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Mechanical aspects of the pool reactor for the Ultra-Low Energy plant

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MECHANICAL ASPECTS OF THE POOL REACTOR FOR THE ULTRA-LOW ENERGY PLANT

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Author(s)	Mark Wagemans
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TABLE OF CONTENTS

1. Abstract 3
2. Introduction and background 3
3. Process description of the Ultra Low Energy Design Design 4
4. Considerations for the Pool Reactor Design 5
4.1. Mechanical design... 5
4.2. Fluid flow analysis in distribution channel 7
5. Operational experiences with pool reactor 8
6. Conclusions 9

1. ABSTRACT

The Ultra-Low Energy urea plant concept (part of Stamicarbon's LAUNCH® MELT™ series) launched during the Stamicarbon Symposium in 2012 as 5XX design, is designed, constructed and successfully put into operation for two grassroot plants in China since the beginning of 2021. Both plants have a similar nameplate capacity of 2334 MTPD urea. To date, two more Ultra-Low Energy grassroot plants are under construction and are expected to be in operation in mid-2023.

The Ultra-Low Energy Design for a melt plant with prilled product results in the steam consumption (23 bara, 330 ºC) ≤ 560 kg steam/ton product compared to traditional Pool Reactor Design (former Urea 2000plus™) ≤ 870 kg steam/ton product.

This paper highlights the design aspects and the operational experiences with the special pool reactor with a dual bundle (steam and carbamate) for the Ultra-Low Energy plant. The paper "Experiences with Ultra Low Energy Design plant operation" highlights the detailed process description.

2. INTRODUCTION AND BACKGROUND

Stamicarbon is a well-known innovative company that has developed several successful concepts for urea plants in the past. These innovations primarily aimed at reducing OPEX without compromising the CAPEX and improving the process safety of the plants, resulting in lower total cost of ownership.

The Ultra-Low Energy Design is the latest Stamicarbon urea process technology, launched at the Stamicarbon Symposium in 2012 and by now contracted for six grassroot plants. This technology is considered a next generation of the Pool Condenser and Pool Reactor Designs (former Urea 2000plus™, now part of Stamicarbon's LAUNCH MELT™ series). It significantly reduces steam consumption and utilizes Stamicarbon's major proven technological developments as listed below:

- Pool condensation in synthesis.
- Applying Safurex® Infinity∞ steel as the material of construction for synthesis.
- Utilizing proven medium pressure recirculation design/operation.

This paper is restricted to the pool reactor concept since to date several Ultra Low Energy (ULE) concepts have been materialized and are explained in this paper.

The traditional urea processes were based on the so-called N=2 heat integration concept, in which the heat supplied to the urea plant in the form of extraction steam from the steam turbine is used twice. The first time this steam is used as a heating agent to obtain high stripping efficiencies in the high-pressure stripper. Subsequently, the heat is recovered by condensing the strip gas in the high-pressure carbamate condenser, pool condenser or pool reactor in the synthesis section to produce low-pressure steam used in the sections downstream the synthesis section.

The Ultra-Low Energy Design utilizes an N=3 heat integration concept, in which the heat supplied in the form of high-pressure extraction steam is used three times in the urea plant. For that, generation of vapor by medium pressure carbamate dissociation is required by utilizing the heat from condensing the strip gas in the pool condensation section of the synthesis. Then, the heat of condensation of this medium pressure carbamate dissociation vapor is used to concentrate the urea solution in the evaporation section.

3. PROCESS DESCRIPTION OF ULTRA-LOW ENERGY DESIGN

The synthesis section of the Ultra-Low Energy Design process according to the pool reactor concept is represented in Figure 1.

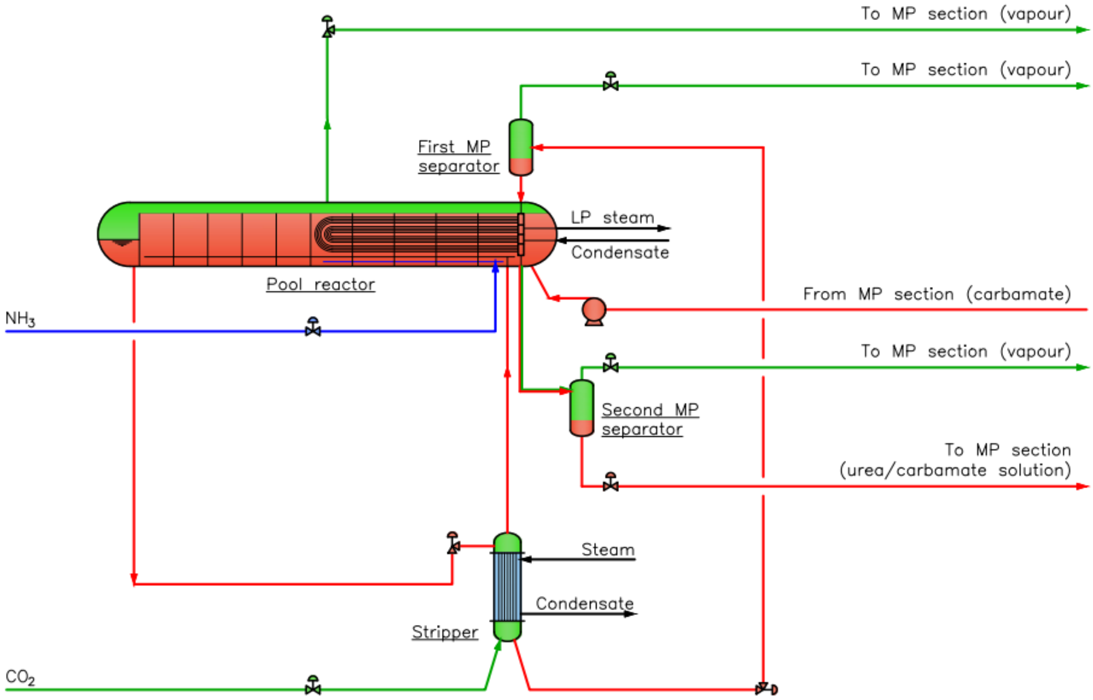

Figure 1: The synthesis section and connected medium pressure equipment of the Ultra-Low Energy Design

As illustrated in Figure 1, the synthesis for the Ultra-Low Energy Design process as implemented in four grassroot pool reactor plants includes only two high-pressure equipment items (high-pressure stripper and pool reactor). The medium pressure separators and the high-pressure carbamate pump are part of the medium pressure section.

Essentially it is similar to the synthesis of Flash Design consisting of a high-pressure stripper and a pool reactor, without a high-pressure scrubber. The high-pressure scrubber is not required in the Ultra-Low Energy Design either. However, a closer look at the pool reactor reveals that the U-tube bundle has two separate sections and is handling two different fluid mediums (steam/condensate and a urea and carbamate solution/carbamate dissociation vapor), which have been incorporated in the shell side of the pool reactor. The inner part of the bundle is called ‘steam bundle,’ which is used for generating low-pressure steam as is commonly found in Stamicarbon pool condenser and pool reactor plants.

The outer part of the bundle, referred to as the 'carbamate bundle,' is used for heat integration with the medium pressure recirculation section. On the shell side of this bundle, condensation of strip gas releases heat (at about 144 bara and 175 °C), which is used to decompose carbamate into ammonia and carbon dioxide at the tube side. Consequently, the tube side of this tube bundle in the pool reactor functions as a medium pressure rectifying heater. By integrating these two functions without any intermediate heat transfer medium, the available temperature difference between both process sides allows the bundle to be relatively small.

4. CONSIDERATIONS FOR POOL REACTOR DESIGN

A dual bundle has been integrated into the pool reactor to establish the N=3 concept without compromising on CAPEX. For this concept, we fully utilized the superior corrosion-resistant properties of Safurex® Infinity∞ steel by simplifying the design. The proprietary design is patent-protected.

4.1. MECHANICAL DESIGN

One of the challenges was designing the pool reactor that allows corrosive media on the shell side and the tube side. One way was to build the internal tube sheet out of Safurex® Infinity∞ steel as the material of construction. Compared with the conventional pool reactor or pool condenser, the tube sheet, together with its distribution channels, is built inside the pressure vessel. The tube sheet thickness for a conventional pool reactor is typically about 500 mm. The big advantage of installing the tube sheet inside the vessel is that it requires a much thinner tube sheet. Figure 2 represents the differences in tube sheet configuration and connecting distribution channels.

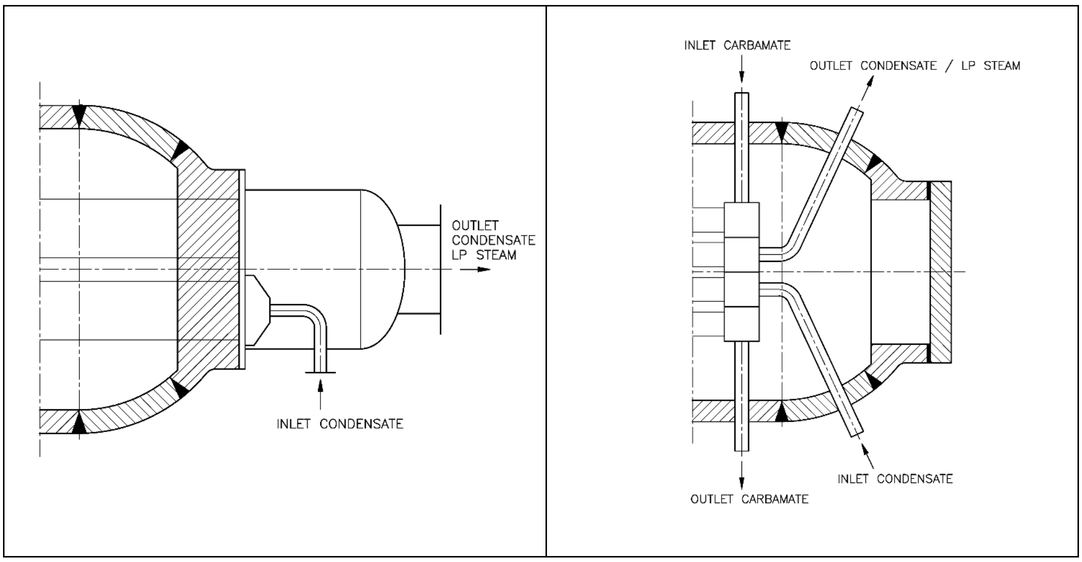

Figure 2: The difference in tube sheet configuration between the conventional pool reactor or pool condenser and the pool reactor for the Ultra-Low Energy Design

All the process fluids at the tube sides are collected in a distribution box and connected to the external equipment nozzles via high-pressure piping. This enables the construction of the tube sheet and distribution channels entirely from a lower thickness of the Safurex® Infinity∞ steel plate, avoiding the thick weld overlayed carbon steel tube sheet. More than that, the tube-to-tube sheet welding replaces the special inner bore welding technique, utilizing the common fillet weld design as is used, for example, in the stripper tube-to-tube sheet connections.

The conceptual layout of the pool reactor with a dual bundle is shown in Figure 3.

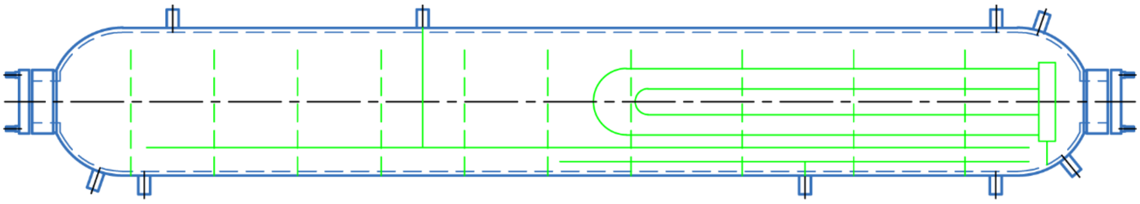

Figure 3: Concept layout of the pool reactor for the Ultra-Low Energy Design

The tube bundles and the internals of the distribution box are accessible through the manway by opening the internal covers and thus enabling NDT (Non-Destructive Testing) inspection without restrictions and without dismantling of heavy parts, as represented in Figure 4.

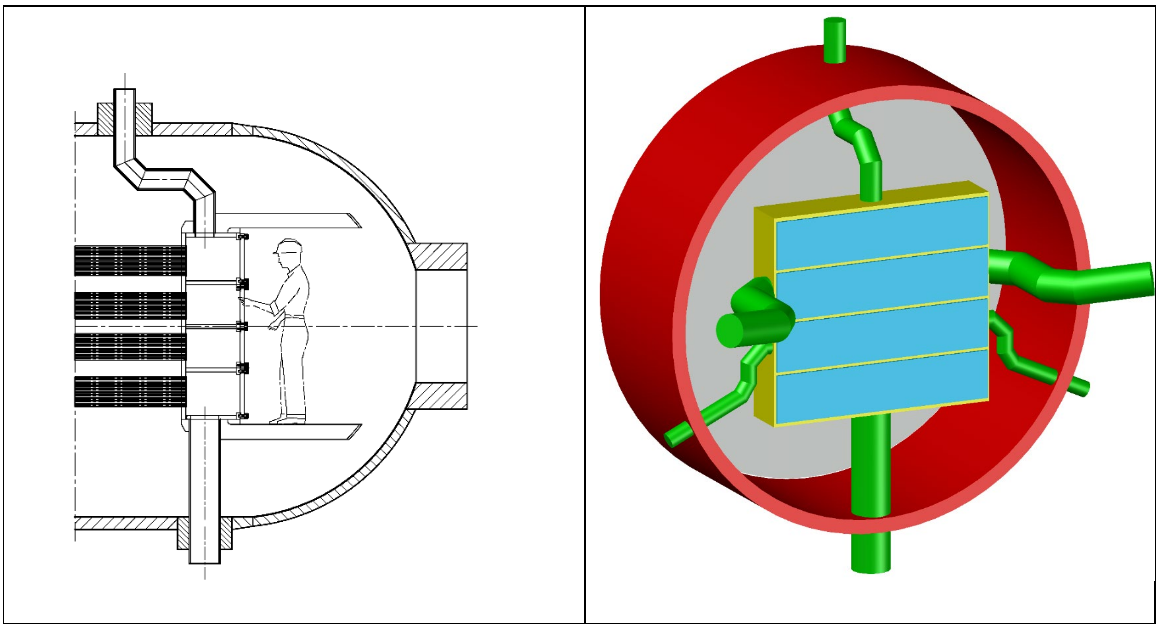

Figure 4: Accessibility of internal distribution box including covers

A special sealing system on the internal covers has been developed to withstand the different operating conditions of all distribution box compartments.

Depending on the equipment size, the piping elbows can be made either from segments or from bent pipes. The pool reactor is designed according to standard design rules combined with Finite Element Analysis. In addition, a Computation Fluid Dynamic (CFD) study was performed to investigate the behavior of the medium pressure outlet flow inside the pool reactor.

4.2. FLUID FLOW ANALYSIS IN DISTRIBUTION CHANNEL

In order to get a better understanding of the fluid flow pattern and the pressure drop inside the two-phase flow outlet channel in the pool reactor, CFD calculations were performed. This is to verify the fluid flow pattern inside the outlet channel along with its effect, if any, on the mechanical structure. In the outlet channel, the vapor/liquid received from the carbamate bundle is collected and transferred from the pool reactor to the second medium pressure separator. The two-phase fluid velocity profile and pressure drop profile inside the outlet channel are qualitatively represented in Figure 5.

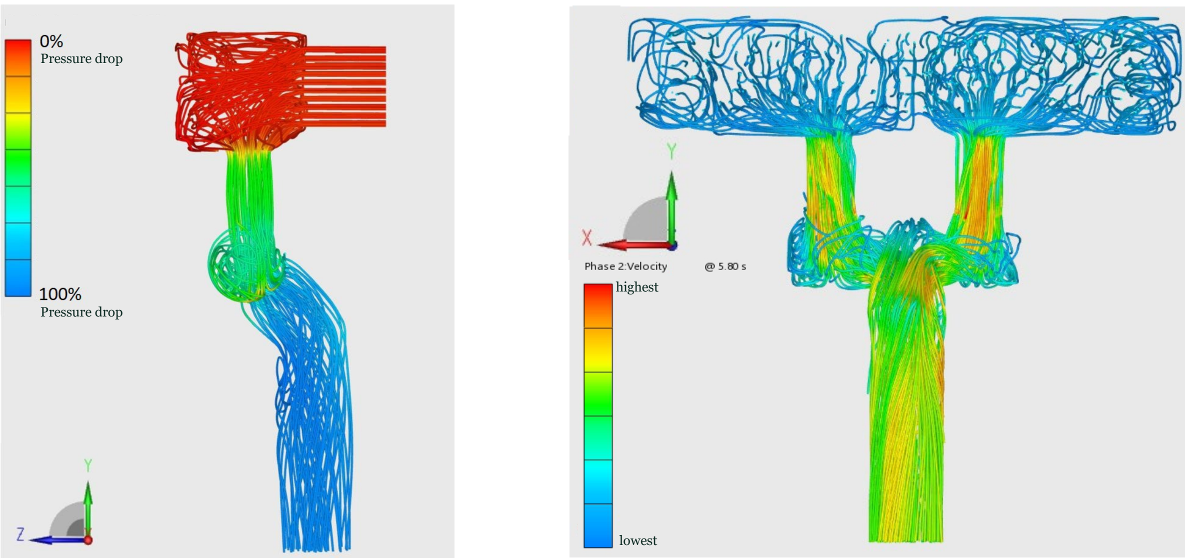

Figure 5: The figure on the left side is the profile for change in pressure between 'two-phase flow outlet channel' till outlet nozzle of the pool reactor. The figure on the right shows the relative fluid velocity profile

Based on the CFD simulations, it was concluded that the pressure drop between the 'two-phase flow outlet channel' and the two-phase outlet nozzle is smaller than initially anticipated during thermal design, which has a positive impact on the actual thermal performance.

It was also concluded that fluid-dynamic effects at the 'two-phase flow outlet channel' do not add any significant forces or fluctuations to connecting parts, which could harm in any situation the mechanical structure inside the pool reactor.

5. OPERATIONAL EXPERIENCES WITH POOL REACTOR

Two grassroot plants in China went into operation since the beginning of 2021: Jiujiang XLX and Sanning, both designed for a production capacity of 2334 MTPD. Two other pool reactors, one for a grassroot plant in China and one for a grassroot plant in Turkey, are currently in the manufacturing phase.

The picture below shows the first manufactured pool reactor for the Ultra-Low Energy Design ready for transport.

Figure 6: First manufactured pool reactor for the Ultra-Low Energy Design ready for transport

The plant operational staff from Jiujiang XLX and Sanning was trained by means of a toolbox session during the pre-commissioning of the plant. Detailed instructions were given regarding the design peculiarities, inspection details and start-up preparations for the equipment. Furthermore, a Risk-Based Inspection (RBI) program dedicated for the special pool reactor has been developed in which inspection locations and inspection techniques are defined. This program is advised to be executed during the first scheduled shutdown of the plant.

Both Ultra-low Energy plants were put into operation and have been running stable since then. The targeted energy savings were within the expectations and are further elaborated in the paper

"Experiences with Ultra Low Energy Design plant operation." This validates the Ultra-Low Energy concept and the mechanical design of the pool reactor with the dual bundle.

6. CONCLUSIONS

To date, the Ultra-Low Energy Design plant concept is already licensed six times. Two grassroot plants in China have been successfully in operation since the beginning of 2021: Jiujiang XLX and Sanning, both designed for a production capacity of 2334 MTPD. The plants are running stable and the targeted energy savings are met. Two other grassroot plants are currently in the construction phase, and contract has been recently signed for two new plants in China.

The successful commissioning and stable operation since then also validated the mechanical design of the pool reactor. The design fully employs the superior corrosion-resistant properties of Safurex® Infinity∞ steel. The internal parts like tubes and distribution box are easily accessible for maintenance and inspection purposes.

Stamicarbon B.V.
Mercator 3
6135 KW Sittard
The Netherlands

P.O. Box 53
6160 AB Geleen
The Netherlands

Tel. +31 46 4237000
Fax +31 46 4237001
info@stamicarbon.com
www.stamicarbon.com