BEYOND OPTIMIZATION:

AN INNOVATIVE REVAMP CONCEPT FOR UNLOCKING ENERGY EFFICIENCY AND BOOSTING CAPACITY

STAMICARBON

NEXTCHEM
MAIRE Sustainable Technology Solutions

Conference name	Stamicarbon Symposium
Conference date	May 18-21, 2026
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Classification	PUBLIC

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ABSTRACT

In response to growing demands for energy efficiency, sustainability, and production optimization in urea manufacturing, Stamicarbon has developed the Ultra-Low Energy (ULE) revamp concept - a transformative solution for urea stripping plants. This concept is built on the N=3 philosophy, where the heat of the High-Pressure (HP) steam is utilized three times, significantly reducing specific steam consumption up to 30% and enabling capacity increases of up to 45%.

The cornerstone of the ULE revamp concept is the ULE carbamate condenser, a specially engineered shell-and-tube heat exchanger with U-tubes. While this design provides additional reaction volume and an expanded heat recovery capacity, it also introduces process challenges related to hydraulic impact in the synthesis loop, plug flow behavior, and heat recovery configuration.

These challenges are resolved in the developed ULE revamp design, which allows installation in either vertical or horizontal orientation, offering greater flexibility for plant layout and integration. In addition, the concept incorporates a medium-pressure (MP) section that improves operational stability and maximizes energy recovery in the urea plant.

Mechanical reliability is ensured through optimized design features including advanced leak detection systems, improved accessibility, corrosion resistant liners, duplex welding, and constructability enhancements. The ULE carbamate condenser incorporates special trays, integral TEMA baffles and strip baffles for tube support, etc., all designed to balance reliability, maintainability, and cost efficiency.

Safety evaluations confirm that the introduction of the new ULE revamp concept does not create any additional risks for the existing HP section. This is ensured by applying the best available materials of construction and incorporating an efficient leak detection system. In Stamicarbon plants, whenever new high-pressure scenarios arise in the MP or LP sections, they are safeguarded accordingly via proper safety measures, including appropriate materials of construction, pressure safety valves, and interlock systems.

Overall, the ULE revamp concept offers a strong combination of energy savings, capacity enhancement, operational flexibility, and safety assurance, making it a strategic solution for modernizing urea plants worldwide.

GLOSSARY

CSTR	Continuous stirred tank reactor
DEF	Diesel Exhaust Fluid
E.I-type™	Super duplex stainless steel specifically developed for high-pressure urea plant equipment operating in extremely corrosive environments, formerly known as “Safurex”, provides exceptional corrosion resistance and reliability under harsh process conditions.
HPCC	High pressure carbamate condenser
HP	High-pressure
LP	Low-pressure
MP	Medium-pressure
ULE	Ultra-Low Energy
UAN	Urea Ammonium Nitrate

1 INTRODUCTION

In today's evolving landscape, urea producers face increasing pressure to reduce energy consumption, alongside other critical goals such as minimizing emissions, in general lowering the carbon footprint of their plants, all within competitive CAPEX and OPEX constraints. As a global leader in urea licensing, Stamicarbon, the innovation and license company of MAIRE Group, has consistently pursued process optimization to meet customer demands and fulfill its purpose: enabling the world to feed itself.

In recent years, Stamicarbon has made remarkable progress by developing innovative energy-saving technologies that enable urea producers to operate more efficiently, with optimized energy consumption, without compromising emission standards. Among these advancements is the successful implementation of low-energy concepts for grassroots plants, starting with the MP Adiabatic Flash concept. The evolution of this concept has been concluded in the ULE concept (N=3) with double bundle (carbamate and steam bundles), which maximizes the use of HP steam by utilizing it three times, as depicted in Figure 1, as follows:

- **N=1:** HP steam provides heat to the HP stripper / synthesis section.
- **N=2**: via 2 bundles installed in the HP ULE condenser as follows:
    - Steam bundle: condensation of HP carbamate gas at the shell side of the ULE condenser generates LP steam at the tube side.
    - Carbamate bundle: condensation of HP carbamate gas in the shell side of the ULE condenser decomposes the carbamate liquid received from the MP section.
- **N=3** (new in ULE concept and main differentiator from typical N=2 stripping plants):

MP carbamate condenser evaporator reuses the heat again to:

- Condense carbamate at MP conditions
- Simultaneously evaporate and concentrate urea solution in the evaporation section

As a result, energy consumption can be reduced below 600 kg per ton of urea, depending on the quality of the steam supplied to the plant.

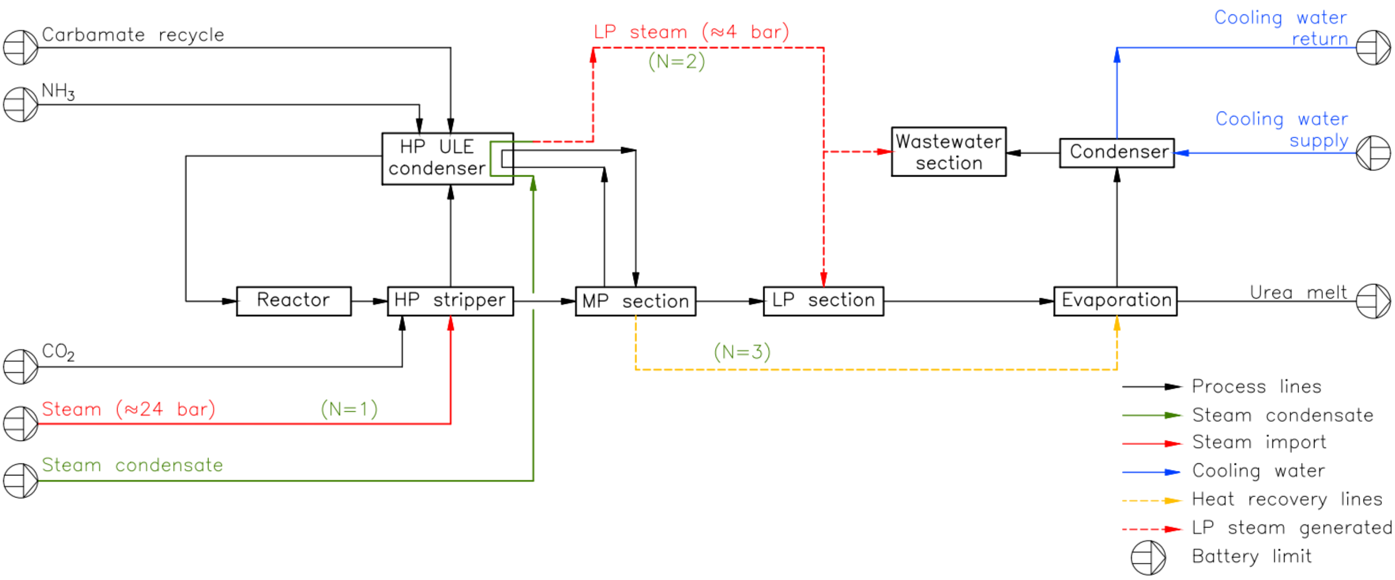


Figure 1: N=3 concept (using heat of HP steam three times by process-process heat exchange).

To date, the ULE concept for grassroot plants has been licensed 10 times, with six plants already operating successfully and achieving all key performance indicators. The remaining plants are currently under construction and are expected to be commissioned in the coming years.

Stamicarbon brings extensive experience not only in designing new urea plants but also in revamping existing ones, having successfully completed over 90 revamp projects. Originally designed for grassroots applications, the ULE concept has now been further developed by Stamicarbon for revamp applications, making it a highly attractive solution for plants aiming to reduce energy consumption, with the additional option of increasing production capacity.

By integrating the ULE concept into revamp strategies, Stamicarbon enables clients to achieve up to 45% additional production capacity while simultaneously lowering specific energy usage. This delivers a strong combination of sustainability and profitability.

Moreover, the ULE concept is not limited to Stamicarbon-designed plants. It can be effectively applied to non-Stamicarbon facilities, offering a versatile and impactful revamp solution across a wide range of plant designs.

2 DRIVERS AND CHALLENGES OF UREA PLANT REVAMPING

Changes to a plant’s status quo are typically triggered by specific events and driven by strategic objectives.

In the case of urea plants, the most common drivers for initiating a revamp include but are not limited to:

- Capacity expansion (enabled by feedstock or utility availability)
- Product diversification (e.g., Diesel Exhaust Fluid (DEF), Urea Ammonium Nitrate (UAN))
- Energy consumption reduction
- Replacement of aging or obsolete equipment
- Safety enhancements
- Compliance with environmental regulations and legislation
- Market competition

Each of these drivers involves different stakeholders, with unique interests, budgets, and constraints. These boundary conditions may include local market dynamics, short- and long-term corporate strategies, economic feasibility, environmental policies, and national or international standards.

Stamicarbon’s extensive experience enables and supports clients to adopt a structured, stepwise approach to revamping—tailored to both immediate needs and long-term goals.

Typically, existing urea plants run at maximum loads well above their nameplate capacity. Revamping these urea plants to further increase capacity and/or improve efficiency often presents a set of recurring challenges, including but not limited to:

- Increased energy consumption, especially when capacity expansion is involved.
- Higher synthesis loop load can reduce reactor conversion efficiency and lead to increased steam demand in the HP stripper.
- Size limitations and lifetime of HP equipment such as CO_2 compressor(s), HP carbamate pump(s), HP carbamate condenser (HPCC), HP stripper and HP reactor.
- Higher load on LP recirculation, evaporation, and wastewater sections after increasing the plant capacity.
- Higher cooling water demand, potentially due to additional consumers and/or due to increased thermal loads.
- Layout and footprint constraints can limit the integration of new equipment.

- Extended downtime during revamp execution, often caused by the complexity of integrating new systems into existing configurations. This can lead to prolonged shutdowns and increased project costs.

To address these challenges, Stamicarbon has a large portfolio of revamp options. Most of these options can be executed through a stepwise approach, ensuring flexibility, optimized performance, and seamless integration into existing operations. The latest addition to the revamp portfolio is the ULE revamp concept, which has biggest potential for capacity expansion and energy consumption reduction for the short and long term as a robust and optimum revamp solution.

This innovative concept provides several key advantages:

1. **Enhanced reaction volume**
   The ULE carbamate condenser introduces additional reaction space, enabling capacity increases without compromising synthesis conversion efficiency.
2. **Efficient heat integration**
   The specially designed U-tube bundle enables highly efficient process to process heat exchange, significantly reducing steam consumption - even at elevated capacities.
   A process to steam configuration is also possible, delivering HP steam beneficial for downstream consumers.

   Nevertheless, this process to steam heat integration (N=2) is less energy efficient compared to process-to-process (N=3) and therefore, this concept will not be elaborated further in this article.
3. **MP section integration**
   Incorporating the MP section into the revamp adds operational flexibility and acts as a buffer, stabilizing the LP section under high-capacity conditions.
4. **Reduced cooling water demand**
   Thanks to the process-to-process heat integration and steam savings, specific cooling water consumption is expected to decrease easing utility requirements.
5. **Optimized equipment footprint**
   The high efficiency of the ULE carbamate condenser allows for a compact design, ensuring seamless integration within existing plant layouts.
6. **Minimize downtime during the revamp execution**

   The ULE concept addresses the downtime challenge by incorporating a smart and adaptive design, including simplified implementation via an add-on construction concept. This reduces the need for intrusive modifications, and minimizes downtime during the revamp process, making it both time-efficient and economically attractive.

It is worth noting that implementing the ULE revamp concept in plants with specific configurations, such as those already equipped with an MP section or an MP add-on can result in shorter downtime and lower investment costs. This is primarily due to the ability to reuse existing MP equipment within the new configuration, enhancing both efficiency and cost-effectiveness.

3 MAIN OBJECTIVE OF THE ULE CONCEPT AS A REVAMPING TOOL

Applying the ULE concept as a revamp strategy is expected to deliver the following key outcomes:

1. Steam savings: achieve up to 30% reduction in steam consumption, depending on the current system configuration, plant efficiency, and quality/process conditions of the HP steam received from battery limit.
2. Capacity increase: enhance plant throughput by at least 10% and up to about 45% compared to the pre-revamp baseline.
3. Cooling water optimization: minimize specific cooling water usage through smart heat integration techniques that minimize heat dissipation and reduce reliance on additional cooling systems.
4. CAPEX and OPEX efficiency: optimize both capital and operational expenditures through improved energy integration and system performance.

4 FEATURES OF THE ULE CARBAMATE CONDENSER IN UREA REVAMPED PLANTS

4.1 Condenser type

The ULE carbamate condenser is a specially engineered submerged heat exchanger with U-tubes. These U-tubes are selected based on mechanical considerations (refer to section 6.2). The ULE carbamate condenser design provides the necessary additional volume and corresponding surface area for effective heat recovery.

Like a standard vertical urea reactor, the ULE carbamate condenser is designed to promote plug flow behavior. This is achieved through siphon jet pump trays in the vertical configuration, or through process baffles when the condenser is installed in a horizontal orientation.

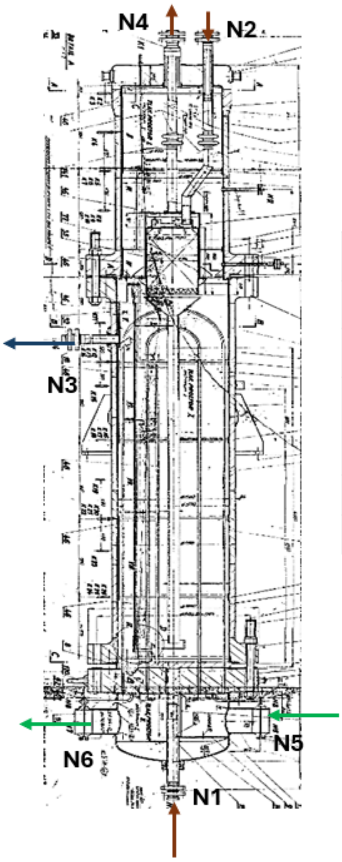
4.2 Orientation of the condenser

The ULE carbamate condenser can be installed in either a vertical or horizontal position. The choice of orientation depends on specific project requirements, such as:

- Space constraints
- Hydraulic limitations within the synthesis loop
- Overall plant configuration as defined by the urea licensor

In Stamicarbon's STAMI Urea™ design, the horizontal condenser configuration is commonly applied. Stamicarbon already possesses extensive know-how and design experience with this setup.

The vertical condenser configuration is a submerged-type design, historically used as an HP scrubber in 1970-1980 (see Figure 2). Stamicarbon has refined this design for the vertical variant of the ULE carbamate condenser.



Nozzle	Nozzle description
N1	Inlet gas from HP reactor
N2	Inlet carbamate from LP recirculation section
N3	Outlet liquid to HP reactor
N4	Outlet gas to LP absorber
N5	Cooling water supply
N6	Cooling water return

Figure 2: HP scrubber submerged vertical design applied in Stamicarbon plants between 1970-1980.

The installation height of the ULE carbamate condenser is optimized based on the height constraints specified by the technology licensor and the specific requirements of the revamp project. Depending on the plant configuration, the condenser can be installed either at ground level or at an elevated position.

Several layout configurations, as illustrated in Figure 3, are available for integrating the condenser into the plant design. Each option presents distinct advantages and limitations, which should be evaluated on a case-by-case basis in alignment with the project objectives.

In the vertical design, a gas sparger is not required, as gas distribution is achieved via the siphon jet pump trays, resulting in Continuous Stirred Tank Reactor (CSTR) flow behavior between the trays. If level measurement at the top of the ULE carbamate condenser is necessary, concept A shown in Figure 3.1, with the tube-sheet positioned at the bottom, may be selected.

From a corrosion mitigation perspective, fully submerged equipment such as concepts B and C shown in Figures 3.2 and 3.3 are generally advantageous. However, these designs do not support level measurement functionality.

A horizontal orientation, as depicted in concept D Figure 3.4, offers hydraulic benefits by reducing static height and thereby minimizing pressure drop within the synthesis loop. This configuration, however, requires sufficient footprint availability in the existing plant. If space is limited, a parallel structure dedicated to housing the condenser may be considered.

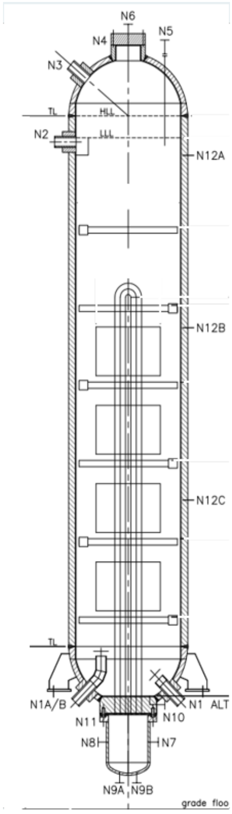


Figure 3.1, **Concept A**: Tube sheet at the bottom, including level measurement at the top hemi-head of the ULE carbamate condenser.

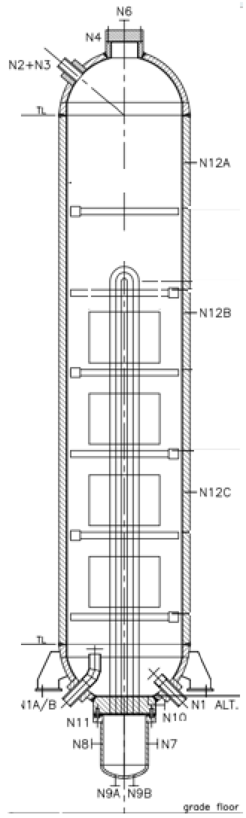


Figure 3.2, **Concept B**: Tube sheet at the bottom, the ULE carbamate condenser is fully submerged (no level control).

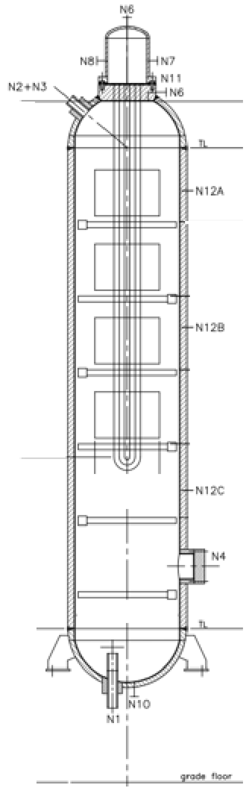


Figure 3.3, **Concept C**: Tube sheet at the top, the ULE carbamate condenser is fully submerged (no level control).

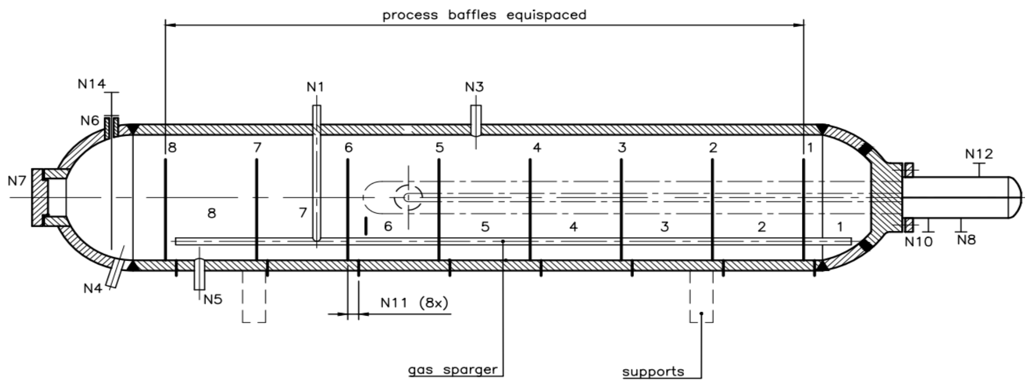


Figure 3.4, **Concept D**: Horizontal layout which is typically used in the grassroots but can also be a perfect fit for revamping concepts.

Figure 3: Different layouts of ULE carbamate condenser.

5 REVAMPING STAMICARBON CO_2 STRIPPING PLANT

5.1 Base case: CO_2 stripping combined with HPCC

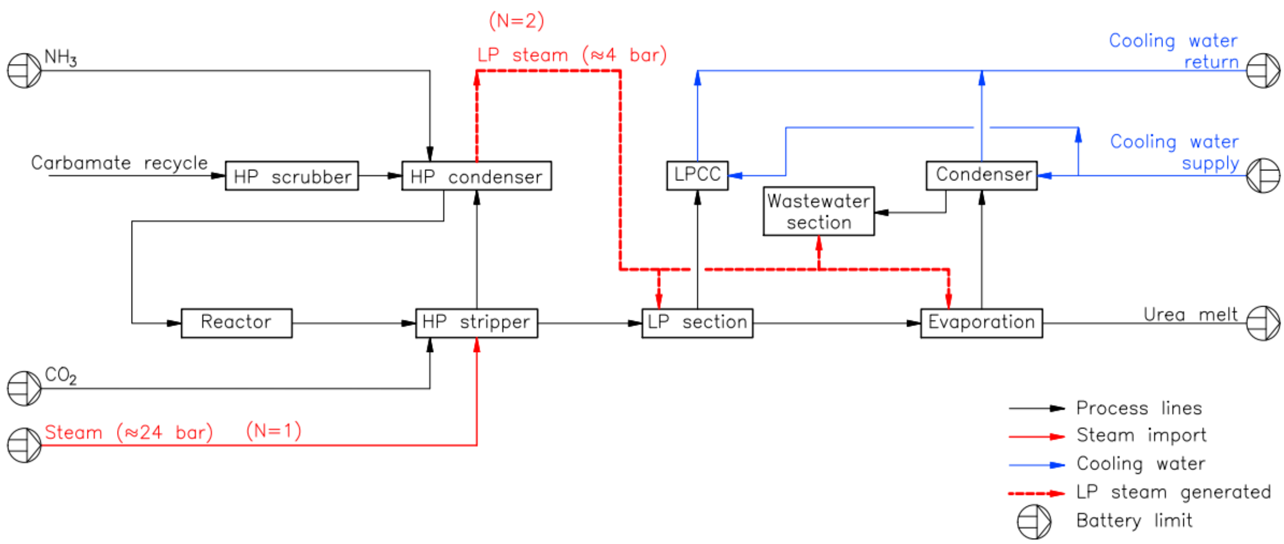
The base case illustrated in Figure 4 refers to Stamicarbon plants utilizing the CO_2 stripping concept in combination with HPCC, a configuration that represents a significant portion of urea plants installed globally.

This base case leverages the energy of HP steam twice (N=2), as follows:

- **N=1:** High-pressure steam provides heat to the high-pressure stripper / synthesis section.
- **N=2**: condensation of HP carbamate gas at the tube side of the HPCC generates LP steam at the shell side, to be used for LP steam consumers in the urea plant.

The typical steam consumption for this configuration is approximately 900 kg of steam per ton of urea produced, making it a relatively high steam consuming concept compared to the new energy concepts in the market.

Applying the ULE revamp concept is not limited to this configuration. It can also be effectively applied to other setups, including Stamicarbon pool condensers, pool reactors as well as non-Stamicarbon stripping plants, demonstrating its versatility across a wide range of plant designs.



5.2 Utilizing ULE revamp concept

The core objective of the ULE revamp concept is to reduce the specific steam consumption of the plant with the additional option of increasing production capacity. Energy savings are achieved through the N=3 philosophy, which utilizes steam heat three times, as illustrated in Figure 5.

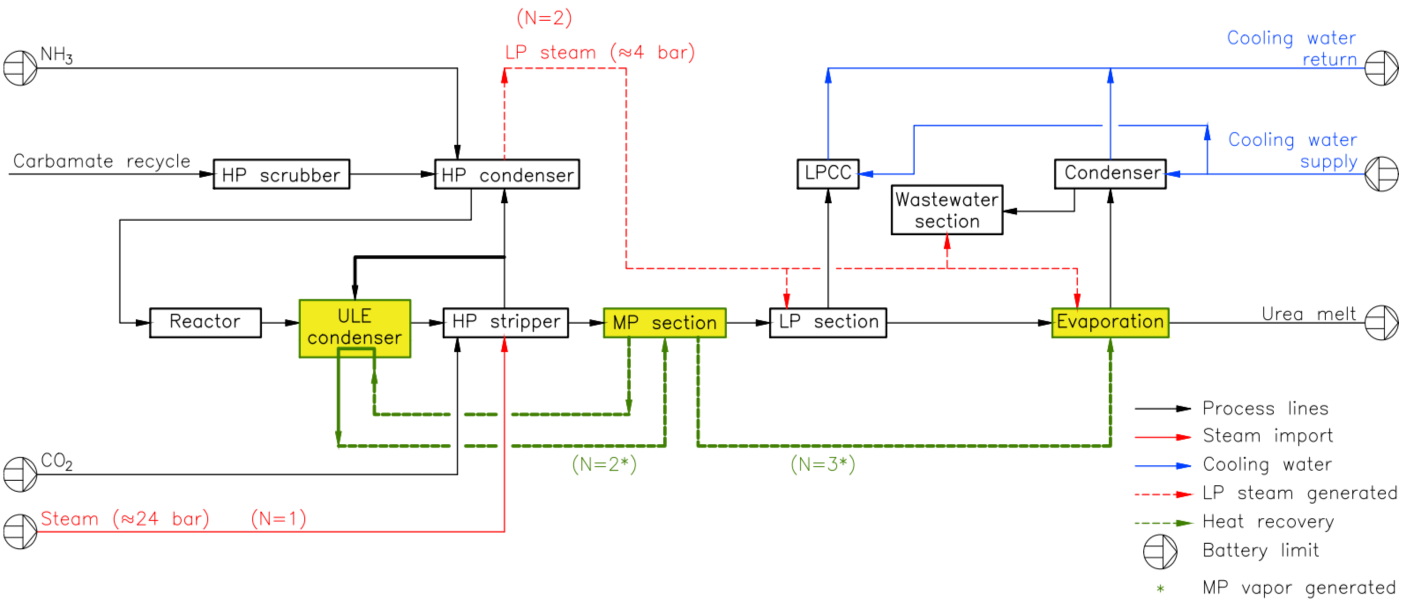


Figure 5: Use the ULE concept as revamp tool to achieve N=3 philosophy.

5.2.1 Revamp concept: Integration of ULE carbamate condenser (Process-to-Process scheme)

As part of the proposed revamp concept, the synthesis section is expanded through the integration of the ULE carbamate condenser, which utilizes condensation heat to drive the dissociation of non-converted carbamate in the urea solution outlet of the HP stripper. This condenser can be configured in either vertical or horizontal orientation. A vertical design as indicated in figure 3.1,3.2 or 3.3 is generally preferred due to layout constraints encountered in existing plant plot plans. However, due to hydraulic limitations within the synthesis loop, a horizontal configuration may prove to be the most practical and feasible solution in case located downstream the existing HP reactor.

In general, alternative locations within the synthesis loop, rather than solely downstream of the existing HP reactor, can also be considered when implementing the ULE revamp concept in urea stripping plants, including but not limited to Stamicarbon designs. The optimal placement of the ULE condenser ultimately depends on specific project constraints, such as the licensor's requirements, plant layout, and available pressure drop.

The new ULE carbamate condenser provides additional liquid volume, effectively expanding the synthesis section. Furthermore, the increased heat transfer surface enhances the overall condensation capacity, enabling higher throughput and improves the energy efficiency by generating MP gases within the tubes, which are subsequently utilized for heat integration in the downstream section.

Moreover, the integration of the new ULE carbamate condenser helps to unload the existing HPCC. As a result, the plant generates less LP steam, but at a higher pressure, which is advantageous for downstream LP steam consumers.

The liquid outlet from the new ULE condenser is sent to the existing HP stripper where the unconverted carbamate is decomposed using saturated HP steam (N=1).

Part of the HP stripper off-gases, containing ammonia, CO_2 and water vapors, is introduced to the ULE carbamate condenser via a sparger. The condensation heat from the stripped vapor is utilized to decompose the carbamate before it enters the MP recirculation section, operating at pressures between 10 and 30 bar(a). The released ammonia and carbon dioxide are subsequently condensed in the shell side of the new pre-evaporator, and the associated condensation heat is used to concentrate the urea solution in the tube side of pre-evaporator, enhancing overall process efficiency. The amount of stripped gases to the ULE condenser will be adjusted to meet the heat requirements for the new MP recirculation heater (bundle of the ULE carbamate condenser).

The non-condensed gases from the newly installed ULE condenser are combined with the overhead gases from the HP reactor, and the resulting mixture is directed to the HP scrubber for further treatment and recovery.

The process-to-process heat exchanger (bundle of the ULE carbamate condenser) operates with two pressure levels:

- Shell side matches the synthesis pressure, where stripped gases are introduced.
- Tube side operates at MP recirculation pressure, where the expanded stripper effluent is processed.

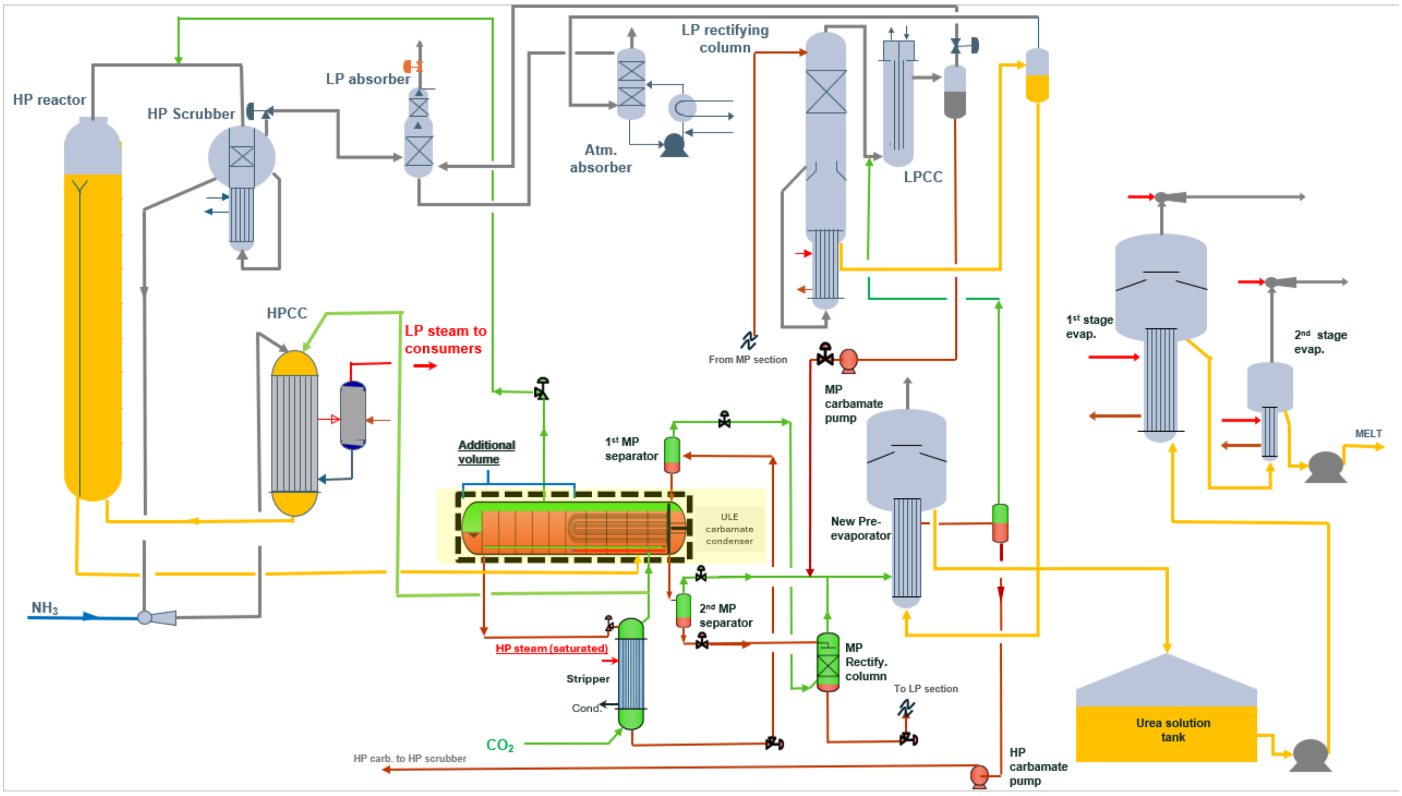


Figure 6: Overall schematic process flow diagram for the new ULE concept for revamping the urea plants.

The key factor in achieving the lowest steam consumption is to operate the HP stripper at low stripping efficiency which also allows optimum flashing in the downstream. To maintain this operational philosophy, it is essential to minimize LP steam export as much as possible, ensuring that the available energy is efficiently utilized within the process. The implications of this operating strategy on the admission steam requirements of the HP CO_2 compressor steam turbine should be assessed accordingly.

5.2.2 MP section operation and integration

The urea solution exiting the HP stripper is flashed to a medium pressure range (10–30 bar). This adiabatic flash facilitates partial decomposition of the carbamate into ammonia and carbon dioxide vapors. The resulting gas-liquid mixture is separated in the first MP separator as indicated in process scheme figure 6.

The liquid stream from the first MP separator is then heated in the carbamate bundle of the ULE condenser, promoting further decomposition of the remaining carbamate (N=2). The gas and liquid phases leaving the ULE condenser are separated in the second MP separator.

The liquid from the second MP separator flows into the MP rectifying column. To optimize the ammonia-to-carbon dioxide ratio of the incoming liquid, the CO_2-rich gas from the first MP separator is introduced into the bottom section of the MP rectifying column. The resulting urea solution from the MP rectifying column is then discharged to the existing LP recirculation section.

The off gases from the MP rectifying column, along with those from the second MP separator, are combined and condensed in the shell side of the new pre-evaporator. The released condensation heat is utilized on the tube side to concentrate the urea solution (N=3).

The carbamate and non-condensed gases leaving the pre-evaporator are separated in the MP carbamate level tank. The carbamate is then transferred to the existing HP scrubber via the HP carbamate pump, while the low-inert off-gases are routed to the LP section.

Additionally, carbamate from the LP recirculation section is sent to the shell side of the new pre-evaporator via the new MP carbamate pump, serving as an absorbent agent.

The required duty of the shell side depends on the selected operating pressure of the MP section. If additional condensation duty is needed, process water from the ammonia water tank and wet recycle from the granulation unit can be added to the urea solution at the inlet of the new pre-evaporator, helping to balance the thermal loads between the shell and tube sides.

In the ULE concept, the feed to the LP section is rerouted from the outlet of the HP stripper to the outlet of the MP rectifying column.

This rerouting is a direct result of operating the HP stripper at reduced stripping efficiency to achieve significant energy savings, like what is achieved in ULE grassroot plants. Consequently, the urea solution entering the LP section contains higher ammonia content, leading to an increased N/C (nitrogen-to-carbon) ratio. LP section will be operating accordingly based on the new conditions after the revamp.

Lowering the stripping efficiency can be also beneficial in extending the lifetime of the stripper due to operating at lower temperatures at the shell side. Additionally, lower biuret content and lower hydrolysis, lower flooding risks for the HP stripper are anticipated at these new conditions.

6 CHALLENGES OF ULE CONCEPT AS A REVAMPING TOOL

6.1 Process challenges

While the ULE carbamate condenser introduces a transformative concept in plant revamping, the following process-related challenges must be considered:

- **Achieving revamp objectives**
  As outlined in Section 4, the implementation of the ULE carbamate condenser aims to meet specific revamp goals. Tailoring the design and integration of the ULE carbamate condenser to align with these objectives is essential for project success.
- **Hydraulic impact on the synthesis loop**
  In Stamicarbon-designed plants, integrating the ULE carbamate condenser into the existing synthesis loop introduces an additional pressure drop. While Stamicarbon's gravity-driven loop design is inherently energy-efficient, this added hydraulic resistance poses a challenge to overall loop performance.

  To address this, Stamicarbon has developed innovative solutions, to draw a portion of the stripped gases from the HP stripper and redirect them to the ULE carbamate condenser, thereby compensating for the additional pressure drop.

  In non-Stamicarbon plants where gravity is not employed as the driving force for flow within the synthesis loop, the integration of the ULE carbamate condenser is less critical. The absence of gravity-driven flow reduces the impact of pressure drop, making the need for such compensatory measures less pronounced.
- **Plug flow regime via CSTR compartments**
  Similar to conventional vertical HP reactors, the ULE carbamate condenser increases reaction yield by promoting a plug flow regime through multiple CSTR compartments. In vertically oriented ULE carbamate condensers, these compartments are separated by siphon jet pump trays, which enhance gas–liquid mixing and thereby improve urea conversion and overall yield. In horizontally oriented ULE carbamate condensers, process baffles serve the same purpose by directing flow and maintaining effective phase contact. For the vertical design, both the compartments and trays must be carefully engineered to minimize back mixing and ensure optimal interaction between the gas and liquid phases.

- **Heat integration configuration**
  The revamp concept supports various heat integration schemes, such as process-to-process or process-to-steam configurations (e.g., generating LP steam at elevated pressure levels). These configurations aim to maximize plant performance by reducing energy consumption. The selection of the appropriate scheme should be based on the specific revamp goals and agreed upon in collaboration with the client.
- **Layout and Dimensions of the ULE carbamate condenser**
  As already indicated and discussed in Section 4.2, multiple orientation options are available for the ULE carbamate condenser. The final layout and dimensions should be determined on a case-by-case basis, considering the spatial constraints and performance requirements of the revamp.

6.2 Mechanical challenges

This chapter presents the mechanical design, challenges, and solutions developed for the ULE carbamate condenser. Key topics include equipment design concepts, leak detection systems, accessibility, constructability, and cost estimation.

6.2.1 Equipment design concepts

Four design concepts were evaluated and can be offered for the condenser:

- **Concept A:** Vertical orientation, tube-sheet at the bottom with top level control (see figure 3.1)
- **Concept B:** Vertical orientation, tube-sheet at the bottom, fully submerged (no level control) (see figure 3.2)
- **Concept C:** Vertical orientation, tube sheet at the top, fully submerged (no level control) (see figure 3.3)
- **Concept D:** Horizontal orientation, similar to the design of the pool reactor/pool condenser (see figure 3.4)

The ULE carbamate condenser utilizes a U-tube design, which is standard for Stamicarbon HP pool condensers and HP pool reactors. Conventional shell-and-tube heat exchanger configurations are unsuitable due to high-pressure requirements for expansion joints.

6.2.2 Leak detection system

a) **Process-to-Process Design:**

Traditional conductivity-based tube leakage detection is ineffective when both sides contain liquid ammonium carbamate. To address this, a dedicated leak detection system, as applied in ULE pool condenser/pool reactor utilized in the grassroot projects, is implemented. This system features radially drilled holes in the tube-sheet, subdivided into several sections for precise isolation and detection of sleeve leakage.

b) **Process-to-Steam Design:**

For process-to-steam designs, tube leakage is detected via conductivity meters indicating ammonia in the vapor/steam outlet line.

6.2.3 Accessibility and maintenance

In general, for the ULE carbamate condensers whether installed vertically or horizontally, the design must ensure full accessibility and compliance with all maintenance requirements

The following measures shall be considered especially in case of vertically oriented ULE carbamate condenser:

- **Installation and inspection access:**
  Access for installation and inspection is provided via a manway with a minimum diameter of 800 mm. Tray cutouts will be optimized to meet inspection requirements.

  The following measures are considered:

  - sufficient spacing between tray skirts and equipment walls to ensure accessibility to E.I-type™ liner plates.
  - the ULE carbamate condenser is mounted on legs to allow removal of the bottom head for tube and sleeve inspection. Skirt-mounted installation is avoided due to access limitations.

- **Removability:**
  All segmental parts of the trays are designed to be removable through the manway, except for TEMA baffles, which are integral. Strip baffles are accessible by removing tray skirts.

6.2.4 Constructability and materials

- **Corrosion protection:**
  E.I-type™ liner plates and overlay welding are used on the shell, manway cover, and tube-sheet to protect against corrosion. Duplex overlay welding is applied on the tube side.
- **Nozzle and flange design:**
  Shell-side nozzles are butt-welded, while tube-side nozzles use flanges for head removal during inspection. Inlet nozzles are designed for optimal flow distribution and protection against erosion.
- **Tube sheet and sleeves:**
  The tube sheet is constructed from carbon steel with E.I-type™ and duplex overlays. Sleeves are seal-welded for leak-tightness due to the corrosive medium.
- **Shell construction:**
  The shell and hemi heads are made from carbon steel with E.I-type™ liners.

6.2.5 Mechanical features

- **U-Tube bundle:**
  The bundle has 1-inch (25.4 mm) tubes with 2.413 mm wall thickness, installed from the bottom or the top hemi-head, with trade-offs in heat exchange and level measurement device placement.
- **Siphon jet pump trays and baffles:**
  In case of vertical ULE carbamate condenser, several trays are installed at equal distances, with U-tubes routed through the tray skirts. TEMA baffles are integral, and gas holes are drilled in the trays for process requirements. Strip baffles are added for tube support, following TEMA rules and Stamicarbon's updated unsupported tube length criteria.

  In case of horizontal ULE carbamate condenser, instead of trays, process baffles are installed at equal distances.
- **Additional features:**
  Tie-rods, temperature wells, insulation, and a radar-level measurement device are included as per standard designs. Leak detection systems monitor liner plates and tube sleeves.

7 SAFETY EVALUATION

As the ULE revamp concept is integrated into an existing Stamicarbon plant, all newly introduced safety scenarios must be assessed, and any new risks must be reduced to an acceptable level. This evaluation assumes the existing plant operates safely prior to the revamp. The assessment below is preliminary and will be refined during project execution based on the finalized revamp scheme and client standards.

7.1 Impact on existing HP section

The preliminary evaluation confirms that implementing the ULE carbamate condenser revamp introduces no new safety scenarios in the HP synthesis section, since the revamp does not change fundamental HP operating conditions or add new risk factors.

7.2 Impact on new MP add-on section

Rerouting the HP section to the new MP section after the ULE condenser revamp introduces new high-pressure scenarios:

1. **Pressurization from HP Section:** Gas slippage from the HP stripper during upsets (e.g., loss of bottom level or valve failure) or during draining may pressurize the new MP section.
2. **ULE condenser tube rupture:** A tube rupture may introduce HP into the MP section.
3. **Backflow via HP carbamate pump:** HP backflow to the MP section may occur through the pump.

To mitigate these risks and ensure compliance with safety standards, the following measures are incorporated into the design:

- **Material selection:** ULE condenser built from E.I-type™ for maximum corrosion resistance and reduced rupture risk.
- **Leak detection:** Installation of an efficient leak detection system.
- **Pressure protection:** Pressure safety valves in the MP section sized for all HP-origin scenarios.
- **Interlock system:** Reliable interlock system with shut-off valve to isolate HP from MP.

7.3 Impact on existing LP Section

In Stamicarbon plants without MP sections, the LP section will be connected to the new MP section instead of the HP section. New high-pressure scenarios may appear but with lower severity due to reduced pressure differential.

Identified scenarios are as follows:

1. **Pressurization from MP Section:** Gas slippage from the MP stripper during operation or draining.
2. **Pre-evaporator tube rupture:** MP pressure may enter the LP section.
3. **Backflow via MP carbamate pump:** Backflow from MP to LP.

To mitigate these risks, the following measures are proposed:

- **Corrosion-resistant materials:** Appropriate materials for the MP section.
- **Re-evaluation of LP safety systems:** Review of existing LP protections for backflow, draining, and tube rupture scenarios, with modifications as needed.
- **Interlock system:** Reliable interlock and shut-off valve between MP and LP.

- **Water seal review:** Verification that atmospheric tank water seals can handle new pressure scenarios.

7.4 Impact on existing steam system

If the ULE carbamate condenser is integrated with the steam system (process-to-steam heat integration), a tube rupture may introduce a new high-pressure scenario. Although similar to existing scenarios from HPCC tube rupture, the specific effects of a ULE condenser rupture must be reassessed. Existing steam safety provisions must therefore be reevaluated to ensure they adequately address this additional risk.

8 CONCLUSIONS

In a market where every kilowatt of energy saved and every extra ton of urea produced matters, the ULE revamp concept stands out as far more than a technical upgrade—it is a strategic transformation. ULE reshapes how existing urea plants recover heat, integrate process steps, and accommodate capacity expansion, setting a new benchmark for smart, future-ready revamping.

Why ULE represents the next generation of plant revamps:

- **Exceptional performance gains:**
  ULE enables plant owners to achieve up to 30% steam savings, as much as 45% additional capacity, and significantly reduced operating costs—without compromising safety, quality, or reliability. These benefits are driven by a powerful combination of increased reaction volume, superior N=3 heat recovery, inherently safe process design, and robust mechanical reliability.
- **Versatile and compatible with Stamicarbon and non-Stamicarbon plants:**
  The ULE concept has been successfully demonstrated in grassroots designs, delivering its expected advantages in energy efficiency and scalability. Its application as a revamp solution for existing urea plants, whether Stamicarbon or non-Stamicarbon, remains a promising next step. The concept is inherently designed to accommodate the typical brownfield constraints, such as synthesis loop hydraulic limitations, layout restrictions, and the need for improved operational stability. The added MP section acts as a buffer between HP and LP sections, helping stabilize plant performance and enhance controllability.
- **A breakthrough heat recovery solution the ULE Carbamate Condenser:**
  At the core of the concept is the ULE carbamate condenser, an advanced shell-and-tube U-tube heat exchanger that combines highly efficient heat recovery with additional reaction volume. Its flexible design allows vertical or horizontal installation at several potential locations within the synthesis loop, with the optimal configuration tailored to each specific project.

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