

Overcoming Caustic-Free Cleaning Challenges with MVR Evaporator-Crystalliser

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Abstract

ALTEO's Gardanne refinery has faced significant operational challenges following its rapid transition from bauxite feed to alumina trihydrate (ATH) feed, which has eliminated the need for caustic soda. Key issues include the descaling of existing refinery tanks without fresh caustic, as well as managing sodium carbonate (Na_2CO_3) levels in the liquor, now that desilication product (DSP) and carbonate causticisation no longer provide a removal pathway. Additionally, ALTEO is committed to achieving net-zero CO_2 emissions by 2050 and eliminating process water discharge to the environment by 2030.

To address these challenges, ALTEO requires a sustainable method for producing caustic cleaning liquor without relying on fresh caustic soda. The proposed solution is a Mechanical Vapour Recompression (MVR) forced circulation evaporator-crystalliser to produce of strong caustic liquor for effective descaling, which offers multiple advantages: i) it operates on France's low-carbon electricity; ii) it provides high energy efficiency; iii) it crystallises Na_2CO_3 for separation.

GEA is supporting ALTEO with its expertise in MVR evaporation and liquor concentration, delivering a tailored design to meet strict capital cost constraints. The system features a compact, skid-mounted configuration for ease of installation, optimised delivery timelines, and energy-efficient operation. The MVR evaporator-crystalliser will contribute to balancing water use, reducing environmental impact, and maintaining operational efficiency within ALTEO's broader refinery transformation. The remaining challenges and future optimisation strategies will also be presented.

Keywords: Strong Liquor, Caustic Descaling, Mechanical Vapour Recompression MVR, Energy consumption, CO_2 emission.

1. Introduction

ALTEO Gardanne, a specialty alumina refinery in France, has strategically transitioned from bauxite feed to alumina trihydrate (ATH) feed [1]. This change, while environmentally beneficial, introduces several new operational challenges. Notably, the transition eliminates the net consumption of caustic soda, which historically played a crucial role in refinery descaling and impurity control. In parallel, ALTEO is pursuing ambitious environmental objectives, including net-zero CO_2 emissions by 2050 and zero process water discharge by 2030.

The design and implementation of the transition from bauxite feed to ATH feed was completed in an exceedingly short time: about 12 months to update the refinery's P&IDs (process and

instrumentation diagrams) and make the necessary design changes, scope the physical changes, and 3 weeks to shut down and implement those changes.

This paper presents the rationale, design, and implementation strategy for a 3 t/h Mechanical Vapour Recompression (MVR) evaporator-crystalliser (“MVR Concentrator”) supplied by GEA. This will serve both as an immediate operational solution and a low-risk pilot for future full-scale deployment of MVR Evaporation.

2. Challenges Created by the Transition to Alumina Trihydrate

The elimination of net caustic consumption has created two significant challenges:

- **Descaling:** Without fresh caustic addition, the refinery lacks a direct source of strong liquor for cleaning tanks and process lines from hydrate scale.
- **Impurity Management:** Sodium carbonate (Na_2CO_3), previously removed via desilication product (DSP) formation, now accumulates in the liquor, affecting process chemistry.

These technical hurdles are compounded by tight regulatory requirements and the alumina industry’s historical aversion to technology risk – a cautious stance rooted in past experiences with costly and disruptive innovations.

3. Short-Term Strategy Post Transition to Alumina Trihydrate

The short-term strategy was to find the most straightforward, most expedient solutions.

Descaling of Whiteside precipitators, tanks, pipes, and seed filters was performed using cleaning liquor prepared with spent liquor and purchased fresh caustic. This was not sustainable, as this would add to the caustic inventory of the refinery. If necessary, a standby digestion unit could have been put online to evaporate spent liquor and produce a caustic cleaning liquor. Again, not ideal as the energy efficiency or coefficient of performance (CoP) would have been exceedingly low, less than 0.5 kJ of evaporation / kJ of steam supplied.

The increase in sodium carbonate concentration in the refinery liquor due to carbonation from atmospheric carbon dioxide was minimised by reducing or eliminating air ingress into the refinery liquor from drops of liquor and slurries entering tanks. However, despite these improvements, carbonate concentrations were still slowly rising by around 0.5 to 1.0 % of total soda per year.

4. ALTEO’s Long-Term Strategy for Refinery Transformation

It is crucial to ALTEO’s future that it retain mastery of the quality of its hydrate while respecting commitments to Net Zero by 2050 and zero process water discharge by 2030. So as part of its step-wise transformation roadmap, ALTEO plans to replace its current digestion system with a more energy-efficient alternative. This new flowsheet will require integrated systems for caustic recovery, impurity control, and water management. Electrification and modularity are key design drivers to ensure compatibility with short-term and long-term decarbonisation goals. The water management would likely include installing an evaporator, as the new digestion envisaged would not remove water from the refinery.

However, in the short to medium term, we still need to produce a strong cleaning liquor from spent liquor without adding fresh caustic. Ideally, it would be preferable to first install an evaporator required to meet the refinery’s net-zero process water discharge by 2030, and then feed the concentrated product to a small evaporator-crystalliser to produce caustic cleaning liquor.

To meet all constraints for the refinery, this ideal scenario is not possible, so ALTEO Gardanne has committed to moving forward step-by-step, by first installing an evaporator-crystalliser that can produce strong caustic cleaning liquor directly from the refinery’s spent liquor. The evaporator, which will be installed later, is designed to remove water and meet the Zero process water discharge target by 2030.

5. Evaporator-Crystallisers: Forced Circulation versus Falling Film

A critical design decision for evaporator-crystallisers in refinery applications, particularly where crystallisation and scaling are expected, is whether to adopt a **falling film** or **forced circulation** configuration. This choice has a fundamental impact on energy efficiency, fouling behaviour, process robustness, and maintenance requirements.



Figure 1 - An example of a Forced Circulation arrangement

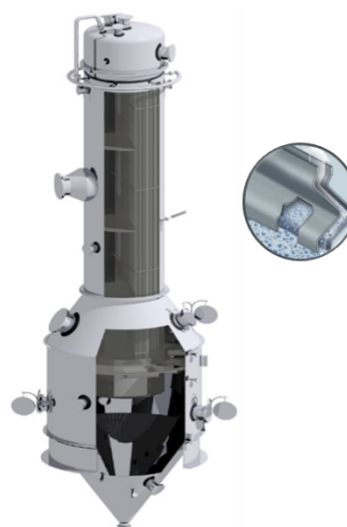


Figure 2 - An example of a Falling Film arrangement

5.1 Design Principles

In falling film evaporators, liquor flows down the inner walls of vertical tubes as a thin film, while steam or recompressed vapour heats the shell side. Evaporation occurs as the film descends, and the vapour-liquid mixture separates at the base. The minimal liquid hold-up, high surface area, and low temperature gradient provide excellent thermal efficiency and low specific energy consumption, particularly advantageous in multi-effect or MVR systems.

However, the very feature that gives falling film units high thermal efficiency – the in-tube boiling – also leads to significant fouling risk, especially with scale-forming solutions such as sodium carbonate-rich Bayer liquors. Vapour nucleation sites on the heating surface can simultaneously become crystal nucleation sites, causing scaling that is difficult to remove without frequent cleaning.

In contrast, forced circulation evaporators pump liquor through the heat exchanger tubes at high velocity and then into a flash vessel where vapour is separated. Since the boiling does not occur inside the tubes, but after, the scaling risk within the heat exchanger is substantially reduced. Crystallisation, when it occurs, happens in the flash vessel, where it is easier to manage. This configuration makes forced circulation ideal for fouling-prone and high-viscosity liquors.

5.2 Comparative Analysis

These design differences directly influence:

- **Fouling Resistance:** Falling film designs are prone to internal scaling due to in-tube evaporation, creating sites for nucleation. Forced circulation units move the boiling phase outside the tubes, dramatically reducing fouling.
- **Process Robustness:** Forced circulation systems tolerate wider feed variability and are less affected by flow or solids content fluctuations.
- **Energy Efficiency:** Falling film units are more thermally efficient due to high heat transfer coefficients, lower temperature inside the tubes and minimal pumping and lower pressure drop. Forced circulation requires higher pumping energy but benefits from reduced downtime and cleaning.
- **Scale Removal:** Only forced circulation systems can accommodate intentional crystallisation of compounds like sodium carbonate and provide robust solids handling design.
- **Operational Complexity:** Forced circulation systems, with easier tube cleaning and isolated crystallisation zones, are generally easier to operate and maintain in scaling applications.

The Table 1 compares the two configurations across key performance criteria:

Table 1 - Forced Circulation versus Falling Film

Criteria	Forced Circulation MVR	Falling Film MVR
Fouling resistance	High (boiling outside tubes)	Lower (boiling inside tubes)
Process robustness	High (handles feed variability well)	Moderate
Energy efficiency	Moderate to good (Higher compression and pumping costs)	Very high (High heat transfer coefficients)
Scale removal	Simpler (crystallisation in flash vessel)	Difficult (In-tube scaling)
Maintenance complexity	Lower (Cleaner tube bundles, easier to access)	Higher (Access to tubes mainly from above)

5.3 Suitability for Alumina Refinery Liquors

Scaling in alumina refinery evaporators and evaporator-crystallisers arises primarily from two types of deposits:

- **Acid-soluble silica scale**, typically associated with high temperatures and moderate caustic concentrations, which promotes the precipitation of sodium aluminosilicates.
- **Water-soluble carbonate and oxalate scales**, which become problematic at high caustic concentrations, due to the reduced solubility of sodium carbonate (Na_2CO_3) and sodium oxalate.

In ALTEO Gardanne’s case, the refinery no longer digests bauxite and therefore no longer generates desilication product (DSP), which previously helped manage carbonate levels. Instead, the goal is to concentrate spent liquor to produce a strong caustic cleaning liquor, with a lower sodium carbonate in solution, down to around 8% of total soda in solution.

This design requirement necessitates significant sodium carbonate crystallization during evaporation. Given this context, a forced circulation evaporator-crystalliser is the optimal choice. Unlike falling film evaporators, where in-tube boiling can trigger premature crystallisation and scaling, the forced circulation design keeps boiling and crystallisation in a separate flash vessel.

This minimises tube fouling, simplifies maintenance, and allows for robust solids handling during the carbonate crystallisation phase.

Moreover, the controlled crystallisation of sodium carbonate within the flash vessel supports future integration of solid-liquid separation equipment, which ALTEO plans to design after commissioning, once the actual particle size distribution of crystallised carbonate is known. The use of a forced circulation system is therefore both a process necessity and a strategic enabler for ALTEO’s long-term water and soda recovery objectives.

6. Energy Technology Selection: MVR versus Steam

6.1 COP Improvements with MVR

MVR can significantly improve the Coefficient of Performance (COP) of the plant [2].

The efficiency of a heat pump is indicated by its COP. The ratio between the amount of useful thermal energy and the electrical energy consumption of the compressor determines the COP.

$$COP = \frac{Q_{thermal}}{Q_{electric}} = \frac{\dot{m} \cdot \Delta h_v}{E_{el}} = \frac{10,000 \text{ kg/h} \cdot 2,202 \text{ kJ/kg}}{170 \text{ kW} \cdot 3600 \text{ s/h}} = \frac{6,117 \text{ kW}_{th}}{170 \text{ kW}_{el}} = 36 \quad (1)$$

The COP is a suitable characteristic value for assessing the energy-saving potential of an evaporation plant with mechanical vapor recompression compared to a thermally heated evaporation plant.

Equation (1) is a generic example of an evaporator having a capacity of 10 t/h of evaporation, as per Figure 3. This is not the capacity of the Gardanne project; rather, it illustrates the potential improvements that can be achieved with MVR.

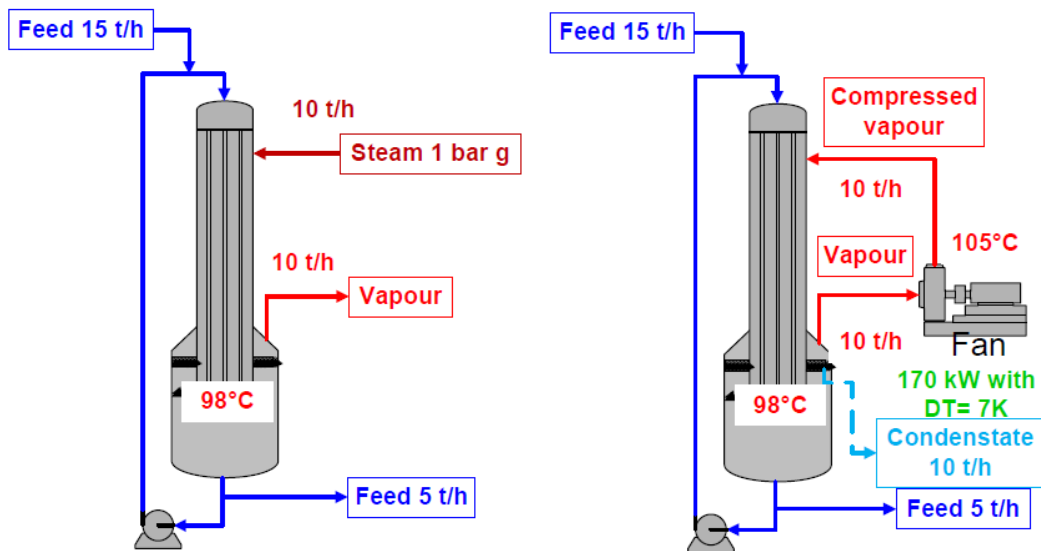


Figure 3. COP comparison of a single-effect evaporator and an MVR evaporator for 10t/h of evaporation.

The above example gives a very valuable COP figure.

Now, if we compare a typical super-concentration unit integrated into a 6-effect evaporation unit with a steam economy of 4 t evaporated / t steam, and a MVR unit with a delta T of 32°C, which is needed for a super-concentrator, we then obtain a COP of 1,9. Here is the calculation, again for 10 t/h of evaporation:

$$COP = \frac{Q_{thermal}}{Q_{electric}} = m * \frac{\Delta hv}{E_{el}} = \frac{\frac{10\,000}{4} * 2202}{800kW * 3600} = \frac{1529\,kW\,th}{800\,kW\,el} = 1.91 \quad (2)$$

This is what we would have obtained with an integration into a multiple-effect system, but the CAPEX would have been too high. The only possibility to have a project was to set up a single effect, either steam-driven or with MVR.

If we consider the super-concentrator as a single effect with a steam-driven system, the comparison with an MVR system comes with more evidence:

$$COP = \frac{Q_{thermal}}{Q_{electric}} = m * \frac{\Delta hv}{E_{el}} = \frac{10\,000 * 2\,202}{1\,250kW * 3\,600} = \frac{6\,117\,kW\,th}{1\,250\,kW\,el} = 4.89 \quad (3)$$

The conclusion is that if a super-concentrator cannot be integrated into an existing multiple-effect unit, it should be implemented with Mechanical Vapour Recompression. Note that the electrical power used above is the maximum installed power; in actuality, the power consumption will be less, and so the actual COP will be greater than 4.89.

A high COP value expresses high efficiency. Revamps from thermal to MVR heating with COP values of approx. ≥ 3 are profitable, depending on energy costs and the expected amortization period, while MVR technology for new systems is profitable at lower COP values, as in the example given above.

In summary, the choice for ALTEO is whether the Evaporator-Crystalliser will be steam-driven or an MVR. The options were:

1. **Multiple-effect evaporator** for energy efficiency, but the capital cost would have been exorbitant and prohibitive for such a small quantity of evaporation.
2. **Single-effect steam evaporator:** The energy efficiency, as the coefficient of performance, would have been around 0.9 kJ of evaporation / kJ supplied steam, meaning that it would consume more than 1 t of live steam to evaporate 1 t of water. This would have required ALTEO to install a larger electrical boiler to meet Net Zero by 2050.
3. **Single-effect MVR evaporator:** Here, the coefficient of performance, despite the high (> 20 °C boiling point elevation), is 4.89 kJ of evaporation / kJ supplied electrical energy. Due to France's robust power infrastructure, its carbon footprint is now relatively low.

7. MVR Evaporation in the Alumina Industry: Background and Barriers

The next issue for ALTEO to consider was the risk of “new” technology.

In the chemical process industry, we estimate there is well over 1 000 MW of installed MVR Evaporation capacity, mainly in China, followed by Europe and the USA. Escher-Wyss (GEA Messo) built its first MVR Evaporator in the 1920s, starting with a pilot. As of 2008, there were 80 MW of installed MVR Evaporation just in the Swiss salt industry. Dr. Martin Zogg provides an excellent history of MVR and the heat pump industry from a Swiss perspective [3]. The application of large-scale MVR Evaporation is primarily in the following industries:

- **Salt and Trona Production:** MVR is a standard technology for concentrating sodium chloride and sodium carbonate solutions, particularly in Europe, China, and the United States (e.g., Wyoming's Green River trona mines).
- **Sugar Industry:** Used for juice and syrup concentration in cane and beet sugar refining across Brazil, India, and Europe.
- **Pulp and Paper:** MVR is employed to concentrate black liquor prior to combustion, particularly in Scandinavia and North America.
- **Water Reuse and Desalination:** Integrated into Zero Liquid Discharge (ZLD) systems, especially in regions like the Middle East, China, and India.
- **Lithium and Battery Materials:** Concentrates lithium brines or spodumene leachates in South America and Australia.

Although **Mechanical Vapour Recompression (MVR)** is a mature and widely adopted technology in the chemical and salt processing industries, it remains largely underutilised in alumina refining. MVR evaporators have been commercially deployed for decades to reduce steam demand and operating costs, particularly in applications where waste heat recovery or low-grade energy is available. However, the alumina industry's limited experience with MVR—especially under the scaling and fouling conditions typical of Bayer liquors—has contributed to a cautious attitude toward its adoption.

Two notable examples demonstrate the viability of MVR evaporation in alumina operations:

- **Martinswerk Refinery, Germany:** A large **153 t/h single-effect MVR evaporator**, designed and installed in **1957 by Escher Wyss** (now part of GEA), is one of the earliest industrial-scale MVR applications in the alumina industry. During a site visit in 1995 by Rob Clegg, the unit was observed to be operating satisfactorily. However, no recent data is available on its current performance.
- **Pingguo Refinery, China:** GEA Kestner supplied a **single-effect MVR evaporator** to the refinery, which operated independently for approximately seven years. It was later reconfigured to serve as the **sixth effect** in a five-effect falling film evaporator train – an adaptation likely made to align with the refinery's evolving steam and power balance rather than any performance shortfall.

These examples highlight both the **technical viability** and **integration challenges** of MVR in alumina refining. While the energy efficiency advantages of MVR are well established, their implementation in alumina operations demands careful attention to **scale formation**, **process robustness**, and long-term reliability.

8. Selection of the 3 t/h MVR Concentrator

Given the above context and challenges, ALTEO has selected a 3 t/h GEA MVR forced-circulation evaporator-crystalliser to produce concentrated caustic cleaning liquor for dissolving alumina hydrate scale in the refinery. The unit is a forced circulation arrangement as the sodium carbonate will crystallise, reducing the concentration in solution to well below the level typically found in metallurgical alumina refineries, to less than 8% of total soda.

Separating the sodium carbonate precipitate will not be part of the project's initial scope, as the precipitate's particle size distribution (PSD) is complex to determine prior to commissioning. The PSD will directly impact the type and size selection of solid-liquid separation equipment. By deferring the separation and processing of the sodium carbonate and other co-precipitated impurities, we reduce the risk of poorly designed processing steps.

The design is modular, skid-mounted, and electrically driven—ideal for integration into ALTEO’s constrained site.

The small-scale evaporation capacity of 3 t/h at the highest caustic concentration, in excess of 250 g/L Na₂O, will provide more confidence in the much larger, less challenging MVR Evaporator’s ability to meet net-zero process water discharge to the environment. The design of the sodium carbonate removal equipment will be finalised after commissioning, based on empirical measurements of the particle size distribution of crystallised solids—a key parameter not reliably predictable by simulation.

9. Materials of Construction

The construction materials have been reviewed to optimise the project's cost. Different options, such as Monel 400, Super-duplex 2507, and 316L SS, were studied. The forced circulation technology requires a relatively high circulation flow rate, which leads to high velocities and can accelerate corrosion and potentially damaging the piping of the recirculation loop or the heat exchanger tubes. The more resistant the construction material is, the longer the technology will last.

GEA, in consultation with ALTEO, has selected moderately noble construction materials as the unit will not always be required, and the operating factor will decrease after a few years of operation. Regular inspections will be necessary to monitor for caustic corrosion cracking and replace damaged sections as needed.

10. Risk Management

10.1 Project Risk Strategy

Adopting new process technology in the alumina industry requires careful risk mitigation, given the sector’s well-founded caution. Past experiences – where the introduction of unproven equipment or process modifications led to serious operational and financial consequences – have ingrained a deep aversion to innovation risk, particularly for core refinery operations such as evaporation.

To overcome these barriers, ALTEO Gardanne and GEA structured the MVR evaporator-crystalliser project to explicitly share risk and demonstrate performance through a phased, evidence-based approach. Key elements include:

- **Performance Guarantees:** GEA has committed to guarantees on evaporation capacity, specific energy consumption, and the concentration of the caustic liquor produced. These are contractually defined and reflect ALTEO’s core technical requirements for descaling.
- **Pilot-Scale Capacity:** The initial unit is limited to 3 t/h of water evaporation – enough to supply cleaning liquor, yet small enough to manage risk. This scale enables ALTEO to validate crystallisation behaviour, reliability, and operational integration before considering a larger-capacity MVR unit for its future digestion circuit.
- **Modular and Skid-Mounted Design:** To minimise site integration risk, the MVR unit is supplied in a pre-assembled format with minimal refinery interface. This enables fast installation and commissioning with low disruption.
- **Crystallisation Flexibility:** While the MVR unit will promote sodium carbonate crystallisation, the solid-liquid separation equipment will be designed and installed after the unit is commissioned. This ensures the chosen design reflects the actual particle size distribution observed in practice.

This structured approach gives ALTEO high confidence in the equipment's performance while reducing exposure to technological and financial uncertainty – key for fostering internal support and long-term refinery transformation.

10.2 Risk Mitigation

There are four basic strategies for Risk Management:

1. Avoid
2. Accept
3. Transfer, and
4. Mitigate

Avoid: Producing strong caustic cleaning liquor with an MVR forced circulation evaporator crystalliser cannot be avoided, as the alternatives are not sustainable and costly.

Accept: ALTEO believes that selecting GEA Kestner as the technology supplier, which has extensive experience supplying evaporators to the alumina industry and MVR evaporators to the broader chemical industry, is the lowest acceptable risk.

Transfer: The performance guarantees in the supply contract ensure that GEA, the supplier, bears at least some of the risk. Insurance is also an option.

Mitigate: The combined project team has identified known risks and has put in place a Risk Register, which includes:

- Damage to high-speed compressors from entrained solute:
 - Multi-stage compressors that were used in the past have been replaced with a series of more robust single-stage compressors
 - Vapour cleaning with a proven system reduces risk to negligible levels
 - Conductivity meters on condensate will indicate if there is an anomalous level of solute in the vapour
 - Robust liquor level measurement to reduce risk of carryover
 - Vibration sensors on the compressors will indicate a buildup of solute
- Caustic corrosion cracking:
 - Regular inspections and replacement as necessary
 - The unit for ALTEO is designed for a limited life, as per ALTEO requirements
 - If in the future, ALTEO wishes to extend the life of the MVR Concentrator beyond the original scope, the equipment is small enough for all elements to be easily replaced with more noble materials as required
- Scaling of the equipment, particularly the heat transfer surfaces
 - For ALTEO, there is little to no risk of silica and oxalate scaling as the refinery no longer processes bauxite
 - There will be carbonate scaling, mainly in the inlet pipe to the vapour/liquid separator, and in the separator itself, which can be removed by hot water washing with the product condensate
 - There will be provision to acid-wash, but at an infrequent basis
 - There will be no hydrate scaling
- Alumina hydrate in the feed
 - Not expected to be an issue as it will dissolve in the strong evaporated liquor
- Power failure
 - Fail-close valves will be included at appropriate locations
- Low temperature of the feed

- Live steam is added to the heat exchanger, especially during the startup of the equipment
- High temperature of the feed
 - Vent vapour from the heat exchanger
- Hole in heat exchanger tube
 - Will be detected by the conductivity of the product condensate
- Errors in operating and maintaining the equipment
 - GEA will provide training and documentation
 - ALTEO has developed its own SysCAD model of the MVR Concentrator to understand better the technology that they will have to manage

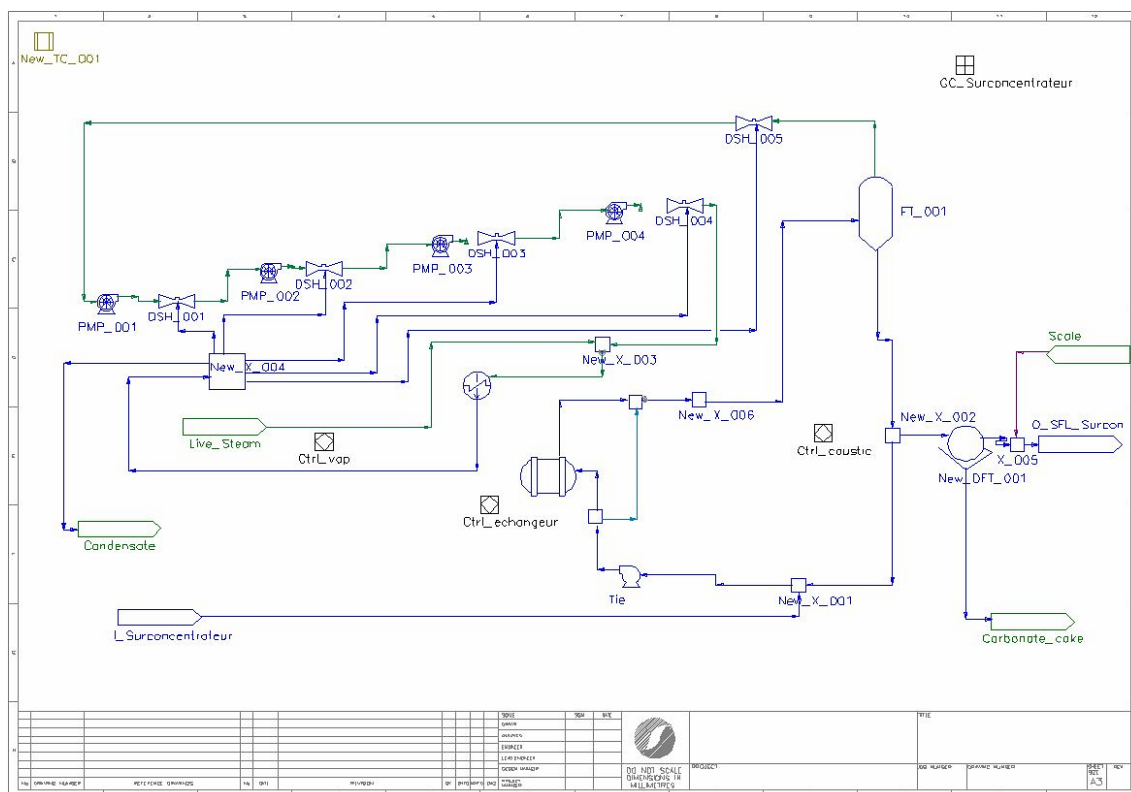


Figure 4. ALTEO's SysCAD model of the MVR Concentrator

These provisions reflect ALTEO's strategy to de-risk innovation while building toward a scalable, long-term solution.

11. Contribution to Net Zero and Long-Term Refinery Transformation

The MVR Concentrator supports ALTEO's decarbonisation goals through:

- **Electrification:** Zero direct CO₂ emissions from this operation
- **High energy efficiency:** 4.89 kJ evaporation per kJ of energy supplied, coefficient of performance
- **Low operating costs** relative to steam evaporation
- **No cooling water requirement**, reducing water footprint
- **Crystallisation of sodium carbonate**, aiding impurity control

This initiative marks the first significant step in transitioning Bayer's legacy operations to a cleaner, more energy-efficient refinery. The unit utilises France's low-carbon electricity and eliminates the need to consume fresh caustic soda for cleaning operations. Concentrating refinery

spent liquor enables sodium carbonate crystallisation, helping to manage impurities without the need for chemical additives or additional CO₂ emissions.

Additionally, the unit enhances ALTEO's circular water management strategy by recovering water from spent liquor for reuse, thereby contributing directly to reduced discharge volumes. Its relatively small capacity makes it ideal as a low-risk pilot for a larger future MVR evaporator that will be critical in removing water from liquor in the new digestion system.

In this way, the project not only addresses immediate descaling needs but also provides essential operational experience and design input for a future high-capacity MVR system – an enabler of ALTEO's complete refinery decarbonisation pathway.

12. Conclusions and Next Steps

ALTEO Gardanne's transition from bauxite to alumina trihydrate feed has eliminated the natural caustic consumption previously used to manage impurities and control scaling. This shift introduced a new operational challenge: generating high-strength caustic cleaning liquor without relying on fresh caustic soda – while meeting ambitious sustainability goals.

The selected solution – a small-scale, single-effect MVR evaporator-crystalliser – offers a technically robust and energy-efficient approach. It concentrates spent liquor using France's low-carbon electricity and enables sodium carbonate crystallisation for potential impurity removal. Its forced circulation design is tailored to handle the scaling behaviour of refinery liquors and reduces fouling risk. GEA has committed to performance guarantees, and the skid-mounted modular design minimises integration risk, allowing rapid commissioning and reduced disruption to ongoing operations.

This MVR unit serves not only to meet the immediate descaling needs but also as a **pilot project** that will inform the design of a more extensive, high-capacity MVR system to be integrated with ALTEO's future energy-efficient digestion process.

The next step in the project is the implementation of sodium carbonate removal equipment, to be designed and installed once the MVR unit is commissioned and the particle size distribution of crystallised carbonate is fully characterised. This staged approach ensures the solid-liquid separation process will be both efficient and refinery-specific.

Importantly, this initiative offers a replicable model for the wider alumina industry – particularly for refineries processing low-silica bauxites, which generate little desilication product and therefore have limited capacity to produce strong caustic liquor for descaling their whiteside. Such refineries may benefit from adopting ALTEO Gardanne's energy-efficient approach to generating cleaning liquor using MVR technology.

This project demonstrates how pilot-scale innovation, supported by appropriate guarantees and phased risk management, can unlock decarbonisation and circular water strategies in alumina refining, contributing meaningfully to Net Zero targets without compromising process reliability or cost efficiency.

13. Acknowledgements

The authors gratefully acknowledge the collaboration between **ALTEO Gardanne**, **GEA Process Engineering**, and **Sahl Regen** in advancing sustainable solutions for alumina refining. The success of this initiative reflects the shared commitment to innovation, operational reliability, and long-term environmental responsibility.

14. References

1. Guillaume Bastien et al., Alteo Gardanne Refinery: 130 Years of adaptation to meet the dual challenges of environmental protection and added value, TRAVAUX 53, Proceedings of the 42nd International ICSOBA Conference, Lyon, 27 - 31 October 2024 <https://doi.org/10.71659/icsoba2024-kn003>.
2. François Delannoy et al., Diversity of Applications for the Mechanical Vapour Recompression Technology, 12th International *Alumina Quality Workshop*, 22–24 April 2024, Dubai, United Arab Emirates, <https://aqw.com.au/papers/item/diversity-of-applications-for-the-mechanical-vapour-recompression-technology>.
3. Dr. Martin Zogg, History of Heat Pumps, Swiss Contribution and International Milestones, 9th International *IEA Heat Pump Conference*, Zurich, Switzerland, 20–22 May 2008, <https://www.zogg-engineering.ch/publi/historyhp.pdf> (Accessed on 29 May 2025) and https://www.zogg-engineering.ch/publi/iea_hpc08_zogg.pdf (shorter version) (Accessed on 29 May 2025).