DUAL ENHANCED TUBES FOR LARGE SHELL AND TUBE HEAT EXCHANGERS FOR LNG – A MATURE TECHNOLOGY

Brigitte PLOIX Heat Transfer Dept. Manager
Technip, 92973 Paris La Défense, CEDEX France

Thomas LANG, Business Development
Wieland-Werke AG 89070 Ulm, Germany

ABSTRACT

Extruded low-finned and dual enhanced tubes are an established heat transfer enhancement technology used since decades in multiple industries such as the heating, automotive, air-conditioning and refrigeration industries as well as the power and hydrocarbon industries. Over the last 15 years, Technip and Wieland have collaborated to qualify dual enhanced tubes with the aim of becoming a hydrocarbon processing industry standard especially for large shell-and-tube heat exchangers for grassroots LNG and ethylene plants.

From 1996 onward, a joint academia-industry R&D program supported by the EU established the necessary thermal design information for enhanced horizontal shellside nucleate boiling operations for light hydrocarbons, primarily propane. Further work packages concentrated on enhanced tubeside heat transfer and pressure drop performance in single-phase as well as two-phase / condensation forming a solid basis for compact and efficient enhanced heat exchanger designs.

Industrial references have been established starting in 2000 for thermosiphon, kettle reboiler and chilling services in polypropylene, ethylene and LNG plants - first in debottlenecking and finally in grassroots applications. The key advantages are:

- Higher overall heat transfer coefficient, compared to conventional technologies
- Improved process efficiency based on very low temperature approaches, compared to conventional technologies

The paper reviews the whole development and qualification process, the implementation of the dual enhanced tubes first in debottlenecking then in grassroot applications. Field test data confirm the industrial suitability of this technology from start-up with stable performance over the years in line with the design expectations.

Furthermore, dedicated preservation guidelines for the whole supply chain from tube fabrication to start-up confirm proper operation.

DUAL ENHANCED TUBES FOR LARGE SHELL AND TUBE HEAT EXCHANGERS FOR LNG – A MATURE TECHNOLOGY

INTRODUCTION

Applications for extruded low-finned (LF) and dual enhanced tubes are widespread in multiple industries, ranging from the air-conditioning and refrigeration, heating, automotive, power as well as hydrocarbon processing industry. A few selected examples are shown in Figure 1 below:

- Dual enhanced boiling and condensation tubes for packaged chillers
- Inner grooved tubes for coil heat exchangers in the air-conditioning and refrigeration industry
- Dual enhanced tubes for the hydrocarbon processing industry
- Dual enhanced tubes for power steering oil cooling in the automotive industry

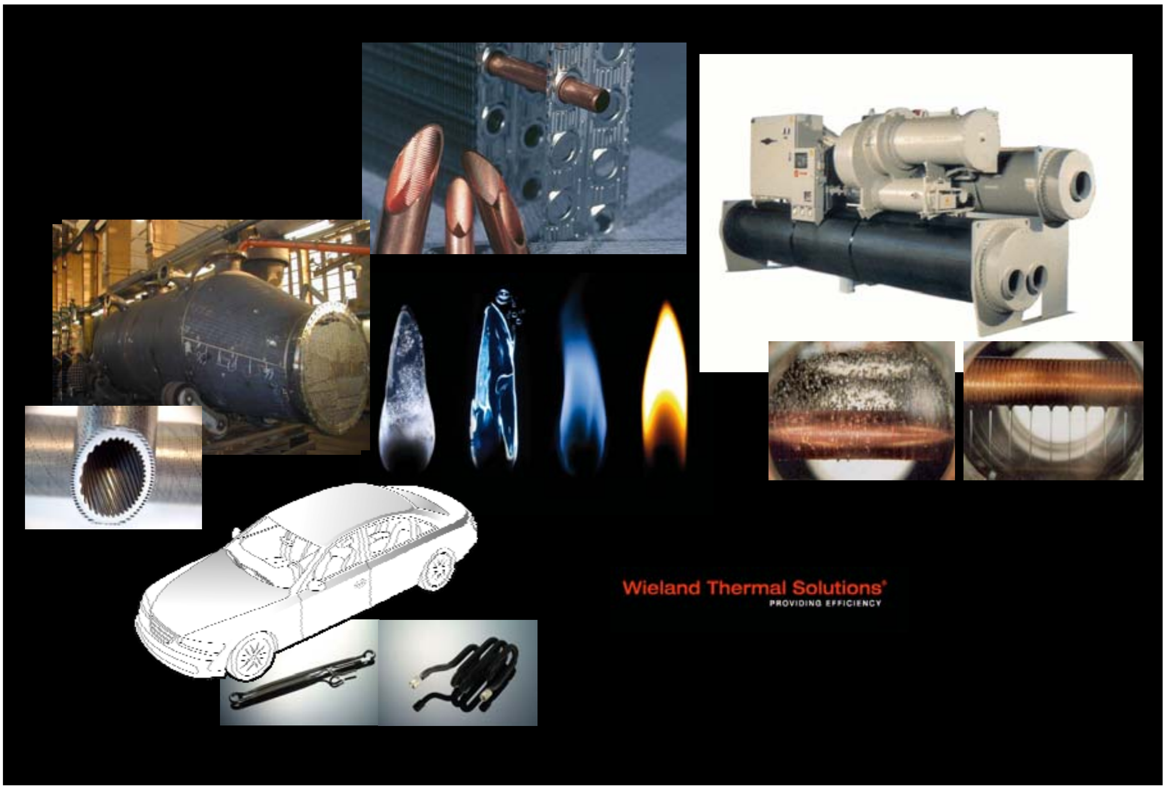

Figure 1. Selected Applications with Extruded Finned Tubes for Multiple Industries

For the hydrocarbon processing industry distinct dual enhanced tubes for boiling and condensing as well as single phase heat transfer services have been derived from standard LF tubes (see Figure 2). A wide range of proven references for both LF and dual enhanced tubes exists in the hydrocarbon processing industry since decades ranging from refining, petrochemical, chemical and gas processing applications [1, 2, 3]. Standard tube materials are copper-nickel carbon and low temperature carbon steels, but solutions are also available in low alloy carbon steel as well as stainless steel and titanium. These technologies resolve both capacity and plot space limitations for existing plants and provide compact and most efficient solution for new plants design. Very attractive applications are identified in LNG and Ethylene plant due to the drastic increase of plant capacity in the recent years (see Fig 3A and 3B).

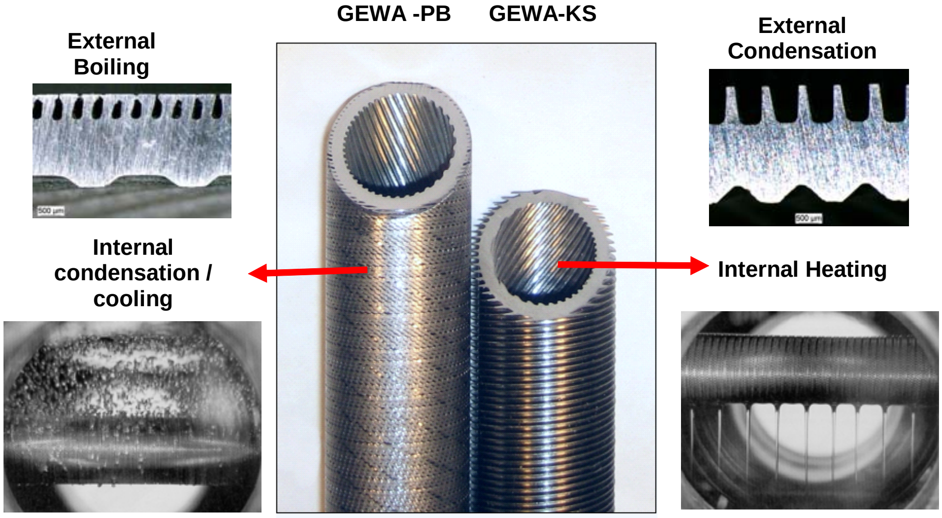

Figure 2. Wieland Dual Enhanced GEWA-PB and -KS Tubes

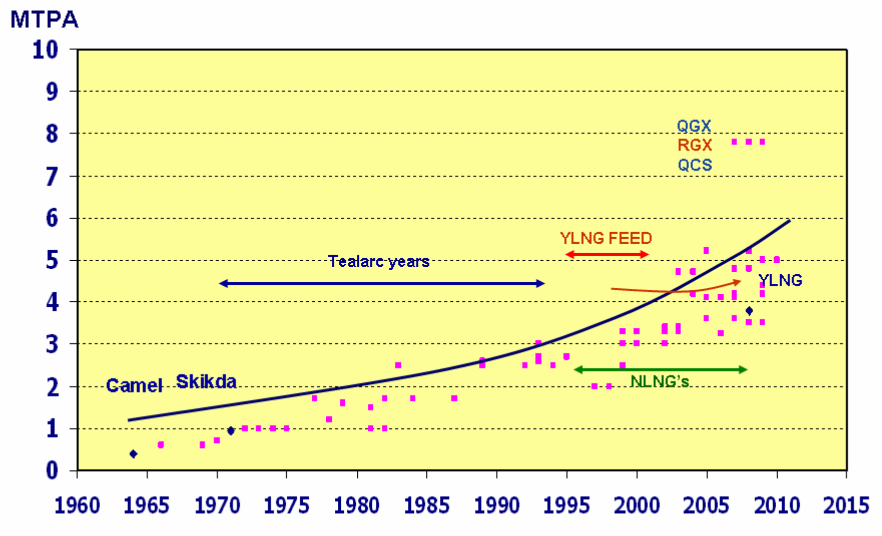

Figure 3A. LNG plants capacity (Technip references)

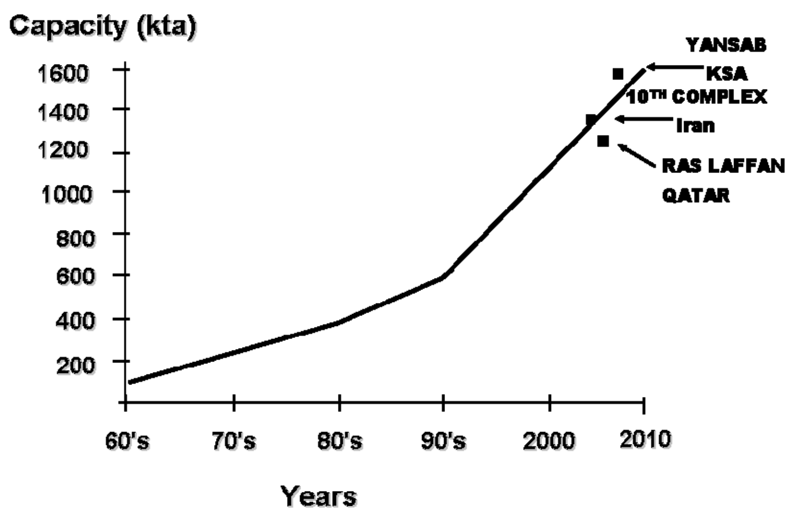

Figure 3B. Ethylene plants capacity (Technip references)

Over the last decades Wieland has developed an outstanding record of key applications with dual enhanced tubes. Combining this innovative heat transfer technology from Wieland with worldscale EPC engineering from Technip resulted in highly attractive enhanced heat transfer solutions allowing for more compact and efficient heat transfer equipment solutions as well as lower investment costs (see Figure 4).

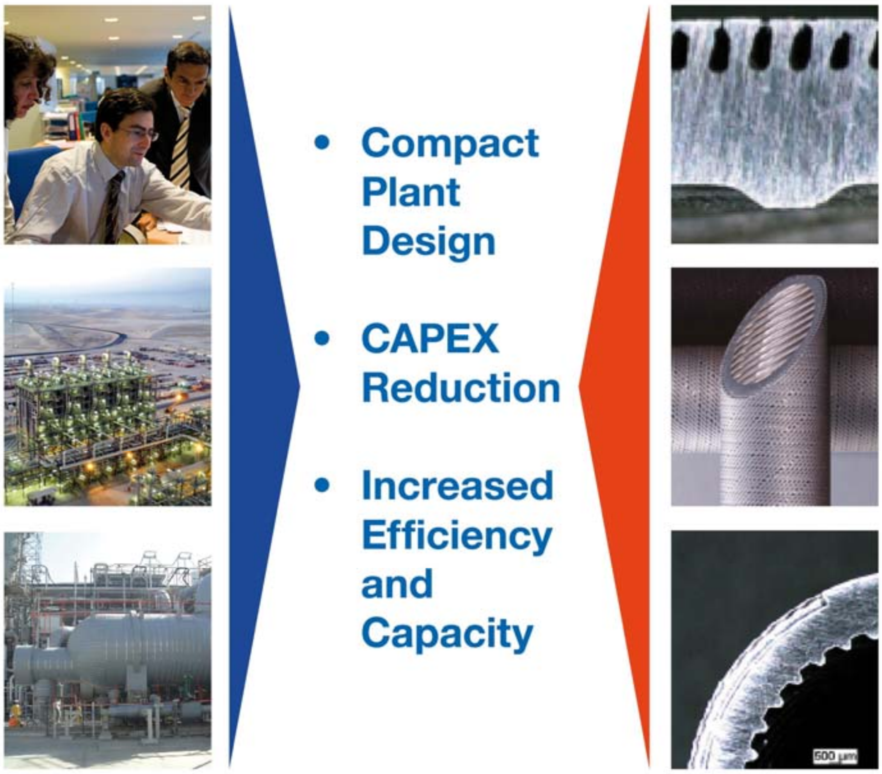

Figure 4. Joining EPC Engineering from Technip with Enhanced Heat Transfer Tube Technology from Wieland

R&D ACTIVITIES

Since 1996 Technip France and Wieland are collaborating in the development of a new dual enhanced nucleate boiling tube, called GEWA-PB. During two joint industry and academia research projects [4, 5,], JOULE III and AHEAD, funded by the EU, fundamental research and qualification has been conducted. Key activities have been the development and characterization of enhanced shellside nucleate boiling structure, especially at low temperature approaches, as well as tubeside enhancement structure for both single-phase gas and liquid as well as two-phase condensate heat transfer. The different steps from lab scale testing to industrial application stretched over a period of almost one decade (see Figure 5).

The thermal advantage of the GEWA-PB tube with for example shellside boiling propane versus a plain tube is between a factor 2 and 3 of the boiling heat transfer coefficient. Together with an improved tube side performance ranging between a factor 1.6 to 2.4, depending on single- and two-phase flow conditions, the overall heat transfer benefit leads to substantial overall benefits, see case studies below. At the same time the tubeside pressure drop increases, however, it typically does not exceed the heat transfer improvement, allowing for enhanced shell-and-tube heat exchanger within allowable pressure drop limits.

The key benefit of the GEWA-PB tube is the capability of a superior operation at low temperature approaches down to 2°C and below where standard plain or LF tubes are no longer suitable.

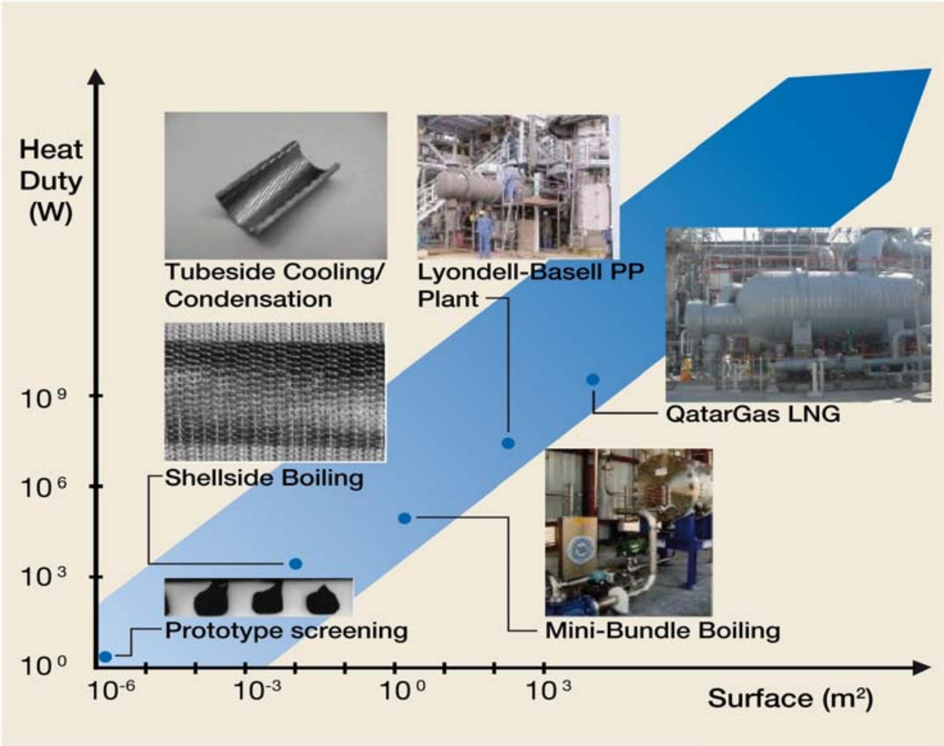

Figure 5. From Lab-Scale Testing to Industrial Application

In various schemes and applications, benefits can be:

- Size reduction
- Reduction of number of heat exchangers per unit
- Capacity increase or energy consumption reduction resulting from improved efficiency

The Technip France Heat Transfer Dept. incorporated the GEWA-PB tube in industrial reboiler applications such as for thermosiphon and kettle heat exchangers. Special attention is given both to the thermal and mechanical design along with an improved kettle design [6] such as:

- Proper fluid distribution at inlet and outlet
- Verification of liquid entrainment especially for suction line to compressor

State of the art thermal design tools from Heat Transfer Research Inc. (HTRI) [7] as well as Enhanced Heat Transfer (EHT) software, developed by Dr. John Thome and licensed to HTRI are used as convenient thermal design tool for enhanced heat transfer solutions.

In a similar way to the enhancement of reboilers, enhanced heat transfer solutions have been developed for horizontal condensers, with shellside condensation of pure streams and tubeside cooling water. A typical solution is with a dual enhanced GEWA-KS tube having a shellside LF structure in combination with an internal helical fin structure, see Figure 2.

These enhanced heat transfer technologies have been made available and qualified for horizontal shell-and-tube type reboilers and condensers within key business areas of Technip such as for LNG and ethylene plants, see Table 1. The pre-requirement for the time being in these applications is for clean refrigerant and process fluids. Further studies are required investigating the suitability of dual enhanced tubes for operating conditions with fouling tendencies.

Table 1. Overview on Enhanced Heat Transfer Technologies in LNG and Ethylene Plants

Plant Type	Service	Enhanced Tube
LNG	Propane refrigerant chiller (pre-cooling cycle for NG and MR)	GEWA-PB
	Propane refrigerant condenser (pre-cooling cycle)	GEWA-KS
Ethylene	Depropaniser condenser C2 refrigerant condenser C3 splitter reboiler C3 splitter condenser C2 splitter condenser Deethaniser condenser Ethane vaporiser C2 splitter reboiler	GEWA-PB
	C3 splitter condenser Propylene refrigerant condenser Propane refrigerant condenser	GEWA-KS

For base-load LNG plants, using the C3/MR process licensed by Air Products, the enhanced heat exchanger technologies are highly attractive within the propane pre-cooling cycle. The major application for enhanced GEWA-PB boiling tubes is for the main propane refrigerant chilling train with cooling/condensation of natural gas (NG) or mixed refrigerant (MR) on the tubeside and propane refrigerant boiling on the shellside. The primary application of the enhanced GEWA-KS condensation tube is for the propane refrigerant condenser with shellside propane refrigerant condensing and tubeside cooling water.

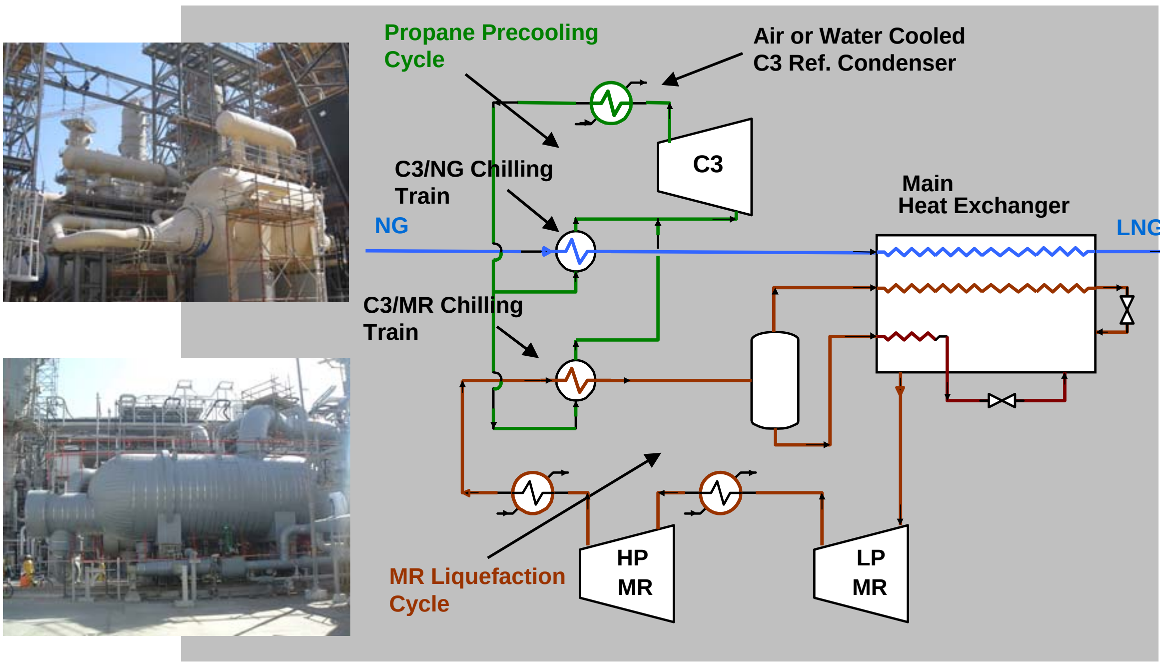

Figure 6. C3MR liquefaction section according to APCI.

For ethylene plants enhanced heat exchanger solutions are available for the majority of reboiler and condenser heat exchangers in the cold section such as the C2 and C3 fractionation and splitting services as well as the refrigerant units (see Table 1).

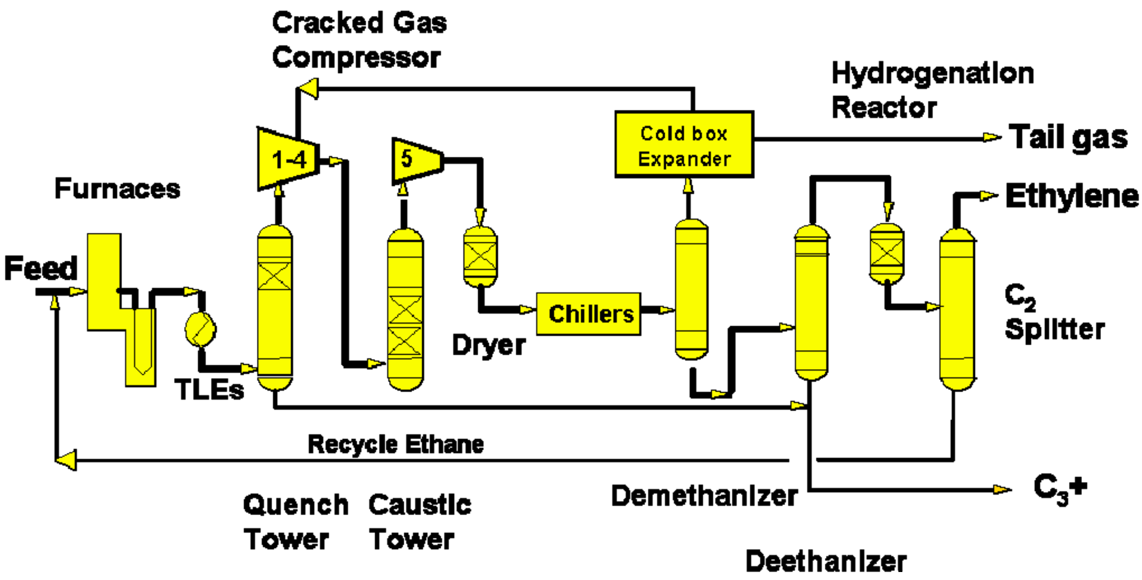

Figure 7. Ethylene Back-End Hydrogenation Process Scheme Based on Ethane Feedstock

ECONOMIC STUDIES

In LNG, the performance of GEWA-PB and GEWA–KS tubes is demonstrated in two representative cases both for a propane refrigerant chiller and condenser in comparison to standard plain and LF tubes, Figures 11 and 12. The cases are taken from a recent Technip project, with the C3/MR process design licensed by APCI.

In both cases substantial size and weight reduction can be achieved by using dual enhanced tubes. Especially for these large equipments the benefit becomes evident when considering the whole supply chain ranging from fabrication, transportation as well as plant aspects covering installation, operation and maintenance.

A detailed technico-economic study by Technip of the two chilling trains for NG and MR, showed very attractive savings in CAPEX, plot space as well as capabilities for efficiency improvements or vice versa an attractive opportunity for capacity increase, see Table 2.

Both solutions with LF and GEWA-PB tubes has been analysed for the two chilling trains such as: Propane / MR chilling train and propane / NG chilling train. Each train is operating at four propane levels. For the GEWA-PB enhanced boiling tube a reduction of the cold approach to 2K is feasible and considered by Technip for improved LNG plant designs. The following items have been considered for the CAPEX: heat exchanger, piping, steel structure, piping and exchanger foundation.

For the standard cold approach of 3K the GEWA-PB allows for a CAPEX reduction of 20 % and a reduction of the plot space of 26% versus a standard solution with LF tubes. Considering a reduced cold approach with 2K for the GEWA-PB tube the compression power is reduced by approximately 2.2% translating into approx. 1% additional LNG capacity. The additional annual income, depending on the LNG price, is far superior compared to the overall cost of the chilling train. It has to be noted that the case with the GEWA-PB tube and 2K cold approach is with 16% plot space reduction still more compact and with the same CAPEX not more expensive compared to the LF case with a 3K cold approach.

Table 2. Comparison of LNG Chilling Train with GEWA-PB and LF Tubes

Temperature Approach	GEWA-PB (3K)	GEWA-PB (2K)
CAPEX	-20 %**	0 %**
Additional Annual Income, MM$/year	0	16.25 (LNG price = 250 $/t*)
	0	26 (LNG price = 440 $/t*)
	0	35.8 (LNG price = 550 $/t*)
Plot Length Reduction	26 %**	16 %**

Notes

* equivalent LNG price in $/MM Btu = 5, 8 and 11

** indicated values are compared to the LF (3K) case

Heat Duty:	45 MW
Shell Design:	NKN, 1-pass, bundle OD = 1500 mm, 3/4" GEWA-PB, tube count: 3745
Shellside Fluid:	Propane ref., boiling, T_{sat} = -21.8°C
Tubeside Fluid:	Mixed ref., condensing, $T_{in/out}$ = -1.9 / -18.5 °C

Figure 11. LP/MR Propane Refrigerant Chiller. Comparison of Plain, LF and GEWA-PB Tube

Heat Duty:	61 MW
Shell Design:	NXN, 1-pass, shell ID = 2280 mm, 3/4" GEWA-KS, tube count: 6467
Shellside Fluid:	Propane ref., condensing, T_{sat} = 36 °C
Tubeside Fluid:	Closed cycle cooling water, $T_{in/out}$ = 22.0 / 31.2 °C

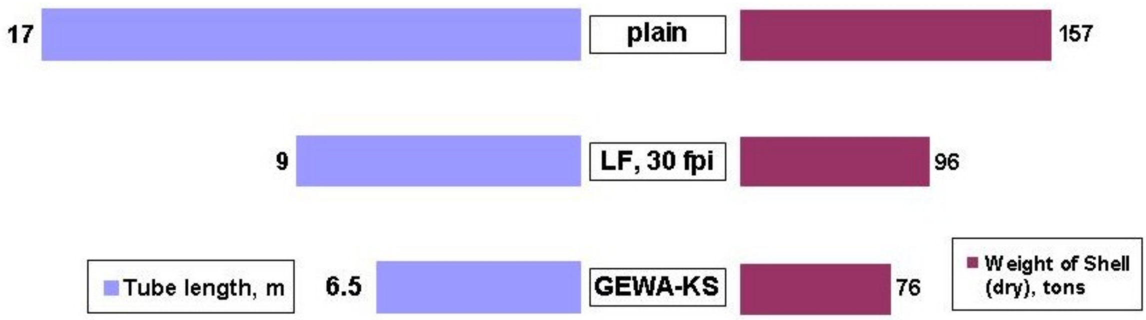

Figure 12. Propane Refrigerant Condenser. Comparison of Plain, LF and GEWA-KS Tube

INDUSTRIAL APPLICATIONS

Polypropylene Plant

The first reference of the GEWA-PB tube dates from 2000 for a horizontal thermosiphon, C3 splitter reboiler as part of the capacity expansion of the Lyondell-Basell polypropylene plant in Knapsack, Germany [4], see Figure 13. The use of GEWA-PB allowed an upgrade from 4 to 5 MW despite a substantial reduction of the LMTD. The cooling water return from the tubular polymerisation reactor was able to be used for heating avoiding the use of stream.

Figure 13. Installation of Horizontal Thermosiphon Reboiler Equipped with GEWA-PB Tubes in a C3 Splitter of a Polypropylene Plant by Lyondell-Basell, Knapsack (D)

LNG Plant

In 2003, the GEWA-PB tube was applied for the first time in an LNG plant as part of the Qatargas debottlenecking project. The objective was to expand the capacity of the existing three trains from 2 MTA to 3 MTA per train. A new kettle type chiller equipped with GEWA-PB tubes, with tube OD of 5/8", was successfully installed in each of the three trains.

Test runs following the start up of Train 2 in 2003, Train 3 in 2004 and Train 1 in 2005 confirmed the thermal and hydraulic tube performance. For train 3, the performance was verified again in 2007, confirming stable performance. In addition a very low cold approach temperature of 1.4 K between tubeside condensing MR and shellside boiling propane is confirmed demonstrating the superior performance of the GEWA-PB tube. Qatargas is very satisfied with the overall performance of these chillers.

Figure 14. Propane Refrigerant Chillers with GEWA-PB Tubes, LNG Plant Ras Laffan (Qatar).

Technip and its joint venture partner Chiyoda have engineered and build 6 trains at Ras Laffan, Qatar, Figure 14, with annual LNG capacity of 7.8 MTA per train. All trains, are in operation at full capacity.

Ethylene Plant

Following the first successful application in the polypropylene plant in 2000 further applications followed both with various expansion projects and new grassroots projects by Technip.

Borealis Polymers, Finland, used GEWA-PB tubes in a C2 splitter reboiler/condenser in a heat pump scheme for an ethylene expansion project in 2002. The stable operation has been reviewed and confirmed in 2007, see Figure 14.

Further applications with the GEWA-PB tube followed within the depropaniser and deethaniser condensers both for the 10th Olefin Complex for JAM Petrochemical, Iran, and Yansab, Saudi Arabia.

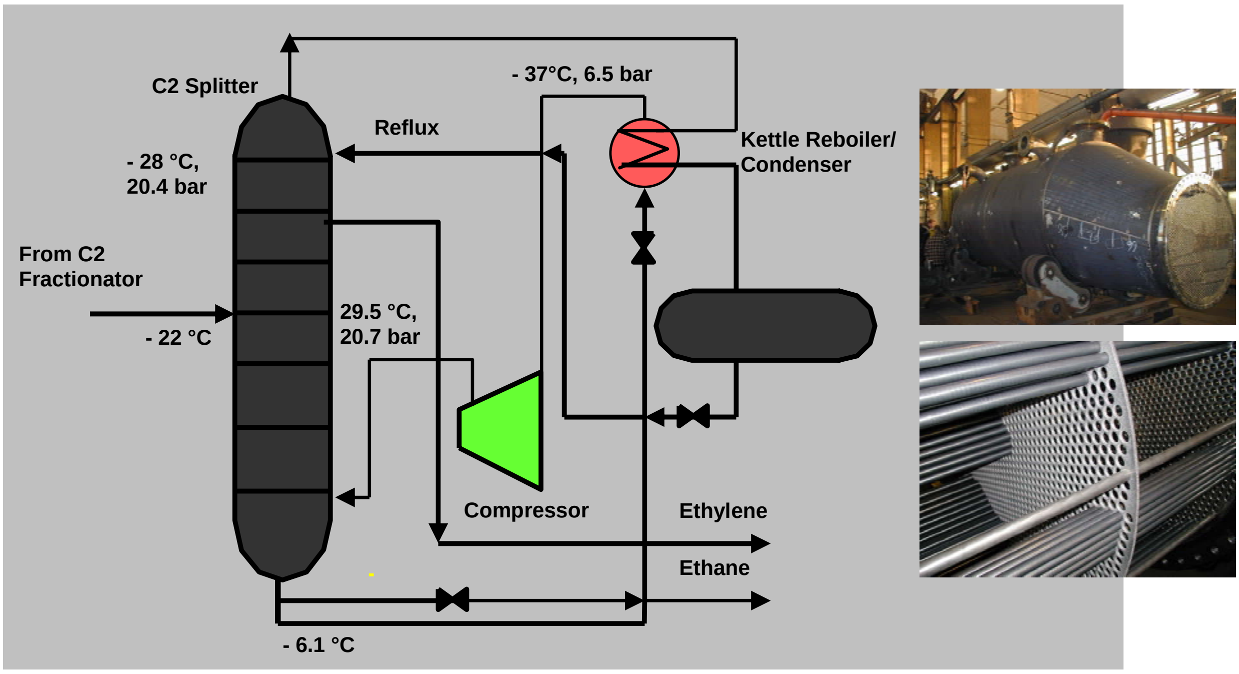

Figure 15. Kettle Type Reboiler/Condenser with GEWA-PB Tubes in Heat Pump Driven C2 Splitter. Borealis Polymers Ethylene Plant, Porvoo (FIN)

Building on these successes, Technip applies GEWA-PB tubes for all large LNG and ethylene projects, see Table 3. The enhanced performance provides clients with technical and economical attractive solutions.

Table 3. References for GEWA-PB and –KS Tubes for LNG, Ethylene and Other Plants

Client	Start-Up	Service	Plant Type	Number of HEXs	Tube Type
QGIV –QP/Shell (1)	2010	C3 Chiller	LNG	8	PB
		C3 Condenser	LNG	2	KS
QGIII QP- ConocoPhillips (1)	2010	C3 Chiller	LNG	8	PB
		C3 Condenser	LNG	2	KS
QGII-QP/ExxonMobil/Total (2)	2009	C3 Chiller	LNG	16	PB
		C3 Condenser	LNG	4	KS
RGIII-QP/ExxonMobil (2)	2009	C3 Chiller	LNG	16	PB
		C3 Condenser	LNG	4	KS
Yansab	2009	Depropaniser Condenser	Ethylene	1	PB
		Deethaniser Condenser	Ethylene	1	PB
JAM Petrochemical	2007	Deethaniser Condenser	Ethylene	1	PB
		Depropaniser Condenser	Ethylene	1	PB
QGI- QP/Total/ExxonMobil	2005	C3 Chiller (train 1)	LNG	1	PB
	2004	C3 Chiller (train 3)	LNG	1	PB
	2003	C3 Chiller (train 2)	LNG	1	PB
Borealis Polymers / Neste Jacobs	2002	Ethylene Reboiler/ Condenser	Ethylene	1	PB
Lyondell-Basell	2000	C3 Splitter Reboiler	Ethylene	1	PB

Notes: (1) One train with 7.8 MTA LNG capacity (2)Two trains with 7.8 MTA LNG capacity each

PRESERVATION RECOMMENDATIONS

As part of the market introduction of dual enhanced GEWA-PB and GEWA-KS tubes together with vendors and operators a guideline for the proper tube preservation from fabrication to operation has been developed, see Table 4. Thereby existing experience of all parties have been brought together. An important feature during fabrication is for example the proper cleaning and degreasing, especially for the enhanced boiling structure, preventing any performance degradation. A thorough preservation program along tube and heat exchanger transportation, heat exchanger assembly and storage on-site is essential especially for bridging long-term storage periods. Also for maintenance activities during operation suitable preservation actions have been proposed.

Table 4. Enhanced Tube Preservation from Fabrication to Operation

Enhanced Tube	Heat Exchanger	On Site (Storage /
• Tube fabrication • Quality control (eddy current, pneumatic and hydrostatic pressure, etc.) • Cleaning and decreasing • Corrosion protection • Packing in wooden boxes, incl. VCI foil and dessicant bags • Visual inspection prior to shipment • Shipment to vendor	• Dry storage inside warehouse • After assembly hydrostatic pressure test in-and outside of tubes • Drying of tubes in- and outside • Preservation with N_2 and desiccant bags • Visual inspection prior to shipment • Shipment on site	• Visual inspection upon arrival of HEX on site • Continuous preservation program during storage on site • „Blowing“ of process lines (no impact on HEXs) • „Box-up“ (removal of seals, N_2 purge and desiccant bags, application of final seals) • „Start-up“ • „Operation“ (preservation actions available)

CONCLUSIONS

Technip and Wieland have worked successfully over the past 15 years in developing and introducing enhanced heat transfer technologies using dual enhanced tubes, both GEWA-PB and GEWA–KS, that are fast becoming standard solutions for certain key heat exchangers in LNG and ethylene plants. The enhanced heat transfer technology is based on experienced thermal design and equipment engineering. Along with field data validation the superior performance is confirmed and a safe transition from revamp to grassroots projects has been realized with more than 50 enhanced heat exchangers supplied in the last 10 years.

Together with the qualification of the enhanced heat transfer technologies the preservation of the dual enhanced tubes along the supply chain has been established. Thereby all steps from the tube fabrication, transportation, assembly of the heat exchanger, including start-up and operation of the equipment in the plant, are covered.

The technology is made available to clients through the projects of Technip and in most cases third parties.

REFERENCES

[1] Webb L. Ralph, Principles of Enhanced Heat Transfer, John Wiley & Sons, 1994

[2] Thome J., Heat Transfer Augmentation of Shell-and-Tube Heat Exchangers for the Chemical Processing Industry, 2nd European Thermal-Sciences and 14th UIT National Heat Transfer Conference, Rome, May 29-31, 1994

[3] Curcio, A. Louis, Ian. M. Fischer, Thomas M. Rudy, Field Applications of Double Enhanced Tubes in Shell-and-Tube and Air-Cooled Heat Exchangers, ASME 30th National Heat Transfer Conference, Portland Oregon, August 7, 1995

[4] Thonon B., Advanced and High-Performance Heat Exchangers for the Hydrocarbon Processing Industry, Heat Transfer Engineering, 28(5), pp. 73-84, 2005

[5] Thonon B., J.J. Delorme, Enhanced Reboilers for the Process Industry, Engineering Foundation Conference, Davos, July 2001

[6] Rabeau P., H. Paradowski, J. Launois, How to reduce CO_2 Emissions in the LNG Chain, LNG15 Conference, Barcelona, 2007

[7] Heat Transfer Research Inc., 150 Venture Drive, College Station, TX 77845, USA