OPERATIONAL EXPERIENCES WITH ULTRA-LOW ENERGY TECHNOLOGY

STAMICARBON

NEXTCHEM
MAIRE Sustainable Technology Solutions

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SUMMARY

1 ABSTRACT

Stamicarbon, the nitrogen technology licensor of NEXTCHEM (MAIRE Group), has established itself as a leader in urea process technologies, setting industry standards through reliable, energy-efficient solutions and innovative designs.

The NX Stami™ Urea Ultra-Low Energy (ULE) plant concept was introduced at the Stamicarbon symposium in 2012 and has since set an industry benchmark for energy efficiency based on its operational performance. There are six ULE plants in operation (as of November 2025), with the first commissioned about five years ago, and three plants licensed and under construction. The largest ULE urea plant, operating since September 2025 at Jiangxi Xinlianxin Chemicals Industry Co. LTD (XLX-3), has a nameplate capacity of 3850 MTPD. The ULE technology is also suitable for higher capacities, as critical equipment in the synthesis section is assessed for capacities up to 6000 MTPD.

The ULE Design for a urea melt plant with prilled product lowers steam consumption (23 bara, 330 ºC) to ≤ 567 kg steam/ton of product compared to ≤ 870 kg steam/ton of product achieved with traditional NX Stami™ Urea Pool Reactor/Condenser Designs (formerly known as Urea 2000plus®). This paper reviews the operational experience and process design aspects of grassroot urea ULE plants in operation, highlighting the key performance parameters, including steam consumption and product quality. The paper also describes the observations from the inspections of the dual-bundle ULE pool reactors and high-pressure strippers after several years in operation. The mechanical design aspects of the dual-bundle pool condenser are highlighted in the paper “New design for Ultra-Low Energy pool reactor/condenser.”

2 INTRODUCTION AND BACKGROUND

Stamicarbon has established a strong reputation for advancing urea process technologies, emphasizing operational efficiency, environmental performance, process safety, and economic viability. Among its latest innovations, the Ultra-Low Energy (ULE) technology plants represent the most energy-efficient urea plants.

The ULE Design was launched at the Stamicarbon symposium in 2012 and has been contracted for nine grassroot plants. Of these, six plants are already in operation, with the first plant (XLX-1) operating since February 2021 and the latest (XLX-3) started up in September 2025. Other three plants are in the construction phase. The ULE Design is considered the latest generation of Pool Condenser and Pool Reactor Designs – part of NX Stami™ Urea and formerly known as Urea 2000plus®. It offers the benefit of significantly reduced steam consumption and leverages major technological advancements developed by Stamicarbon, including:

- The use of pool condensation in the synthesis,
- The application of E-type stainless steels (formerly known as Safurex®) as materials of construction for the synthesis section, and
- The implementation of a proven medium-pressure (MP) recirculation design and operation.

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

The ULE Design utilizes N=3 heat integration. This means that the heat supplied in the form of HP extraction steam is (partly) used three times in the urea plant. To achieve that, MP carbamate dissociation generates vapor by utilizing the heat from condensing the strip gas in the pool condensation section of the synthesis. Then, the heat of condensation of this MP 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 ULE process according to the Pool Reactor concept is represented in Figure 1.

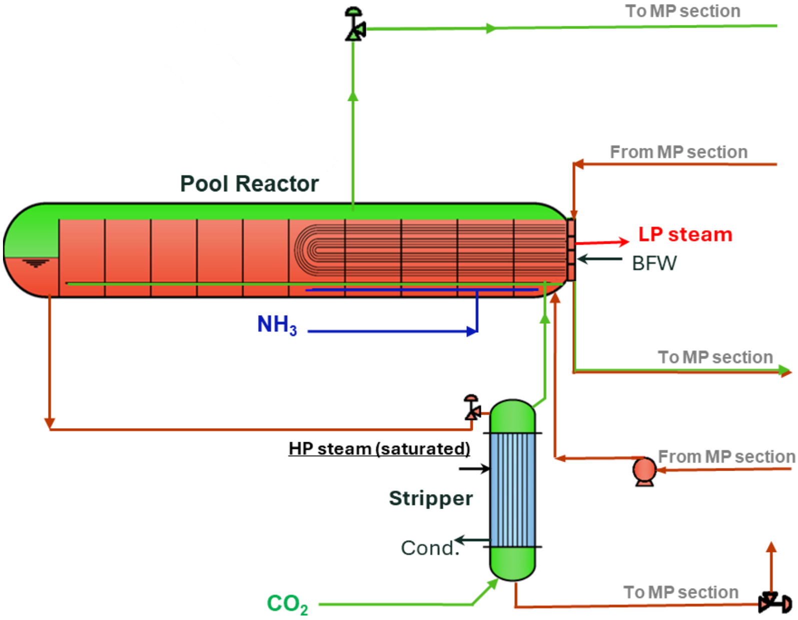


Figure 1: The synthesis section of the ULE Design as implemented in several grassroot plants in operation with pool reactor and HP stripper.

As illustrated in Figure 1, the synthesis for the ULE process, as implemented in several grassroot Pool Reactor Design plants in operation, includes only two pieces of HP equipment. On the high-pressure side, it is similar to the synthesis of Flash Design – part of Launch Melt – consisting of an HP stripper and an HP pool reactor without an HP scrubber. The HP scrubber is not required in the ULE Design either. However, a closer look at the pool reactor shows that its U-tube bundle consists of two distinct sections, each handling a different fluid medium – condensate/steam and carbamate – which are both integrated into the shell side of the pool reactor. The first-generation mechanical design of the ULE pool reactor consisted of distribution chambers on the tube side within the pool reactor. However, this concept has mechanical limitations for higher plant capacities. As can be seen from Figure 1, this is solved by relocating the distribution boxes externally. More details about the new design can be found in the paper "New design for Ultra-Low Energy pool reactor/condenser."

In this dual-bundle design, the inner part of the bundle is called the "steam bundle," which is used to generate low-pressure steam as is commonly found in Stamicarbon's Pool Condenser and Pool Reactor plants. The amount of generated low-pressure steam only fulfills the need of urea plant itself, without excess of (export) low-pressure steam[1].

The outer part of the bundle, called the "carbamate bundle," is used for heat integration with the MP recirculation section. On the shell side of this bundle, condensation of CO_2 and NH_3 vapor releases heat (at about 141 bara and 175 ºC), which is used to decompose carbamate into CO_2 and NH_3 on the tube side. Consequently, the tube side of this bundle in the pool reactor functions as an MP rectifying heater. By integrating these two functions, without any intermediate heat transfer medium, the available temperature difference between both process sides enables the bundle to be relatively small for the required duty.

[1] In Figure 2, the carbamate bundle is located as outer part of the bundle. The relative position of the bundles to each other is an arbitrary selection. Alternatively, the tube bundles could be placed next to each other or one above the other. When the carbamate bundle is located as an outer part, it facilitates easier cleaning of the carbamate bundle in case of fouling due to larger bend radius.

The MP recirculation section of the ULE Design process is represented in Figure 2.

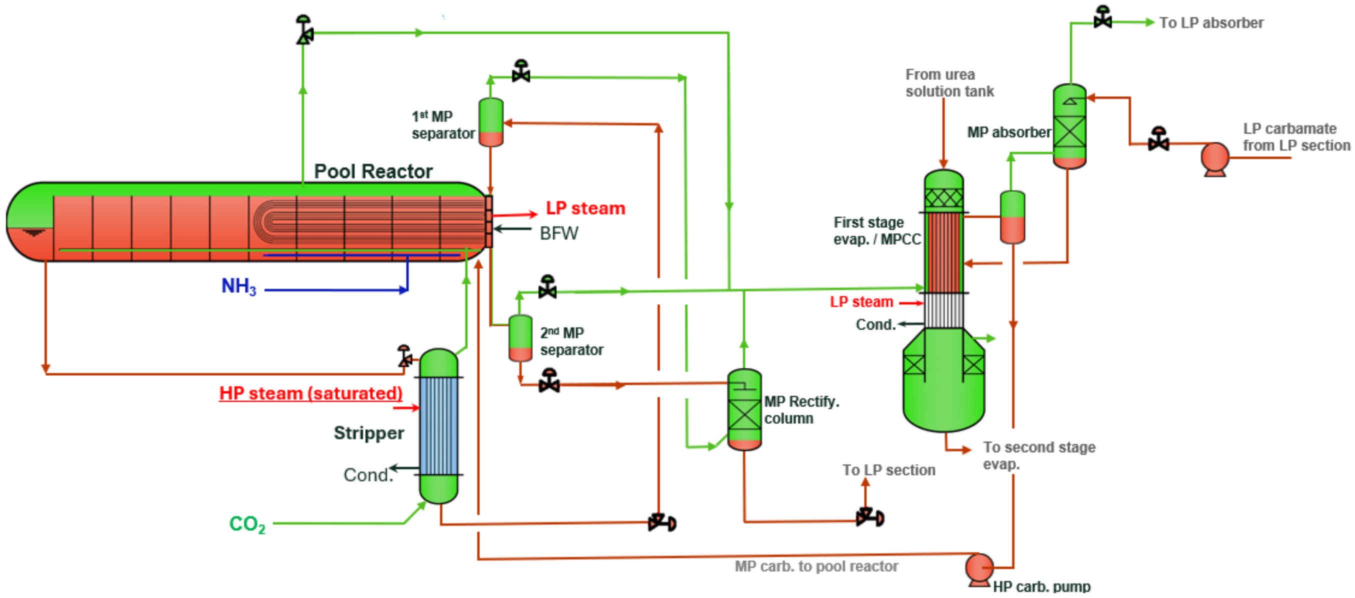


Figure 2: The synthesis including the MP recirculation section of the ULE Design as implemented in several grassroot plants in operation with pool reactor and HP stripper.

After leaving the HP stripper, the urea/carbamate solution is adiabatically flashed at medium pressure in the first MP separator resulting in CO_2 rich vapor and urea solution/carbamate liquid. The first MP separator is located at a higher elevation than the pool reactor. The urea solution/carbamate flows by gravity from the first MP separator to the outer part of the pool reactor bundle (carbamate bundle) where it is heated by condensing strip gas on the shell side, causing some of the carbamate to decompose to NH_3 and CO_2 vapor. This vapor/liquid mixture is sent to the second MP separator, where vapor and liquid get separated. The urea solution/carbamate leaving the second MP separator has a higher NH_3/CO_2 ratio. The liquid from the second MP separator is sent to the MP rectifying column, where CO_2-rich vapor from the first MP separator helps decrease the NH_3/CO_2 ratio of the liquid. Then, the liquid is discharged to the low-pressure (LP) recirculation section – a standard feature in Stamicarbon designs.

The vapor generated in the MP recirculation section, together with off-gas from the synthesis, is condensed on the shell side of the first stage evaporator/medium-pressure carbamate condenser (MPCC) to form MP carbamate. The heat released during condensation is used to concentrate the urea solution in the first-stage evaporation, which is based on falling film evaporation. This allows the ULE Design to utilize the heat supplied to the urea plant as steam three times (N=3):

1. For dissociating the carbamate at synthesis pressure in the HP stripper.
2. For dissociating the carbamate under MP conditions in the carbamate bundle of the pool reactor.
3. For concentrating the urea solution on the tube side of the first-stage evaporator/MPCC under sub-atmospheric pressure conditions.

Figure 3 represents the ULE plant process consisting of three pieces of HP synthesis equipment: pool condenser, stripper and a vertical reactor, as built for XLX-3 with a capacity of 3850 MTPD. The MP recirculation section is identical to that in Figure 2. Considering the transportation limitation, synthesis with two pieces of HP equipment (pool reactor and stripper) typically up to 3000 MTPD in capacity is selected as the most elegant application. For capacities higher than 3000 MTPD, three pieces of HP equipment are considered.

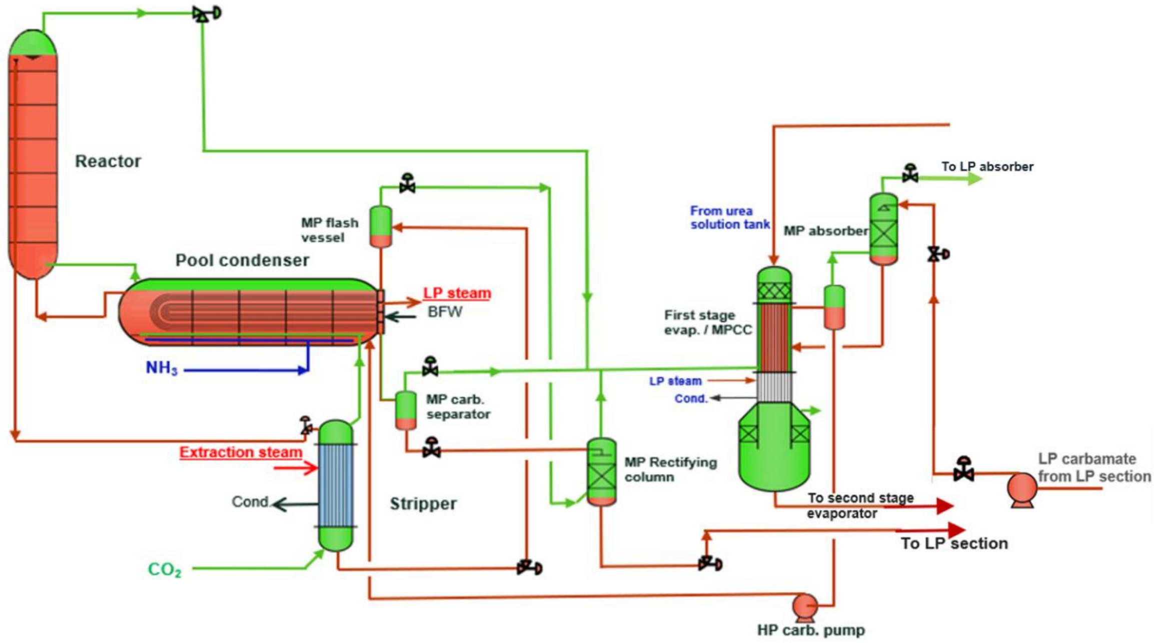


Figure 3: The synthesis including the MP recirculation section of the ULE Design as implemented for larger scale capacity plant (3850 MTPD), with the synthesis consisting of pool condenser, reactor and stripper.

The ULE Design has been optimized from both CAPEX and OPEX perspectives. The introduction of the new MP recirculation section, along with the elimination of the HP scrubber, ensures a balanced CAPEX outcome for the plant compared to Pool Condenser and Pool Reactor Designs. Additionally, steam consumption is significantly reduced. The earlier operational benefits of traditional Pool Condenser and Pool Reactor Designs – such as CO_2 stripping, pool condensation and proven medium and LP recirculation operation – remain intact in the ULE Design. Moreover, higher operational flexibility is introduced by including the MP section. The ULE Design has been technically assessed for plant capacities of up to 6000 MTPD.

4 OPERATIONAL EXPERIENCES AND KEY PERFORMANCE PARAMETERS

The first ULE plant, XLX Jiujiang (XLX-1), was successfully commissioned in February 2021. Prior to the startup of the plant the operational team was thoroughly trained on Stamicarbon's Technology Training Simulator to get a good understanding of the expected ULE plant behavior. The plant started up smoothly without any issues from the first attempt. Shortly after this successful startup, the second ULE plant, Sanning Chemicals, was commissioned.

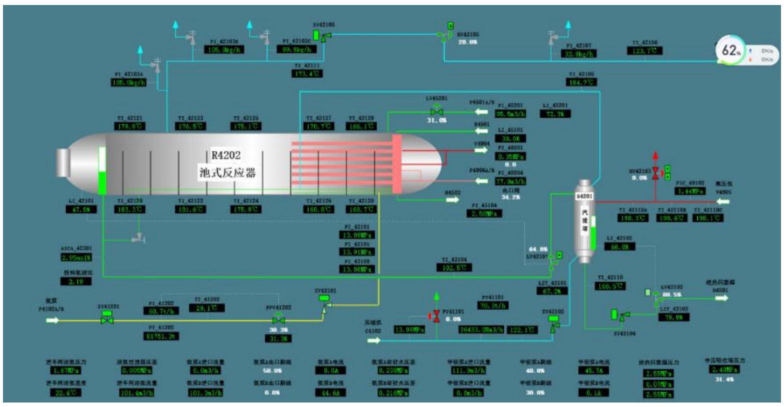
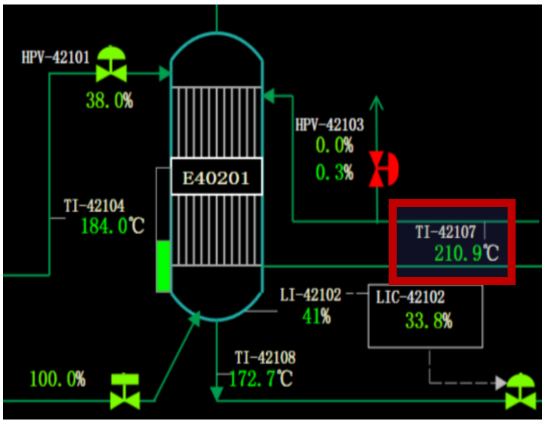


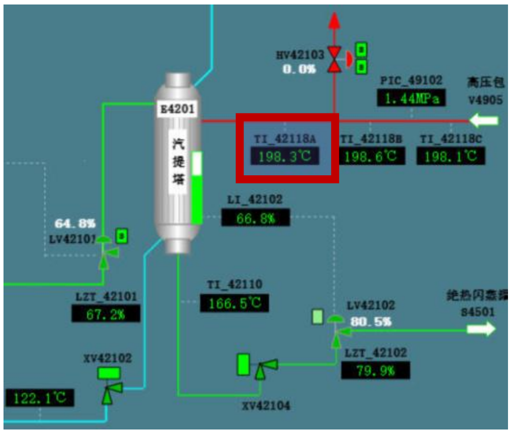
Figure 5: DCS screenshot of XLX-1 from above 110% operation for synthesis and MP section.

Both XLX-1 and Sanning Chemicals urea plants have been operating smoothly since the beginning of 2021. An actual DCS screen of synthesis operation is shown in Figure 5 above. The energy consumption of the ULE plant is considered to be a benchmark of performance worldwide. Apart from energy benefits, the ease of operation, including pool reactor with dual-bundle design, is considered to be another important benefit by all ULE plant owners compared to traditional plants. The presence of the MP recirculation section and the carbamate bundle dampens disturbances – found troublesome in traditional stripping plants – originating from discharging liquid directly from the stripper operation to the LP section. Furthermore, lower biuret in the final urea product compared to product from traditional processes is considered to be a major enhancement in the final product quality – see Table 1.

In the ULE plant, the shell side steam temperature in the stripper is maintained at only about 196-198 °C, which is significantly milder than the 210-215 °C generally required in the traditional stripper. This reduces biuret formation in the stripper resulting in a higher product quality in terms of biuret content (< 0.8 wt%). Additionally, milder operating temperature (see Figure 6) contributes to extended stripper lifetime by lowering the corrosion rate of the heat exchanger tubes due to less aggressive process conditions. In ULE plants, stripping efficiency of the stripper is intentionally reduced to lower its HP steam consumption. At the same time, LP steam excess or export is minimized to zero, along with moving the carbamate dissociation load from the stripper to the MP section.



CO_2 stripper in traditional synthesis



CO_2 stripper in ULE synthesis

Figure 6: DCS screenshots for operation at ~110% capacity. Left: CO_2 stripper in traditional plant synthesis; operating HP steam shell side at 210 to 215 °C, with stripping efficiency ~78 to 80%. Right: CO_2 stripper in ULE plant synthesis; operating HP steam shell side at 195 to 198 °C, with stripping efficiency ~62 to 64%.

Observing the benefit of the ULE plant at Jiujiang, XLX also contracted and commissioned two additional ULE Design urea plants. One is located at Xinxiang (XLX-2) and another one (XLX-3) at Jiujiang. The actual plant performance indicated in Table 1 below is summarized from XLX-1.

Key performance parameters		Units	Expected values from design	Actual plant performance
Production capacity		tons/day	2334	2387
Cooling water[2]		$tons/ton_{urea}$	61 (ΔT = 10 °C)	61 (ΔT = 10 °C)
High-pressure steam[3]	Extraction steam 23 bara, 330 °C [equivalent extraction steam quantities for comparison]	kg/ton_{urea}	577	567
Product quality	Total nitrogen	wt%	46.5	46.6
	Biuret	wt%	0.85	< 0.80

Table 1: ULE plant performance parameters are listed as follows: 'actual plant performance' compared to 'performance guarantee values' from XLX Jiujiang plant performance test. All figures indicated as tons are in metric tons.

The actual performance parameters as indicated in Table 1 with respect to steam consumption and biuret content in the final product demonstrate the ULE plant performance to be a major advancement in urea technology. Key performance parameters are further elaborated below at an average plant operation capacity of 102%. The plant has been operating stably up to capacities of 110%. The performance of the Sanning plant is also comparable to XLX-1.

4.1 Steam consumption

The actual HP steam (23 bara, 330 °C) consumption at XLX-1 is 567 kg/ton urea, which is lower than the value expected during design. These figures are expected to be further reduced by about 20 to 25 kg/ton urea by optimizing the process conditions of the ammonia feed temperature to the synthesis.

4.2 Cooling water consumption

The actual cooling water heat duty observed during performance test is close to the expected value during design. The cooling water flow required considering equivalent ΔT_{cw} = 10 °C is 61 tons/ton urea.

4.3 Product quality

ULE Design, apart from energy benefit, also brought a significant product quality improvement by reducing biuret concentration in the final product by more than 0.05 wt% compared to a traditional stripping process. This is due to the process specifics of the ULE Design, including milder process temperatures in the stripper and process-process heat exchange at the first stage evaporator part. Together, these features result in a lower tube side (for urea solution) wall temperature.

Consumption figures for the ULE Design in operation from performance test at XLX-1 and Pool Condenser and Pool Reactor Designs are as follows.

[2] The cooling water consumption figure is indicated equivalent to ΔTcw = 10 °C.
[3] In XLX-1 only saturated steam is supplied to the urea plant. The above steam consumption figure is indicated based on the steam quality equivalent to standard extraction steam quality (23 bara, 330 °C) for right comparison. The actual saturated steam (26 bara, 226 °C) consumption during operation is 635 kg/ton urea.

Process concept	Steam consumption (23 bara, 330 °C)	Cooling water consumption (ΔT_{cw} as 10 °C)	Expected biuret in final product
ULE plant in operation	kg_{steam} / ton_{urea}	61 ton_{CW} / ton_{urea}	< 0.8 wt%
Pool Reactor Design	870 kg_{steam} / ton_{urea}	73 ton_{CW} / ton_{urea}	0.85 wt%
Improvement	**35%**	**16%**	**> 6%**

Table 2: Steam consumption and biuret content comparison between ULE Design and Pool Condenser and Pool Reactor Designs.

The synthesis equipment of ULE plants XLX-1 and Sanning (pool reactor and stripper), in operation for about five years, is made from E-type material. The synthesis equipment was internally inspected during the first planned turnaround after approximately two years on-stream time. The pool reactor tube side (carbamate side) shows almost negligible corrosion and minor fouling. Furthermore, hardly any corrosion was observed at the HP shell side. The wall thickness measurement of stripper tubes also indicates a much lower corrosion rate due to milder temperature (refer to Figure 6) compared to strippers in traditional CO_2 stripping plants.

5 CONCLUSIONS

The ULE plant concept has proven to be a highly energy-efficient and reliable solution for urea production. It has become a benchmark for energy efficiency in the industry, with nine licensed plants to date. Since early 2021, six grassroot plants in China – Jiujiang XLX-1, Xinxiang XLX-2, Sanning, two lines at Shandong Runyin, and XLX-3 – have been in operation successfully. Five of these plants are designed for production capacity of 2334 MTPD consisting of two synthesis HP equipment items (pool reactor and stripper), while XLX-3 is designed for production capacity of 3850 MTPD consisting of three synthesis equipment items (pool condenser, reactor and stripper). These plants utilize a highly optimized configuration ensuring both operational simplicity and energy efficiency. There are two other grassroot plants in the engineering phase: Shandong Lianmeng (2334 MTPD) and Jiangsu Huachang (1860 MTPD) and one plant close to startup in Turkey at Gemlik Gübre (1640 MTPD).

As highlighted in Table 2, steam consumption for the ULE Design as proven in operation is reduced by about 35% and cooling water consumption is reduced by about 16% compared to traditional Pool Condenser and Pool Reactor Designs. The CAPEX of the ULE Design is comparable to Pool Condenser and Pool Reactor Designs. The 'N=3' heat integration is achieved by integrating heat between the Pool Reactor (condensation strip gas) and the MP carbamate dissociation heater ($NH_3/CO_2/H_2O$ vapor from urea/carbamate solution), also called carbamate bundle. This is followed by heat integration between the MPCC ($NH_3/CO_2/H_2O$ vapor from carbamate) and the first-stage evaporator heater (water evaporated from the urea solution from the storage tank). The heat integration between the pool reactor and the MP recirculation section is achieved via a unique dual-bundle pool reactor design allowing heat exchange with process fluids on both shell and tube side.

At the ULE plant, in addition to energy savings, there was also a significant improvement in product quality, as the biuret concentration in the final product was reduced by approximately 0.05 wt%, compared to the traditional stripping process.

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