer shell was made of carbon steel, while the liner in contact with the process was made of titanium. Stamicarbon advised an improved conversion design for the reactor replacement, including High-Efficiency trays and other internals made of Safurex® material.

After delivering the new reactor made of Safurex® to the client's plant site in 2019, Stamicarbon performed supervision services during the installation of the reactor, including final inspection. After start-up, Stamicarbon gave process support and training to the operational staff on the features and improved performance figures of the new reactor.

Since the diameter and length and thus the reactor volume of the new reactor were kept the same, it offered Stamicarbon the opportunity to compare and evaluate the performance of the reactor before and after the replacement. Any improvement in conversion can be attributed to the introduction of the High-Efficiency trays with hardly any modifications in the downstream section. A complicating factor was the absence of the sample point downstream of the reactor in the plant.

In the SPIC plant, a conventional process is applied in which all reactants (ammonia, CO_2 and carbamate) are added to the reactor. The reactants are present in different phases before being introduced to the reactor. Ammonia and carbamate are in the liquid phase, while CO_2 is in the gas/supercritical phase. To achieve proper mixing of these reactants, an inlet gas/liquid mixer is designed.

3. BOOSTING REACTOR PERFORMANCE BY HIGH-EFFICIENCY TRAYS

In all commercial processes, urea is produced by reacting ammonia and carbon dioxide at elevated temperature and pressure in the urea reactor and can proceed up to chemical equilibrium. Because of the equilibrium nature of the urea reaction, the reaction is preferably done in a plug flow reactor.
This conversion is mainly determined by the residence time, reactor volume and sufficient contact between the gas and liquid phases.

Generally speaking, a plug flow reactor can achieved by installing numerous continuously stirred tank reactors (CSTR) in series, which can substantially improve the reaction kinetics. Practically this can be realized by installing a certain number of sieve trays along the reactor length, which divide the reactor into several compartments. In this way, the reactor turns into a bubble column with a torus circulation, which improves the contact between the gas and liquid and increases urea conversion accordingly. The liquid risers are located at a 180° staggered position to ensure a zigzag flow pattern. This flow pattern will increase the path of the fluids along the reactor, thus increasing the residence time and urea conversion consequently (Fig.1).

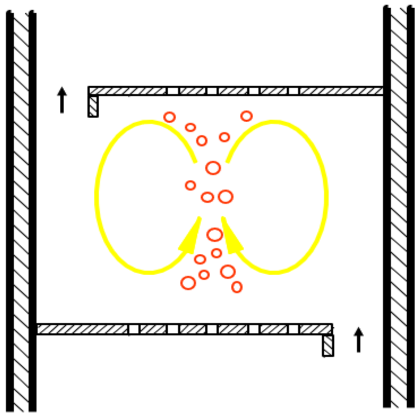


Figure 1: Liquid risers located at a 180° staggered position. Torus circulation in reactor compartments

The condensation of ammonia and carbon dioxide causes the quantity of gas to decrease and the temperature to increase when passing through the reactor. A gas cushion below each tray with a certain height is considered in the design to ensure a sufficient seal between the gas and liquid and avoid the back-mixing effect, which reduces the urea conversion in the reactor. The sieve trays in the top of the reactor have fewer holes than those in the bottom. This ensures that also in the top of the reactor, the cushion of gas present under the sieve trays will prevent back-mixing and thus maintain the plug flow regime. A plug flow in the reactor is a theoretical assumption as the plug flow means there is no back-mixing. In practice, some degree of back mixing is inevitable.

3.1. REACTOR ISSUES

Stamicarbon, the innovation and license company of Maire Tecnimont Group, has developed High-Efficiency Reactor Trays, which have been installed in many urea plants. These trays improve the conversion in the reactor substantially and can solve the common issues in most urea reactors, such as back-mixing, channeling and stagnant zones.

3.1.1. Back-mixing

Back-mixing (Fig. 2a) occurs when the liquid accidentally passes through the gas holes. That normally occurs when no or insufficient gas cushion underneath the tray is present. The High-Efficiency reactor trays, as designed by Stamicarbon, have sufficient gas cushion that will prevent back-mixing from occurring. Back-mixing can also occur due to improper leveling of the tray during the installation which may break or disturb the gas cushion underneath the tray.

3.1.2. Channeling

Channeling (Fig. 2b) normally occurs in reactors with no internals or with conventional trays. Channeling occurs when liquid bypasses the compartment without having proper contact with the gas. As a result, low conversion in the reactor is expected. This issue can be prevented by installing the High-Efficiency reactor trays with a 180° staggered flow path in which a zigzag flow pattern with an optimum gas-liquid contact is ensured.

3.1.3. Stagnant zones

Stagnant zones in the reactor (Fig. 2c) can be an issue for the conversion due to the poor contact between the liquid and the gas, which affects the urea conversion consequently. This issue is also solved with the High-Efficiency reactor trays by having the zigzag flow pattern, which helps avoid stagnant zone formation.

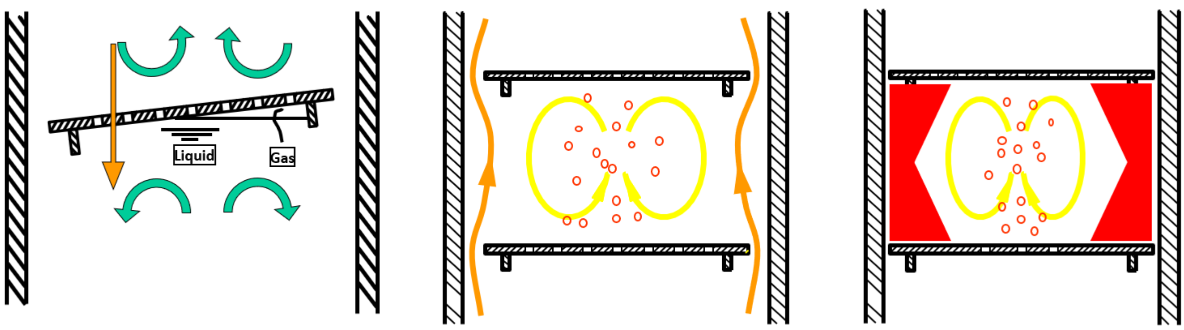


Figure 2: Common issues in urea reactor:
2a) Back-mixing *2b) Channeling* *2c) Stagnant zones*

3.2. GENERAL REACTOR PERFORMANCE

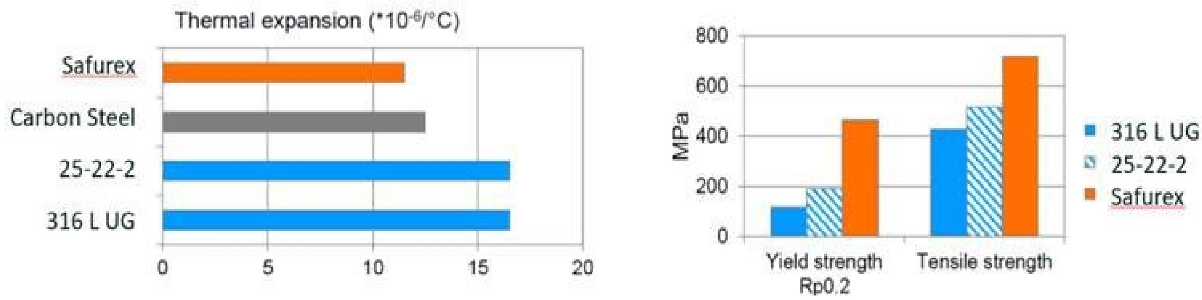
The High-Efficiency reactor trays will increase the conversion in the reactor and hence lower the load on the high-pressure stripper and high-pressure carbamate condenser. This means that the process limits in these equipment items are encountered at a higher plant capacity. The improved reactor conversion is demonstrated by a reduced steam consumption of the high-pressure stripper and reduced steam production from the high-pressure carbamate condenser. Apart from saving energy on the high-pressure stripper, the High-Efficiency Reactor Trays are a possible tool to increase the capacity of the urea plant. The main parameters in the synthesis section are the steam consumption to the high-pressure stripper, steam production from the high-pressure carbamate condenser, N/C ratio in the reactor overflow, CO_2 conversion and the top temperature of the reactor.

4. SAFUREX® AS THE MATERIAL OF CONSTRUCTION

The main advantage of using Safurex® in the high corrosive ammonium carbamate environment are:

- Very low passive corrosion rate in contact with the ammonium carbamate solution
- No or minimum amount of passivation air is required to keep the steel in a passive corrosion state

- Lower risk of active corrosion increases the mechanical reliability and availability of the equipment, improving production output.
- Its superior mechanical properties in terms of high mechanical strength and low thermal expansion, combined with low thermal expansion coefficient, improve the mechanical design and lower the risk of failures.
- The thermal expansion coefficient of Safurex® is almost identical to that of carbon steel, as indicated in the figure below. Therefore, a urea rector made of Safurex® has a much lower risk for buckling of the liner or other types of liner failures.
- Blocking in of the reactor is not critical anymore, providing more flexibility in plant operations.
- Highly reliable construction material with a proven track record of more than 25 years used in more than 250 pieces of high-pressure urea equipment like reactors and heat exchangers.



Thermal expansion coefficient, yield and tensile strength of Safurex® compared to other steel materials

5. PROCESS EVALUATION BEFORE REPLACEMENT

To visualize the differences before and after the reactor replacement, a Stamicarbon model was built to model the “As-Is” situation before the reactor replacement. The as-is balance was used as a starting point to prepare a new balance after installing the High-Efficiency reactor trays. According to the mass balance, the following improvements were expected:

- CO_2 conversion would increase from 59.4% to about 61.2%
- The urea content in the reactor outlet stream would increase from 32.5% to approx. 33.5%
- The amount of carbamate recycle would reduce from 90 m3/h to approx. 80 m3/h
- Due to the higher urea conversion in the reactor, less carbamate would end up in the downstream section. The heat required to decompose the carbamate to gaseous CO_2 and NH_3 would decrease. The steam consumption was expected to be reduced to approximately 4% compared to the current steam consumption.

The predicted promising model figures resulted in the following expectations:

- An increase in the operational flexibility and a reduction in maintenance costs
- Lower steam consumption
- Higher plant capacity preconditioned by feedstock availability and unlimited utility

6. SITUATION AFTER REPLACEMENT

After the reactor replacement and plant start-up, some operational parameters were collected during a plant visit to verify the figures claimed by the model. The main drive was to ensure that the new High-Efficiency reactor trays had the promised added value (Fig. 3 and 4).

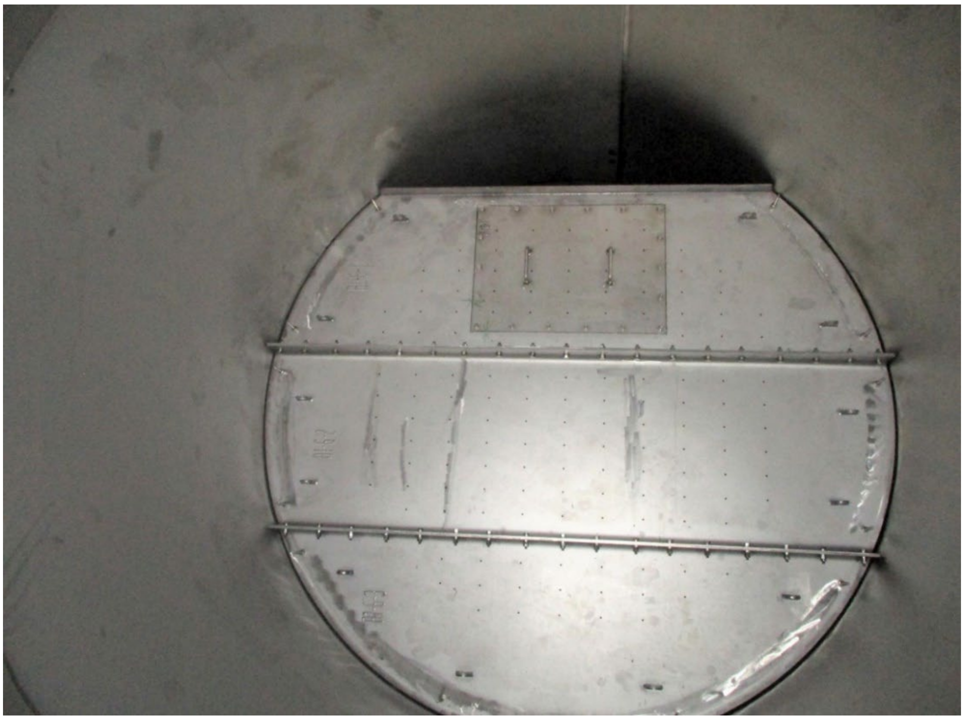


Figure 3: Tray in SPIC reactor

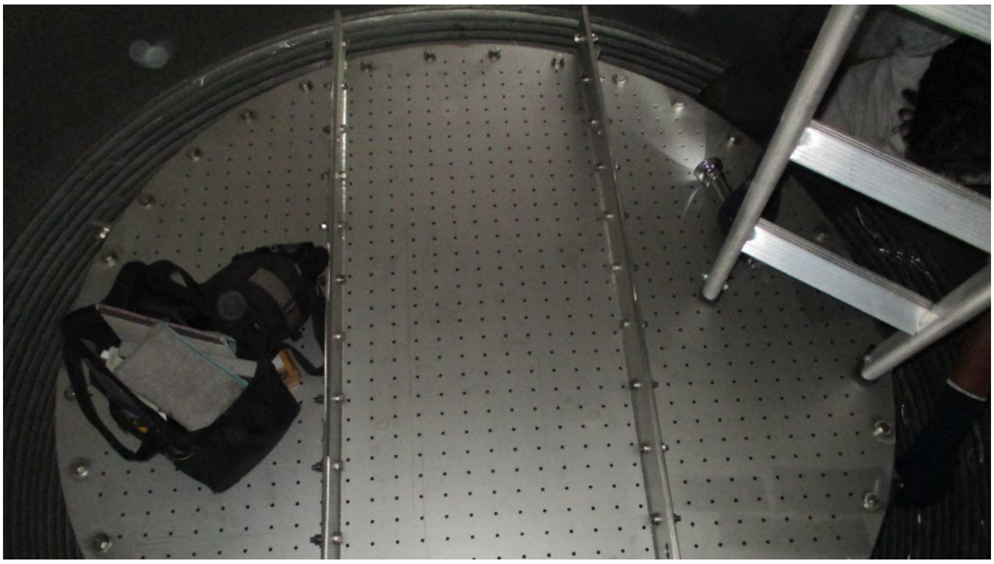


Figure 4: Mixing tray

The plant load achieved a capacity of 5% above the previously reached capacity with the old reactor and increased from 2080 to 2180 MTPD. One of the main influencers that helped increase the plant load was the significant reduction in carbamate recycle. According to the as-is situation, around 103 t/h was recycled back to the reactor. According to the SPIC operation team, this carbamate recycle rate has reduced through recent years to 90 t/h. After reactor replacement, due to the higher urea conversion, a carbamate recycle as low as 78 t/h could be achieved, a reduction of 13%.

Based on the lower carbamate recycle, the lower steam consumption was expected. After starting the plant, a steam reduction of about 4% could be achieved, as predicted by the Stamicarbon model. The reduction in steam consumption is considered a great benefit in OPEX. The steam consumption can be improved further by increasing the efficiency in the downstream section.

Since the material of construction of the liner (wetted parts) was changed from titanium to Safurex®, which allows operation at a lower passivation air flow rate. This flow reduced about 38% compared to the old reactor. This reduces the inert pressure in the reactor, increases the reactor outlet temperature, and consequently increases the urea conversion in the reactor.

7. CONCLUSIONS

With this operational example, Stamicarbon could quantify the added value of installing the High-Efficiency reactor trays in non-Stamicarbon plants. The benefits of installing these trays in this specific plant could be clearly demonstrated.

The process benefits of installing the High-Efficiency reactor trays in this project are :
- Higher urea conversion
- Less carbamate recycle
- Lower steam consumption
- Higher plant output

The mechanical benefits of using Safurex® as the material of construction for the liner are:
- Increases the reliability and availability of the reactor due to the excellent corrosion resistant properties
- Lowers the OPEX costs due to less maintenance and lower inspections costs
- Lowers the O_2 content in the plant, resulting in improvements in plant performance and output
- Creates higher flexibility in plant operations and during upset conditions

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