

A COOLER APPROACH: PART ONE

In the first part of a two-part article, **Andreas Knoepfler, Director Product Management, Wieland-Werke AG (Business Unit Thermal Solutions)**, and **Dr Lotfi Redjem Saad, Head of Heat Transfer Department, Technip Energies**, describe the use of enhanced heat transfer technologies for LNG pre-cooling heat exchangers.

Global natural gas liquefaction capacity reached about 495 million tpy in 2024.¹ Since the first greenfield deployment of GEWA-PB (process boiling) technology for Qatargas debottlenecking in 2003, the authors' dual enhanced tubes have gone on to equip the pre-cooling heat exchangers of more

than about 185 million tpy of LNG capacity in operation or under construction, demonstrating the highest level of reliability and outstanding performances. All applications to date have been on Honeywell's (formerly Air Products) propane pre-cooled MR processes. In preparation of a world which suddenly became thirsty for LNG,



existing and new facilities are looking for any opportunity to push further efficiency, offering highest production rates at lowest power consumption while decreasing carbon footprint and achieving attractive investment decisions (CAPEX).

To reach this level of expertise, Wieland Thermal Solutions and Technip Energies (T.EN) have engaged in a state-of-the-art development programme that includes scientific work and dedicated product development, highly accurate test equipment with specifically adapted procedures in combination with feedback from existing operations in the field of LNG, and other industrial size facilities, such as ethylene plants.

Part one of this article will describe the test equipment used, and achievements made in developing dual enhanced tubes with its enhanced heat transfer surfaces, which are in the meantime widely used in the liquefaction process of LNG plants.

Part two will focus on heat exchanger design aspects and the enormous potential of optimising heat transfer equipment, reducing greenhouse gas emissions (GHG) and demonstrating the advantageous impact on LNG production capacity and beneficial operations efficiency by minimising the approach temperatures in the associated heat exchangers.

Fundamental process scheme

The C3/MR™ liquefaction process (Figure 1) from Honeywell combines a pre-cooling section using propane (C3) as refrigerant followed by a mixed refrigerant (MR) for liquefaction. The pre-cooling cycle ensures natural gas cooling down to approximately -35°C while liquefaction operates from -35°C down to -160°C. The pre-cooling cycle represents about 30 – 35% of the total refrigerant compressor shaft power

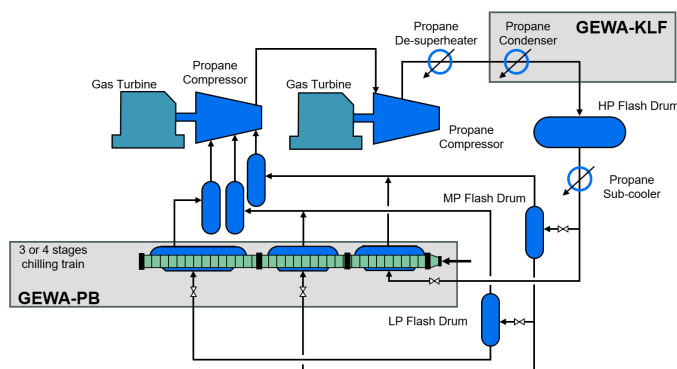


Figure 1. C3/MR process scheme.



Figure 2. Enhanced boiling tube GEWA-PB.

and any kind of increase in efficiency would be of interest.²

One major portion of this pre-cooling equipment are large propane evaporators (often referred to as chilling trains), removing heat from the natural gas and from the condensing MR, which will be used in the liquefaction part. Typically, a chilling train is composed of three or four kettle type heat exchangers installed in series. This equipment can be very large and heavy. Every action to achieve a more compact or more efficient process will be beneficial for all actors: to the manufacturer by proposing a lighter heat exchanger with a reduced need of steel reducing the equipment carbon footprint; to the EPC company by delivering a more compact heat exchanger reducing all surrounding weight (piping, concrete, steel structure, etc.), resulting in cheaper transport and installation and lower overall carbon dioxide (CO₂) emissions; and finally, to the operator by proposing a more economic and efficient process scheme, i.e. a lower carbon footprint per tonne of LNG.

The application of optimised heat exchanger technology, using dual enhanced nucleate boiling tubes GEWA-PB (Figure 2) by T.EN and Wieland, has proven successful since the first installation in 2003. Once Qatar North Field East (NFE) and North Field South (NFS) and other ongoing new installations move to operation, the global LNG capacity will be more than about 185 million tpy of natural gas that will be pre-cooled as a result of this technology.

Test equipment

In collaboration with T.EN, a unique test bench has been designed, built, and commissioned at Wieland Thermal Solutions in Germany to carry out shell side heat transfer measurements with hydrocarbons, called 'KoMeT-1' (Figure 3). This hydrocarbon evaporation and condensation test facility is used for pool boiling measurements at very low heat fluxes, particularly tuned to the operating range of C3/MR pre-cooling conditions. Since it is not easy to receive feedback from the field, this equipment allows for an additional source of information.

Goals and challenges

The purpose of carrying out boiling tests and collecting measurement data with hydrocarbons is:

- To describe fundamental heat transfer characteristics of enhanced nucleate boiling surfaces.
- To incorporate know-how in specific heat transfer correlations.
- To benefit from the use of heat transfer correlations in the design of heat exchangers for LNG pre-cooling heat exchangers.

By designing and building a unique test equipment like 'KoMeT-1', several challenges had to be met. First, the safety requirements of handling explosive fluids in a factory environment had to be considered in the test rig design, building, and construction, and in all test procedures. Second, with the highly enhanced surfaces and the corresponding high heat transfer coefficients, measurement accuracy became more challenging than ever. In this case, electrical heating was evaluated, installed,

and used, which has been proven to be a reliable and practical way of heating.

Test capabilities and test conditions

To comply with actual operating conditions in LNG and ethylene production, KoMeT-1 has been setup to handle the test range as displayed in Table 1.

Table 1. Test conditions	
Fluids available	Pure fluids (C2 to C5) and mixtures with two of these components
Temperature range	$-30^{\circ}\text{C} < T < 70^{\circ}\text{C}$
Operating pressure	Maximum of 50 bar



Figure 3. KoMeT-1 test facility.

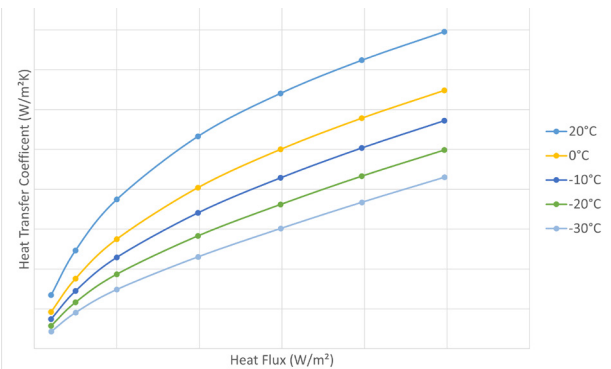


Figure 4. Pool boiling of propane on carbon steel tube.

Safety

Based on many years of experience with pressurised test facilities using synthetic refrigerants, the new challenge was to deal with flammable and potentially explosive atmospheres.

For that reason, the test concept has been designed to a fluid volume of less than 500 g of hydrocarbons. The entire test facility is positioned in a dedicated room with additional precautions, e.g. an encapsulated 'bell', which covers the test chamber and is working under vacuum conditions. Additional equipment is in accordance with the European Directive to work with equipment for potentially explosive atmospheres (ATEX). If there is an issue with any kind of leakage or the system pressure is too high, the safety procedures will immediately release an acoustic alarm, and an emergency programme will be initiated. Amongst other aspects, this includes a controlled release of the test fluid and purging with nitrogen before opening the test chamber. The equipment and test procedures have been certified by an independent third party, TÜV Süd in Germany.

Procedure of experimental measurements

To achieve accurate test data, it was mandatory to work on a dedicated procedure for preparing test specimen and to ensure repeatability regarding all operating conditions, particularly when measurements at low wall to saturation temperature differences are conducted. To support this, measurements have been fully automated and the data acquisition and software has been tailored to the necessary requirements. Thus, the following parameters are safely collected for boiling tests:

- Wall temperature (PT-100) in several locations.
- Liquid and gas phase bulk temperature (PT-100).
- Pressure in gas phase.
- Electric power to calculate heat flux.

Test results for shell side boiling

The following paragraph will briefly describe propane shell side boiling characteristics of plain and enhanced surfaces.

Initial measurements have been carried out with plain tubes and results have been thoroughly reviewed and compared with literature, confirming proper functioning of KoMeT-1 test facility. An important lesson has been that experimental data and available correlations from literature vary significantly. One main reason for this is the tube surface roughness, which depends on the material and on the manufacturing process. The heat transfer performance measured for plain tubes met expectations and it has been proven that the shell side pool boiling heat transfer coefficient (h_o) vs heat flux is dependent of the saturation temperature – test results are shown in Figure 4. It has been confirmed that ' h_o ' increases steadily with increasing heat flux. When the saturation temperature is increasing, the curve shifts to higher levels. This behaviour agrees with experimental data and correlations from literature.

Figure 5 compares propane pool boiling heat transfer coefficient of a carbon steel plain tube to a carbon steel dual enhanced nucleate boiling tube (GEWA-PB) at the same test conditions. With specific enhancements for boiling, the shell side heat transfer can be substantially increased. One key advantage

of Wieland enhanced surfaces is the specific improvement of the boiling heat transfer coefficient at low heat fluxes

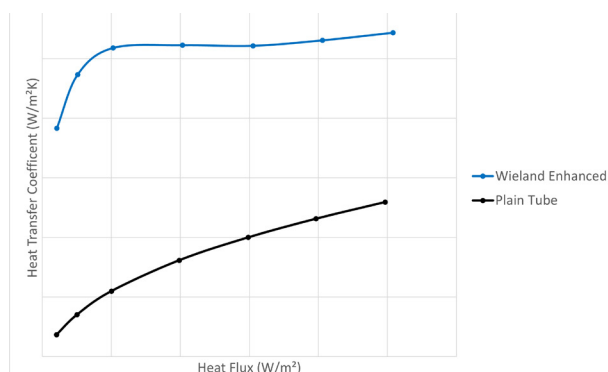


Figure 5. Pool boiling performance of plain tube vs Wieland enhanced nucleate boiling tube (GEWA-PB).

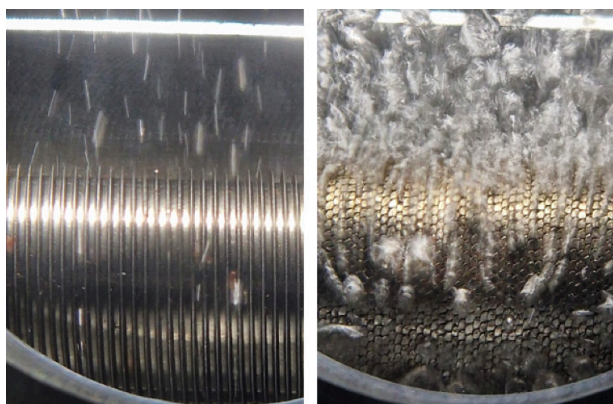


Figure 6. Boiling at 0 °C of propane with 2 K wall superheat. Left 30 fpi low fin tube, right Wieland enhanced boiling tube (GEWA-PB).



Figure 7. Boiling at 0 °C of propane with 0.16 K wall superheat on Wieland enhanced boiling tube (GEWA-PB).

(respectively wall superheat temperatures). This is very important for the design of most compact and efficient refrigerant chillers and reboilers.

Figure 6 shows nucleate boiling characteristics of an enhanced boiling tube vs a low finned tube at the same wall superheat of 2 K. It is noticeable that enhanced surfaces have significantly better performance, and the number of nucleate boiling formation is by far higher than for low finned surfaces. Even at extremely low wall to saturation temperature differences the enhanced surfaces still perform, and nucleate boiling is still active at a wall superheat of as low as 0.16 K (Figure 7).

Tube side heat transfer

For a balanced heat transfer characteristic between shell and tube sides, an additional tube internal enhancement for gas cooling, condensation, and subcooling is the most preferred – if not mandatory – option. Although this article focuses on shell side heat transfer characteristics, it should be mentioned that tube side enhancements further improve the overall heat transfer coefficient by a more balanced distribution of the heat transfer resistance between the outside and inside.

Summary and outlook

Part one of this article focused on the development and performance of dual enhanced nucleate boiling tubes, a key innovation resulting from the collaboration between T.EN and Wieland (Business Unit Thermal Solutions). The article highlighted the advanced testing capabilities of the KoMeT-1 facility, which has been instrumental in refining the design and validating the performance of these enhanced tubes under realistic LNG pre-cooling conditions. This partnership has combined cutting-edge know-how and rigorous testing to optimise heat transfer efficiency and reliability, setting a new benchmark for LNG pre-cooling technology.

Part two will shift the focus to the broader implications of these advancements, presenting a real-world case study to highlight the potential of Smart Enhanced Chillers (S.E.C.) in optimising LNG production. This next section will explore how these innovations contribute to further reducing GHG emissions, optimising CAPEX, and achieving superior operational performance in LNG facilities. **LNG**

References

1. '2025 World LNG Report', *International Gas Union*, (22 May 2025), www.igu.org/igu-reports/2025-world-lng-report
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Note

This article is based on a paper presented at LNG2023: KNOEPFLER, A., LANG, T., and PROVOST, J., 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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