SPIRAL WOUND HEAT EXCHANGERS FOR LNG BASELOAD PLANTS

ECHANGEURS BOBINES POUR LES INSTALLATIONS DE LIQUEFACTION DU GAZ NATUREL

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ABSTRACT

Linde has been designing and manufacturing spiral wound heat exchangers for over one hundred years, air having been liquefied as is known for the first time on an industrial scale in 1895.

By combining its know-how in the engineering, manufacturing and operating of cryogenic heat exchangers, Linde has optimised and even augmented the reliability of its spiral wound heat exchangers (SWHE) for their application in various liquefaction processes, among them Linde's own and proprietary Mixed Fluid Cascade Process (MFCP) for the liquefaction of natural gas.

Recently, one of those spiral wound heat exchangers was installed in a cold box in parallel to the existing plate fin heat exchangers in a LNG plant in Mossel Bay, South Africa. A rigorous and detailed test program confirmed the excellent mechanical behaviour of the heat exchanger manufactured according to the Linde design concept, the thermal and hydraulic calculations as well as the precision of the thermodynamic and physico-chemical properties of the fluids used by Linde.

In this paper, the main features of the Linde SWHE and the test results from the continuous operation in the Mossel Bay LNG plant will be presented. In addition, special aspects of the SWHE design for the application in LNG baseload plants will be described.

RESUME

Linde conçoit et fabrique des échangeurs bobinés depuis plus d'un siècle, à savoir la première liquéfaction d'air à l'échelle industrielle en 1895.

En combinant son savoir-faire dans l'ingénierie, la fabrication et l'exploitation des échangeurs cryogéniques, Linde a optimisé et encore augmenté la fiabilité de ses échangeurs bobinés pour leur utilisation dans plusieurs procédés de liquéfaction, dont son propre procédé MFCP (Mixed Fluid Cascade Process) pour les installations de liquéfaction de gaz naturel .

Récemment, un de ces échangeurs a été installé en parallèle d'une boite froide équipée d'échangeurs à plaques dans une usine de liquéfaction de gaz naturel à Mossel Bay, en Afrique du Sud. Un programme d'essais rigoureux et détaillés a confirmé l'excellente tenue mécanique des échangeurs utilisant la conception de Linde, les calculs thermiques

et hydrauliques ainsi que la précision des propriétés thermodynamiques et physico-chimiques des fluides utilisées par Linde.

Cet exposé montrera les principales caractéristiques des échangeurs bobinés conçus par Linde ainsi que les résultats du test obtenus lors des essais et du fonctionnement en service continu dans l'usine LNG de Mossel Bay. De plus, seront traités certains aspects particuliers des échangeurs bobinés utilisés dans les unités de liquéfaction de gaz naturel.Subhead

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INTRODUCTION AND HISTORY

Spiral wound heat exchangers (SWHEs) have been manufactured by Linde since the early days, when Carl von Linde liquefied air on an industrial scale for the first time in Munich, Germany, in May 1985 [1]. With the establishment of the Process Engineering and Contracting Division in 1902, a fabrication shop was set up in which the first cryogenic plants for the production of oxygen and nitrogen were fabricated (Fig. 1). Sustained by the fast development of the cryogenic technology also for gas processing plants the field of applications grew as well as the size of spiral wound heat exchangers (Fig. 2).

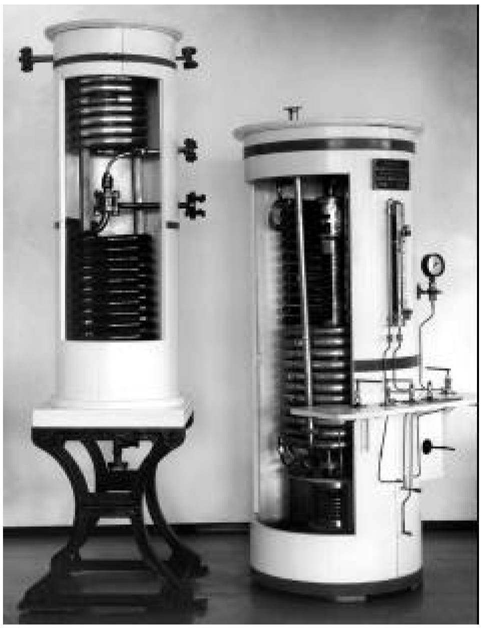

Fig.1: Oxygen Apparatus No. 14 from the Year 1910

Fig.2: Tube Bundle Winding around 1950

The improvement of welding technology for aluminium in the late fifties made it possible to change from rather expensive and heavy copper to the lighter and cheaper all-aluminium-design (Fig. 3). More than one thousand SWHEs for various process services, in different materials such as austenitic steel, nickel and chrome/molybdenum alloys, copper and aluminium, with heating surfaces of up to 11,500 square meters and unit weights of up to 160 metric tons (Fig. 4) have been fabricated since.

As a reference for the mechanical integrity and the outstanding robustness of Linde-designed SWHEs in cryogenic service we are pleased to present the following data:

Five SWHEs were installed in an air separation plant at BASF in Ludwigshafen, Germany, and started up in 1973. They were in operation until 1992. Seven planned shut-downs and no mechanical failures or tube leaking were recorded over 160,000 operating hours.

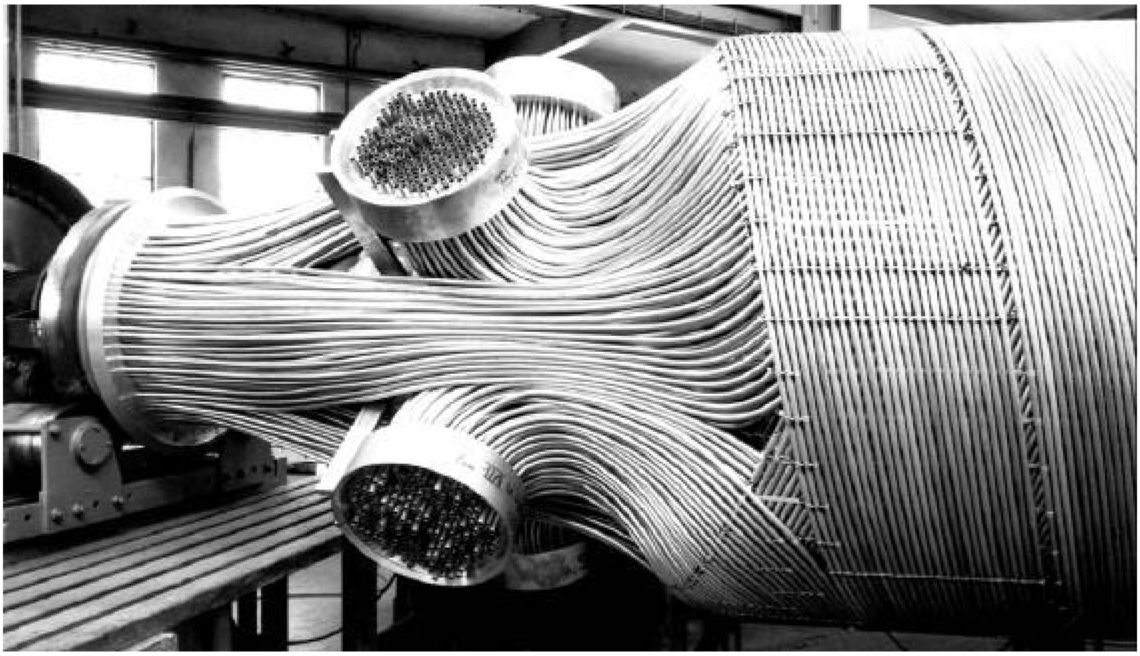

Fig.3: SWHE for Multiple Flows at the Tubeside

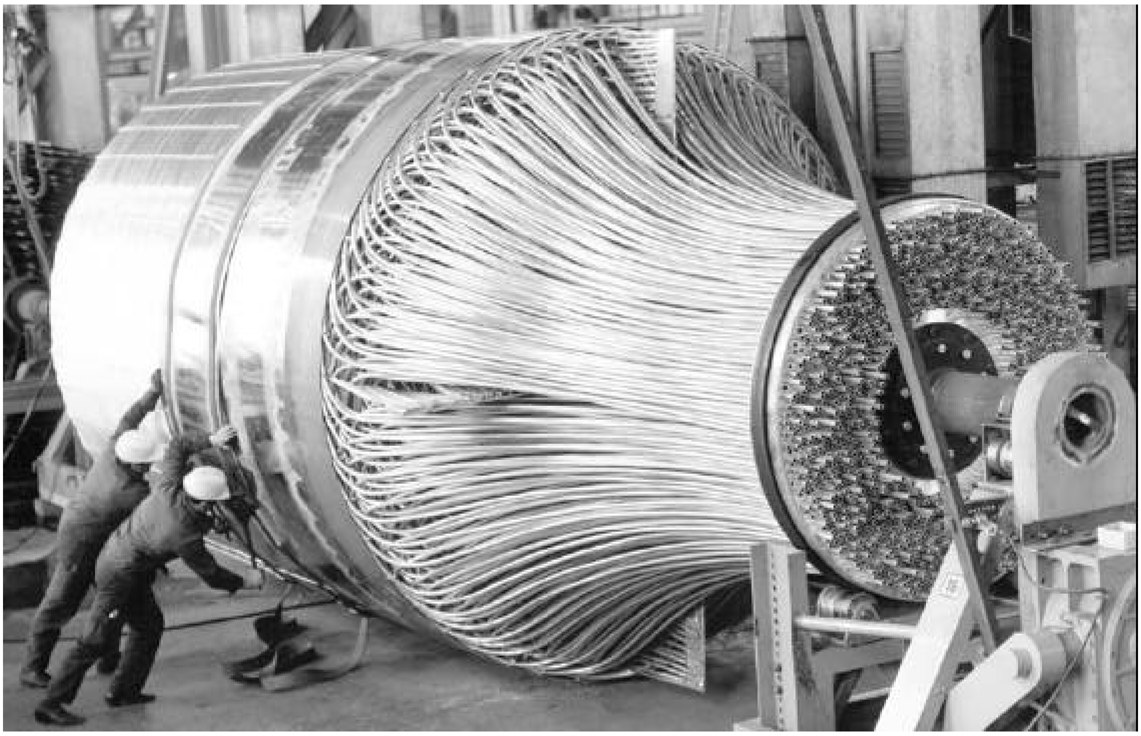

Fig.4: Wrapping the Bundle into a Shroud

MOSSEL BAY SWHE TEST FACILITY

Linde started marketing Main Cryogenic Heat Exchangers (MCHE's) for LNG baseload plants in 1993. In order to demonstrate the mechanical integrity during severe tests as well as the correctness of the thermal, hydraulic and geometrical design, the Statoil / Linde LNG Technology Alliance decided in 1997 to install a spiral-wound NG liquefier within the existing Linde LNG plant at the Mossgas Refinery in Mossel Bay, Republic of South Africa (Fig. 5).

Fig.5: LNG Plant at Mossel Bay, South Africa

The existing LNG Plant for which Linde performed process design, engineering, procurement, construction and commissioning between 1990 and 1992 was the perfect opportunity to carry out the desirable test program.

The plant comprises natural gas pretreatment, liquefaction with plate-fin heat exchangers installed in a cold box, LNG storage and re-evaporation as back-up feedstock in case of interruption of the offshore gas and condensate production [7].

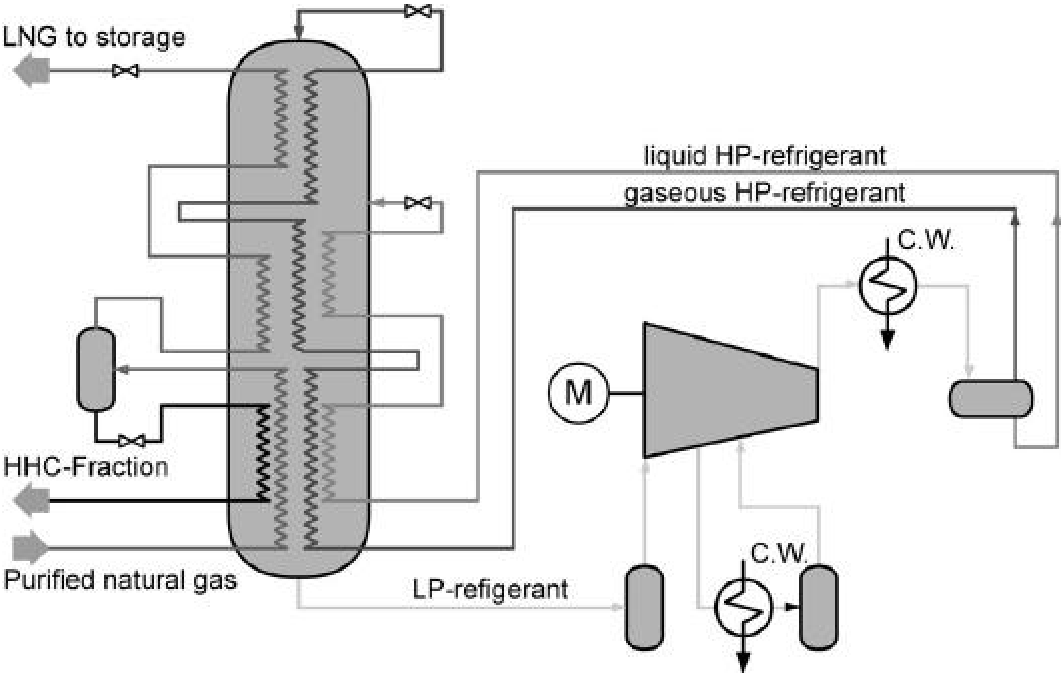

Fig.6: Single Flow Mixed Refrigerant Process

The liquefaction process of the LNG plant with a name plate capacity of 13.5 t/h is a single flow mixed refrigerant cycle consisting of nitrogen, methane, ethylene and isobutane (Fig. 6).

Thermal Design

For the thermodynamic, hydraulic and geometrical design Linde's proprietary computer program Genius [2] was used. Process data as flows, pressures, temperatures and temperature differences were provided by the process calculation program Optisim® [3]. Pressure drops were set by an iterative optimisation. Genius determines the temperature and pressure profiles of the individual streams by calculating the heat transfer coefficients, pressure drops and temperature differentials as driving forces for discrete elements. The number of elements used in the calculation is determined dynamically and depends on the accuracy required and by the non-linearity of the enthalpy-temperature curves of the individual streams. The dew and bubble points as well as the composition of each stream are taken into account by the simulation. All methods used for heat transfer and pressure drop implemented into the program have been carefully tested.

Our own research was complemented by the evaluation of literature and cooperation with major research and development institutions like Heat Transfer Research, Inc. (HTRI) and Heat Transfer and Fluid Flow Service (HTFS). Especially for falling film evaporation at the shell-side of the SWHE Linde [5] and Statoil [6] performed their own measurements and evaluated available literature and produced corresponding calculation methods. As final product, Genius calculates the number and length of the tubes for individual streams, the number of layers, the dimensions of the spacer bars and the distribution of the tubes to the different layers, resulting in the geometry of the bundle.

As to suit process requirements three bundles are arranged in series, installed in a common shell. Each bundle has a diameter of 1,325 mm and the total installed heating surface amounts to 3,900 m². Bundle no. 1 is used to liquefy heavy hydrocarbons of the natural gas stream. Bundle no. 2 leads to partial liquefaction and in bundle no. 3 total liquefaction and subcooling to around –162°C are achieved. Each bundle has a separate distribution system for the shell side MRC (Fig. 7).

Mechanical Design

The SWHE was designed according to AD-Merkblaetter and DIN Standards as far as applicable.

All parts of the exchanger are in aluminium alloys whereby particular care was taken to select the appropriate alloys for critical items.

Design pressure for the shell side is 28 barg due to overall Mossgas plant conditions and for the tube sides 48 barg. Design temperature is +55 / -175°C.

The SWHE is designed in such a way that each of the three tube bundles has its own mandrel, support star, distributor system and shroud. Each bundle is hanging freely on several support arms via special shaped support bars so that shrinkage and expansion of the tube bundle due to rapid temperature changes during start-up or shut-down occurs with a minimum of stress between tube bundle and shell.

The experience gained over many years with distribution systems for packed and trayed rectification columns had a major impact on the design and features of the distribution arrangements for each tube bundle. On one tube bundle arrangements were provided in order to simulate mal-distribution in such a way that 50 % of the distributor tray becomes almost dry.

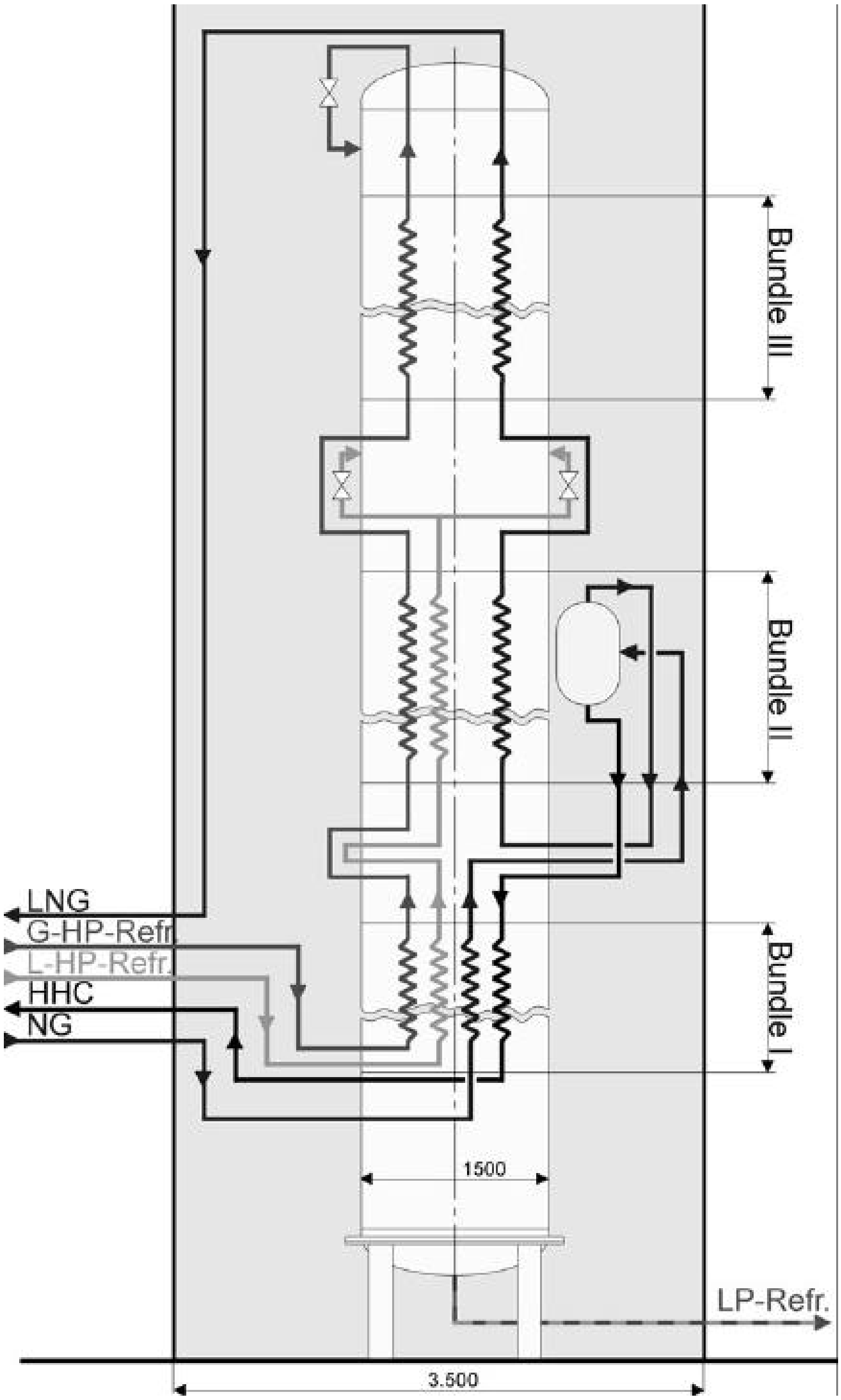

Fig.7: Cold Box Bundle Arrangement

Each tube bundle is to be wrapped into a shroud which is seal-welded on the upper side to the shell to avoid any by-pass of refrigerant between bundle and shell.

The bottom section of the SWHE is designed so that it can be used as a separator.

As the SWHE had to be installed in a cold box all bonnets and nozzles had to be designed for adequate elevation and orientation in particular in view of interconnecting piping and wall penetrations.

It was agreed with Mossgas in order to save time and reduce activities on site to a minimum that the cold box with the SWHE should be installed alongside the existing cold box with the plate fin heat exchangers. The cold box was designed to accommodate the SWHE with a diameter of 1,500 mm and a total height of 28,600 mm including separator, all interconnecting piping, control valves, drains, vents and all instrumentation.

Manufacturing

First the mandrels with support arms and the drilled tube sheets placed in their final position were fabricated and assembled. Distribution trays which were tested in a special facility were installed (Fig. 8).

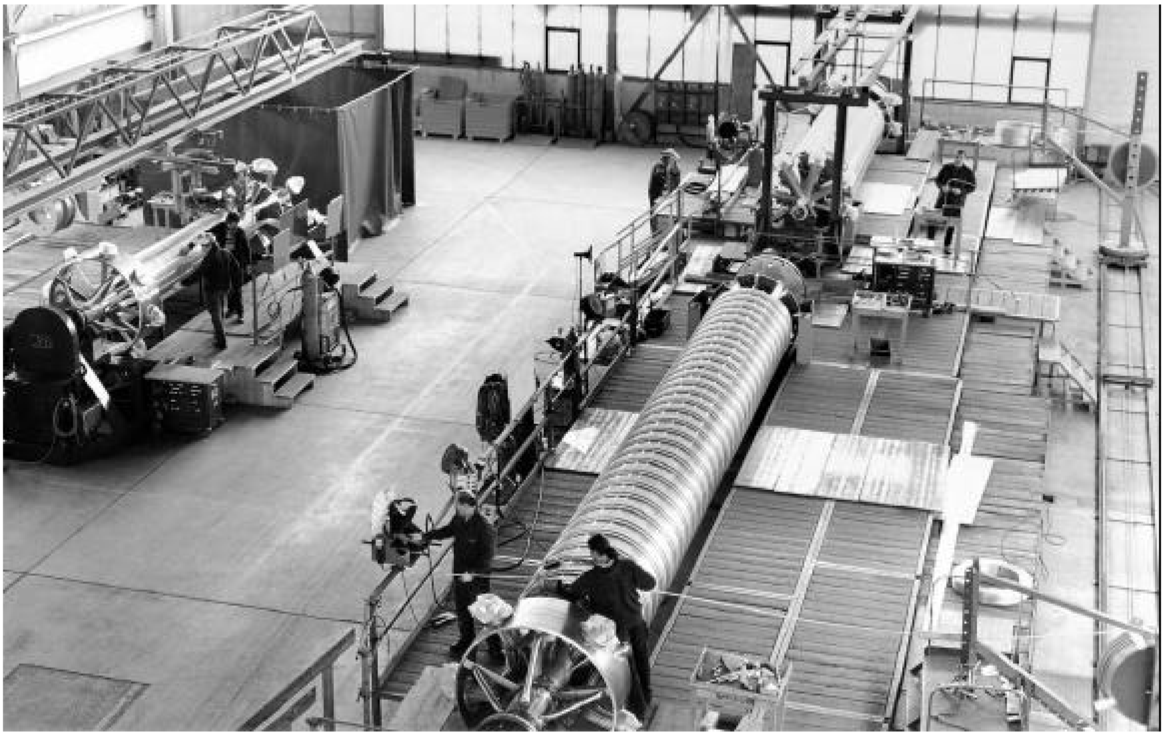

Fig.8: Three Bundles during Winding

Then the tubes were wound helically on the mandrel with a constant pitch and the winding direction being changed at each layer. Spacer bars were installed between each layer to provide the required spacing. Each tube was wound individually as to ensure proper line-up of the tubes. Particular attention was paid to keeping unsupported length of tubes between bundle and tube sheet within given limits. The bundle winding was performed in parallel on three winding benches.

The tube ends on the tube sheets were then prepared for welding. A special welding process was developed for this rather critical welding seam and applied with excellent results.

After the three tube bundles had been wrapped into shrouds they were assembled with the prefabricated shell sections and completed to one exchanger.

As soon as the pneumatic pressure tests on shell and tube sides had been carried out, the SWHE was installed in the cold box (Fig.9). Prefabricated pipe sections were connected to exchanger, separator and valves. The instrumentation was installed followed by an additional pneumatic pressure test for all systems.

Finally the completed cold box was sealed and prepared for transport.

Fig.9: SWHE Installation into Cold Box

Fig.10: The Mossgas SWHE Cold Box

Installation

The completed cold box was shipped via the German North Sea port of Bremen to Port Elisabeth, SA, and then by road to Mossel Bay.

In the meantime, Mossgas had prepared foundations, tie-ins, electrical cabling and instrumentation lines. Erection of the cold box, connecting the unit into the existing plant, pressure testing, cool-down test run and finally filling the cold box with perlite was a matter of three months (Fig. 10).

Pre-commissioning started exactly 16 months after the decision to carry out such a venture had been taken by the Alliance.

OPERATION AND PERFORMANCE

To demonstrate and prove the thermodynamic and hydraulic design as well as the mechanical integrity the exchangers are equipped with a large number of flow -, temperature -, pressure - and pressure difference indicators. As a special feature about 30 calibrated temperature indicators are installed in the three bundles to compare predicted with actual temperature profiles of the SWHE. These temperature indicators provided a complete detailed picture of the temperature profiles of each bundle. Mossgas' Process Information System (PI) in connection with a modern DCS with high resolution and fast cycle-times proved to be an excellent tool for reporting and documenting numerous data sets.

Start-up and Performance Tests

The start-up went smoothly and caused no unusual difficulties. 100 % liquefaction capacity could be reached easily. A maximum capacity of 110 % could be demonstrated. Higher liquefaction rates could not be tested due to the limitations of both the NG pretreatment facilities and the MRC compressor. The turn-down behaviour is exceptional. A stable operation at 20 % liquefaction rate caused no problem.

The composition of the MRC was basically adjusted by judging the actual temperature profiles, pressures and flow rates. For the final adjustment of the MRC composition the results of MRC samples taken by the laboratory from time to time were used as an additional information.

Transient Behaviour

To learn more about the dynamic behaviour of the SWHEs a number of tests have been made:

- Start-ups from warm and different cold conditions
- Load changes
- Controlled shut-downs
- Trip scenarios (refrigerant cycle compressor, NG, ESD)
- Forced mal-distribution

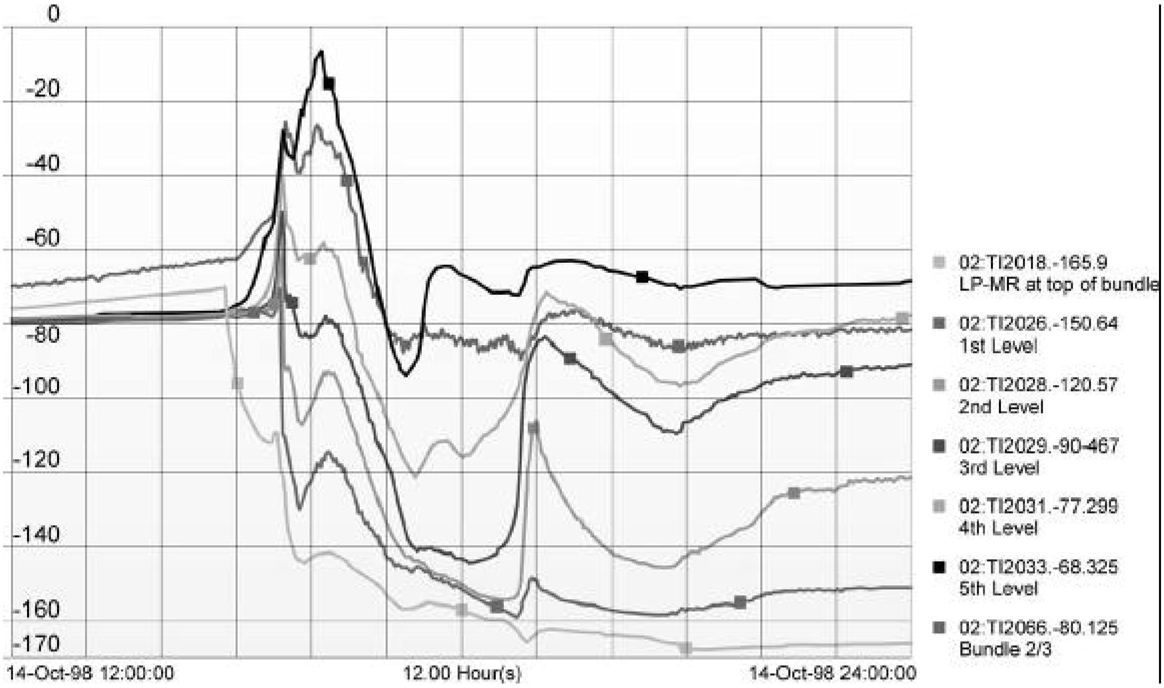

Fig.11: Temeperature Profile of Bundle III during an Early Start-up

Fig. 11 shows one example of such tests. On October 14, 1998, at noon all temperature indicators of the cold bundle showed temperatures around –80°C. This happened after the cycle compressor was shut down and all those temperatures equalised there. After restart of the cycle compressor the expansion valve of the gaseous high pressure refrigerant (G-HP-Refr.) was opened at approx. 14:50 o'clock. On purpose the cold end was cooled down rapidly, while the warm end warmed up to almost 0°C at 16:10 o'clock. Opening and closing of refrigerant valves resulted in additional temperature changes. Around 20:00 o'clock the fluctuations straightened out and the plant was put in stable operation.

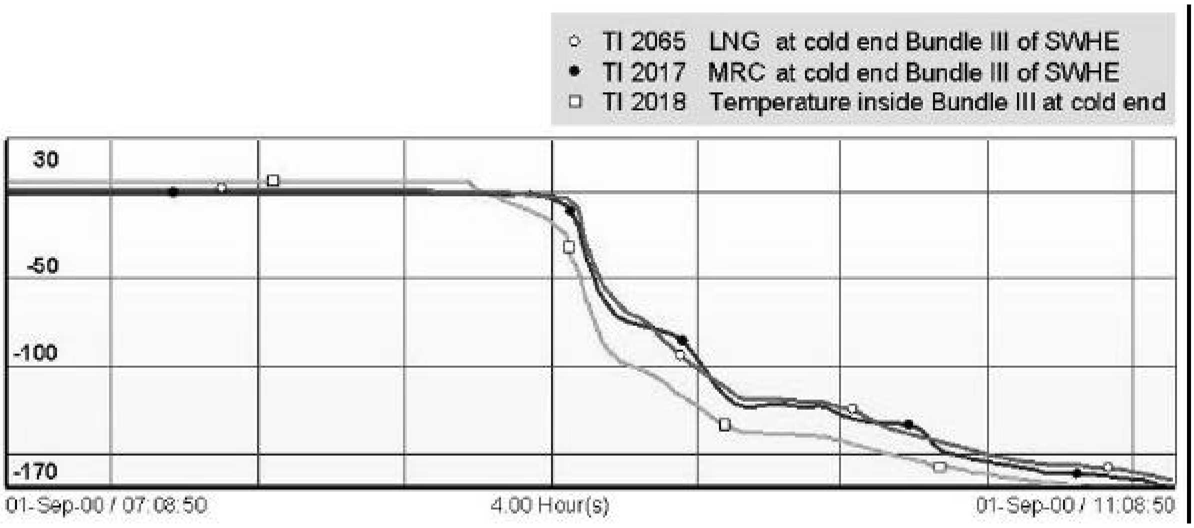

Fig.12: Temperature Profile of the Start-up on Sept. 1, 2000

Fig. 12 shows the temperature profile of the warm start-up on Sept. 1, 2000. Shortly before 9:00 o'clock the cool-down began and was finished within two hours. Changing

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the liquefaction rate was carried out quite rapidly without causing any trouble to the stable operation of the plant.

Tests of mal-distribution confirmed the expected redistributing effects of the bundle. Such tests were carried out by closing one of the two expansion valves of the liquid high pressure refrigerant (L-HP-Refr.), which caused all the liquid being directed to one half of the distributor.

Operation Mode

Mossgas prefers to operate the SWHE-box and has therefore disconnected the PFHE-box. The liquefaction plant is shut down and started up approx. once a month due to the operational requirements of the GTL-plant. In more than two years of operation with over 20 start-ups the SWHEs have shown their robustness and reliability. There has been no mechanical problem or tube failure whatsoever.

COMMERCIAL APPLICATIONS

The positive results of these tests convinced a number of clients of Linde's capability to produce SWHEs for LNG baseload plants.

Woodside Energy Ltd. placed an order for SWHEs for their expansion project on the Burrup Peninsula in Western Australia. The manufacturing in our workshop has started.

Sakhalin Energy Investment Company Ltd. issued a letter of intent for SWHEs for their project on Sakhalin Island in Russia.

The Snoehvit partners selected our SWHEs together with the Statoil / Linde Mixed Fluid Cascade Process (MFCP) for the Hammerfest LNG baseload plant by awarding the front end engineering design (FEED) to Linde.

CONCLUSION

The Statoil / Linde LNG Technology Alliance founded in 1996 decided to build and test SWHEs for LNG baseload plants and to develop its own liquefaction process, the Mixed Fluid Cascade Process (MFCP) [4]. Both undertakings have been successful and are entering the phase of commercialisation.

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