A COOLER APPROACH: PART TWO

In the second part of a two-part article, **Dr Lotfi Redjem Saad, Head of Heat Transfer Department at Technip Energies, and Andreas Knoepfler, Director Product Management at Wieland-Werke AG (Business Unit Thermal Solutions)**, analyse the use of enhanced heat transfer technologies in a real-world case study and its contribution to reducing greenhouse gas emissions for an existing LNG facility.

As the global natural gas liquefaction capacity continues to grow, reaching around 495 million tpy in 2024, the industry is increasingly focused on making LNG production more efficient, reliable, and sustainable. In part one of this article series, the development and deployment of dual-enhanced tubes in LNG pre-cooling heat exchangers was discussed, demonstrating their excellent performance and reliability, which have already contributed significantly to improving efficiency and operational stability.

Building on that progress, part two will explore how innovative heat exchanger design can further optimise plant performance, using a case study of a collaboration between Technip Energies and Wieland. By enhancing heat transfer efficiency and reducing approach temperatures, the companies aim to increase LNG output, lower energy consumption, and minimise environmental impact. This partnership exemplifies how combining expertise and advanced technology can support the industry's shift towards greener, more cost-effective solutions, advancing the global energy transition.

Heat exchanger design aspects

Since heat exchangers in LNG precooling trains play a major role in the operational performance of a LNG facility, it is a perfect opportunity to implement innovative

heat transfer technology. Propane chillers are one-pass design with the tube side stream of natural gas or mixed refrigerant (MR) operating in series. On the kettle-shell side, different pressure levels set the corresponding propane boiling temperatures. Consequently, the heat flux varies from tube inlet to outlet. Table 1 shows the representative conditions in a high-pressure (HP) propane chiller for a Gulf of Mexico project.

Because vapour production is proportional to the temperature difference, about five times more vapour is generated at the heat exchanger inlet. This leads to heterogeneous entrainment behaviour, raising questions about managing liquid carryover. Typical methods for this include:

- Dividing the kettle length into parts and the sizing shell diameter based on the most critical section, relying solely on gravity, which is a very conservative approach.

- Adjusting nozzle sizes and locations along the kettle to match local vapour production, enabling efficient vapour removal, and preventing congestion, though this results in complex piping and stress analysis.

- Installing mist eliminators (Figure 1) horizontally and perpendicular to vapour flow, which forces vapour through wire meshes or perforated plates based on local vapour velocity. Computational fluid dynamics (CFD) studies may be needed to optimise mesh placement, considering disengagement space to limit pressure drop and maximise efficiency. This method stabilises vapour flow and makes nozzle placement independent of vapour generation.

Table 1. Operating conditions for a project in the Gulf of Mexico

Propane boiling temperature = 17˚C	Natural gas temperature (˚C)	Temperature difference (˚C)
Natural gas inlet side	33	16
Natural gas outlet side	20	3

Figure 1. Typical mesh-type mist eliminator pad (left) and mist eliminator with chevron type vanes (right). Source: Koch-Glitsch.

Table 2. Standard K values

Standard K values (m/sec.)	Vertical flow	Horizontal flow
Mesh	0.107	0.128
Vane	0.152	0.198
Vane double pocket	0.305	0.305

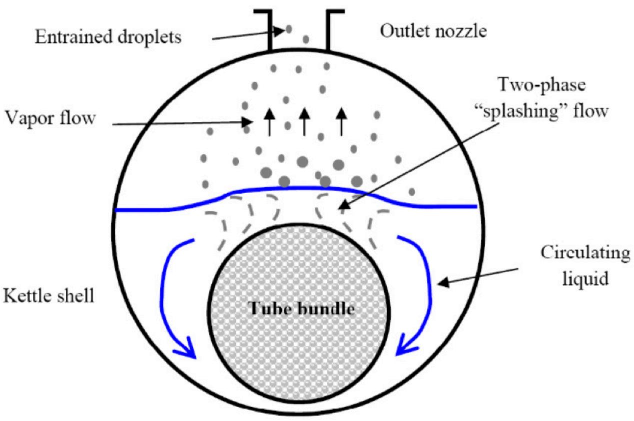

Figure 2. Cross section of a kettle reboiler.

Moving from plain or low fin tubes to dual enhanced nucleate boiling tubes results in lighter, more economical chillers (up to 50% shorter). When entrainment control relies solely on gravity, the separation volume must be maintained, which increases diameter as length decreases. This impacts fluid inventory and safety.

This article focuses in particular on using enhanced heat transfer technology – when using dual enhanced nucleate boiling tubes in gravity-based designs, it is like installing a Formula 1 engine in an outdated car. That is why Technip Energies (T.EN) and Wieland have developed 'enhanced chillers', combining advanced boiling tube technology (GEWA-PB) with optimised kettle design to create the most compact, lightweight solutions with low carbon dioxide (CO_2) emissions.

Liquid separation in chillers with mist eliminators

Chillers in propane precooling cycles of LNG plants are based on shell and tube heat exchangers, known as kettle type (K type per TEMA). The kettle vaporises liquid and ensures droplet removal to protect the compressor. The liquid (droplets) carried with vapour is expressed as a percentage or kilogramme of liquid per kilogramme of vapour and is crucial in kettle design. It involves the total liquid quantity, not droplets size.

The kettle reboiler consists of a tube bundle with hot fluid inside (Figure 2), immersed in a shell acting as a boiling pool and droplet disengager. When boiling occurs, two-phase flow circulates: liquid flows downward, vapour rises. Near the surface, splashing causes large droplets to fall back, while smaller droplets are entrained with vapour (entrainment).

Predicting entrainment is complex; research, such as from HTRI®, offers proprietary correlations linking entrainment ratios to vapour velocity, which depends on vapour flow and kettle geometry. Critical entrainment velocity (Vcr) marks the threshold where shear forces balance gravity, influencing droplet entrainment. Calculations involve vapour flow, physical properties, and iterative sizing of the kettle diameter.

To minimise entrainment, increasing volume or diameter of the kettle is necessary if tube length is fixed.

Mist eliminators – wire mesh or vane types – are used to reduce kettle size.

They operate via inertial impaction, coalescing droplets for gravity separation. Their capacity is limited by flooding and re-entrainment, controlled by the gas velocity, often calculated with the Souders-Brown equation, using standard K values (Table 2).

$$V_G = K\sqrt{\frac{\rho_L - \rho_G}{\rho_G}}$$

Where:

- ◆ VG gas velocity (m^2/sec.).
- ◆ K vapour load velocity (m^2/sec).
- ◆ ρL liquid density (Kg/m^3).
- ◆ ρG gas density (Kg/m^3).

Mist eliminators typically remove over 99% of droplets larger than 3 – 10 μm (mesh) or 10 – 40 μm (vane). Efficiency depends on design parameters like mesh density, plate spacing, and material.

Smart enhanced chiller

Smart enhanced chiller (S.E.C.) designs represent the most compact heat exchanger with minimal refrigerant charge and volume, ensuring proper entrainment behaviour to protect the compressor. The patented S.E.C. uses strategic placement of mist eliminators combined with a deflector plate. This offers several advantages over standard horizontal mist eliminator setups, including:

- Space optimisation within a smaller volume to meet Souders-Brown velocity.
- Higher efficiency through combining wire mesh and vane pack mist eliminators, with coalesced droplets directed downward to the deflector plate and drained back, reducing re-entrainment risk.
- A deflector plate at the bottom ensures even vapour distribution around the mist eliminator, confirmed by CFD studies and vendor validation.
- Unlike standard tubes, dual enhanced nucleate boiling tubes operate efficiently without flooding, maintaining a wet surface in the foam region. This enables lower liquid levels without impacting cooling, as confirmed by numerous site references.
- Proven eliminator technologies can reduce inlet and outlet nozzles on the shell side, depending on process conditions.

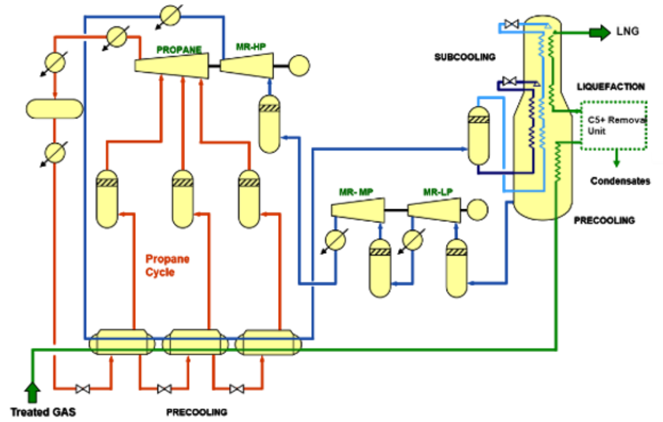

Figure 3. Split-MR liquefaction typical configuration.

Overall, S.E.C. designs produce compact, cost-effective heat exchangers with a smaller carbon footprint by reducing material use. CFD is used for design validation, illustrating velocity fields in a chiller dome (Figure 5). Figure 4 compares conventional sizing with a smart enhanced design, showing potential kettle diameter reductions up to a factor of two, e.g. at HP stage.

Case study: From 3K to 1K temperature approach

Most precooling cycles worldwide are designed using a 3K temperature approach, which is the difference between the outlet FG or MR temperature and the propane boiling point of the chiller.

A generic case was developed to evaluate the performance of precooling cycles at three temperature approaches (3K, 2K, and 1K) on propane vaporisers.

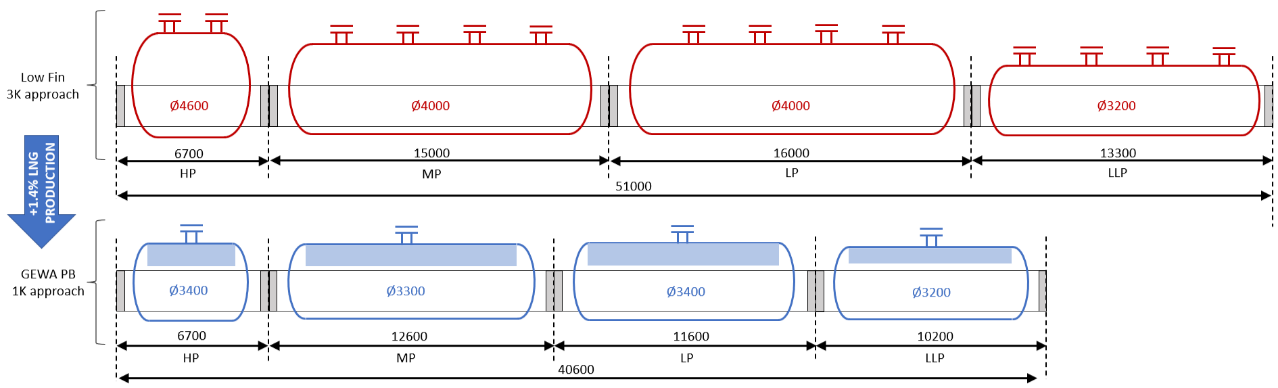

Figure 4. Impact of disengagement method: Conventional method vs smart enhanced chiller (e.g. mixed refrigerant [MR] chilling train at 2K approach design with GEWA-PB tube).

The goal is to demonstrate the benefits of dual enhanced tube technology combined with the S.E.C. design, including improved LNG plant performance, refrigeration efficiency savings, and reduced CO_2 emissions.

The case considers a 5 million tpy LNG train using C3MR technology, with refrigeration compressors arranged in a split-MR configuration (HP compression on the same shaft as the propane compressor) (Figure 3).

The propane precooling cycle includes four pressure stages (HP, MP, LP, LLP) for both natural gas and MR circuits. The LNG train is air-cooled under US Gulf Coast ambient conditions.

The study compares technologies at 3K approach, evaluates propane compressor power at 3K/2K/1K with S.E.C.-based vaporisers featuring dual enhanced nucleate boiling tubes, and assesses LNG capacity gains from propane power savings and tube technology in grassroots and revamp projects.

From conventional to S.E.C. design

The first study, based on 3K approach temperature, confirms the already well-known benefits on the chilling train characteristics of using S.E.C. equipped with dual enhanced nucleate boiling tubes (GEWA-PB), compared to the conventional low-finned tube-based design (26 fpi low fin tube) (Figure 8).

For identical operating process conditions, C3 vaporisers of FG and MR trains, designed with S.E.C. and dual enhanced nucleate boiling tubes, are shorter by about 40% and lighter with a direct positive impact on the weights of piping, concrete for foundation, and steel for structure. Furthermore, the size reduction of the exchangers results in a 40% CO_2 emission reduction during the manufacturing phase compared to a standard design using low-finned tubes; additional savings of CO_2 for surrounding equipment can be added to this value.

The compactness of heat exchangers and use of dual enhanced tubes has an impact on the kettle size for the same liquid/vapour entrainment ratio compared to the outdated industry standards using conventional methods. S.E.C. designs result in an advantage on the kettle diameter, considerably reducing the exchanger dimensions compared to conventional methods (Figure 8). Thus, heat exchanger efficiency, compactness, LNG production rate, and overall greenhouse gas (GHG) emissions can be beneficially balanced.

Lowering temperature approach to reduce energy consumption and GHG emissions

In a liquefaction unit, 30 – 35% of refrigeration power is used for precooling. Since propane compressor duty depends on the temperature approach on vaporisers and condensers, reducing these temperature approaches can improve cycle efficiency by lowering the compression ratio.

Nowadays, the industry is moving to 2K temperature approach in the chilling trains. Nevertheless, with conventional 'low fin design', the heat transfer performance decreases substantially and the use at temperature approaches lower than 3K becomes inefficient. Dual enhanced nucleate boiling surfaces become essential to improve nucleation, as part one of this article described.

Reducing the approach from 3K to 2K and 1K on propane vaporisers – while maintaining LNG capacity – can improve cycle efficiency by 2.2% and 4.4%, respectively, and reduce CO_2 emissions proportionally by decreasing fuel gas consumption (Figure 6).

CO_2 emissions during equipment manufacturing are mainly proportional to the material weight. Based on former studies,[1] CO_2 emissions from heat exchangers have been focused around Scope 3 emissions, according to the Greenhouse Gas Protocol.[2]

For an expected LNG capacity production at identical temperature approach, the change from conventional chiller design equipped with low-finned tubes to S.E.C. design equipped with dual enhanced nucleate boiling tubes leads to a vaporiser weight reduction close to 45%, reducing manufacturing CO_2 emission by about 40% (Figure 7). Considering a reduced temperature approach from 3K to 1K, the material weight and thus CO_2 emissions from heat exchanger manufacturing remain lower than conventionally designed, equipped with low-finned tubes at 3K temperature approach. This can be as high as 15% and 8%, respectively. In addition, it should be noted that propane compressor energy consumption can be lowered by 4.4%.

In the case that this compressor is driven by a gas turbine without CO_2 capture, around 4.4% less CO_2 emissions are recorded. At the liquefaction unit level, it is a CO_2 emission reduction of 1.1% considering that propane compressor power represents about 33% of the whole energy consumption of this unit.

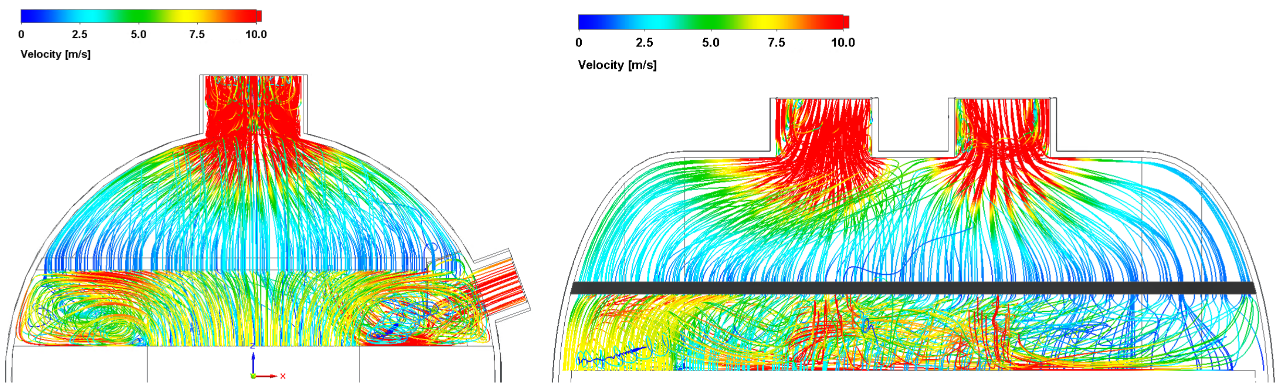

Figure 5. Velocity fields in a chiller dome.

Take aways

T.EN and Wieland have developed a comprehensive knowledge in designing highly efficient chillers for LNG precooling by integrating dual enhanced nucleate boiling tubes (GEWA-PB). These advanced tubes, combined with innovative compact heat exchanger designs like the S.E.C., allow for better heat transfer performance and significantly more compact and lighter equipment. This means chillers can operate effectively at lower temperature differences – down to 1K – leading to improved cycle efficiency. As a result, propane compressor power consumption drops by up to 4.4%, which translates into significant energy savings and a reduction in CO_2 emissions. Additionally, the compact and optimised design reduces material use and overall plant footprint, supporting more sustainable and environmentally-friendly LNG production. Overall, this approach showcases how combining advanced tube technology with smart heat exchanger design can make a meaningful difference in reducing energy use and lowering the carbon footprint of LNG plants. **LNG**

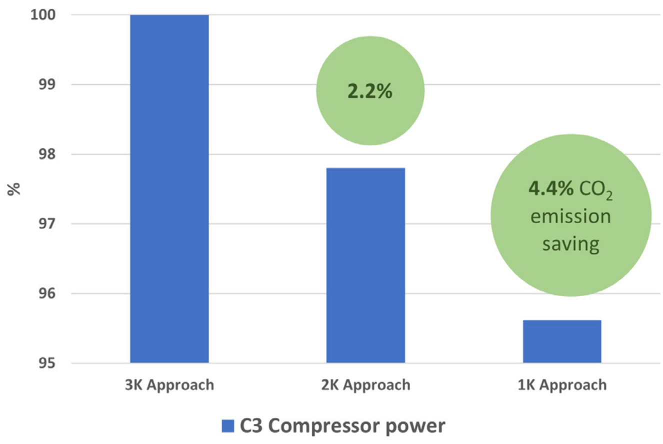

Figure 6. C3-compressor power and emission savings.

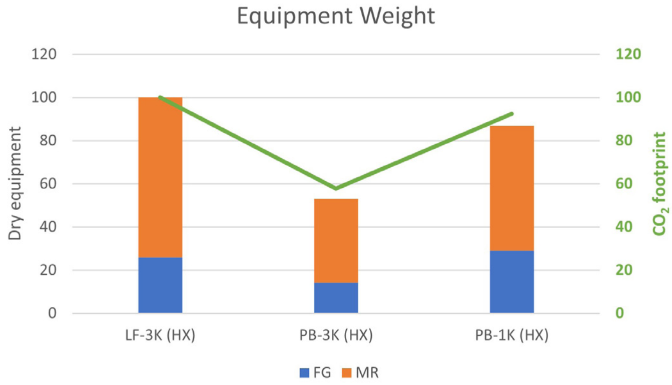

Figure 7. Compressor power and CO_2 emissions saving by using GEWA-PB at different temperature approaches.

References

1. RÖNKA, M., RAMDIN Z., PROVOST, J., LANG, T., and KNÖPFLER, A., 'Enhanced Reboiler for C3 Splitter Heat Pump Improves Energy Efficiency and Reduce CO_2 Footprint', *Hydrocarbon Processing*, (March 2022).
2. 'Corporate Value Chain (Scope 3) Accounting and Reporting Standard', *Greenhouse Gas Protocol*, (September 2011), https://ghgprotocol.org/corporate-value-chain-scope-3-standard

Note

This article is based on a paper presented at LNG2023: KNÖPFLER, A., BUFFET, A., EL HAJAL, J., LANG, T., PROVOST, J., RAMBURE, N., and REDJEM SAAD, L., *3, 2, 1 … K, nucleation! or recent improvements in enhanced heat transfer is further reducing temperature approaches in LNG pre-cooling heat exchangers*, (July 2023).

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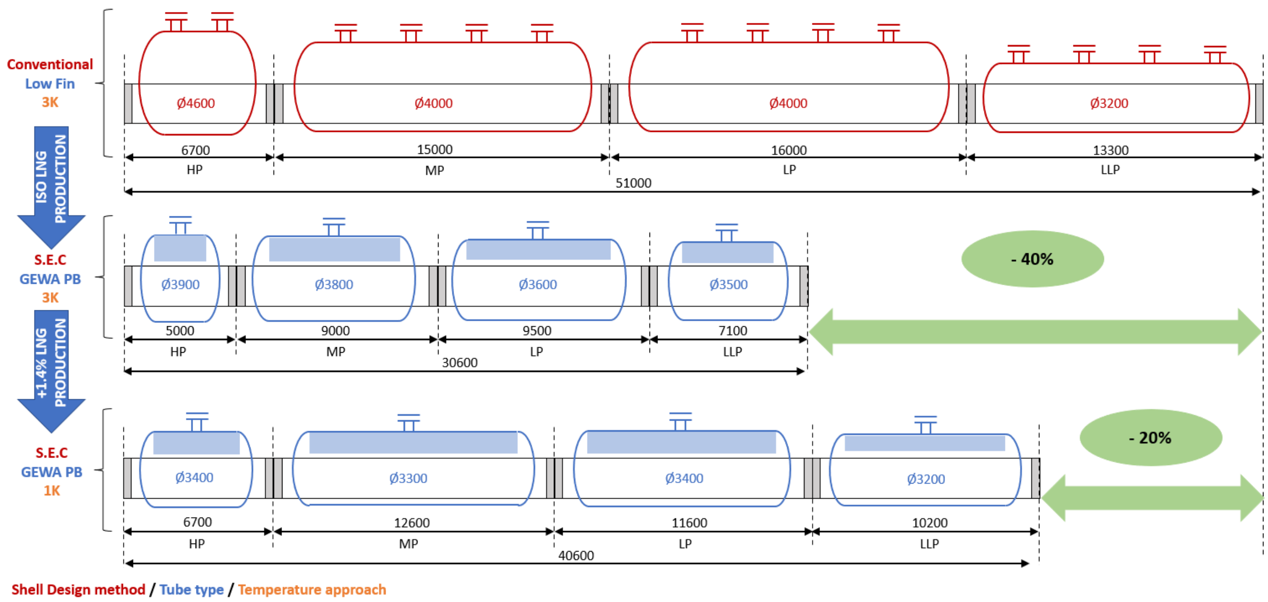

Figure 8. MR chilling train: Dimensions comparisons between low fin tubes at 3K approach vs GEWA PB tubes at 3K and 1K approaches; carbon steel tube material.