Coil wound main cryogenic heat exchangers are at the heart of the vast majority of the world’s natural gas liquefaction plants. From LNG’s early days, coil wound heat exchanger technology has continued to evolve in order to meet industry demands. From an initial requirement to produce approximately 1 million tpy of LNG, today’s units can produce over 10 million tpy in a single train.

This article will describe how 40 years of experience has brought about technical advancements which are essential in meeting today’s challenging requirements. Through the total integration of process and heat exchanger design coupled with manufacturing expertise, today’s more efficient and mechanically robust coil wound heat exchangers are able to meet current market demands of higher throughputs, higher feed gas pressures and harsh operating conditions, including floating service.

The beginning
Baseload liquefaction of natural gas using coil wound heat exchangers is a technology that is over 40 years in the making. Air Products’ experience in LNG began in 1966 when it received a contract from Esso for the process license and supply of the MCR® cryogenic heat exchangers (MCHE) at the natural gas liquefaction plant in Marsa el Brega, Libya. The successful startup of the first
Figure 1. MCHE at dockside being prepared for shipment to LNG plant site.
liquefaction train was in 1971, and Air Products has continued to look forward ever since.

Heart of the plant
The LNG industry may have been born in the 1960s, but the basics of coil wound exchanger fabrication started for Air Products in the 1940s. Initially, the manufacture of hundreds of copper coil wound units for air separation gave way to larger aluminum coil wound exchangers that were used to separate helium from large flows of pipeline natural gas for the US government’s helium conservation programme. The experience gained during the design, manufacture and operation of these very large coil wound heat exchangers became an essential element in the development of the baseload LNG industry.

The MCHE is the heart of the LNG plant and is where natural gas is liquefied and subcooled. Warm gas enters the bottom of the exchanger on the tubeside and exits at the top in the subcooled liquid state. The unit must be designed to take huge volumes of gas from a temperature of -35 to -160 °C.

The MCHE consists of one or more coil wound tube bundles housed within a single pressure shell. The bundles are made up of small bore aluminum tubing, which provides a large amount of heat transfer area in a compact unit and permits operating pressures in excess of 82 bara for greater process efficiency. Tubes are wound in a helical fashion around a long hollow aluminium tube or mandrel. Successive layers are spaced apart from one another to provide uniform shell-side refrigerant flow. A single bundle may contain hundreds of kilometres of tubing. The entire bundle is enclosed within a shroud and supported from the mandrel and the shell. In addition to the intricate internal design of the heat exchanger for gas liquefaction, the external shell has typically been designed to support platforms, ladders, insulation and piping. The MCHE is also designed to resist wind and seismic forces as well as transportation and erection loads.

Air Products provides a unique process design for each liquefaction facility. Each exchanger is custom designed by Air Products’ engineers based on project specific requirements. Over one hundred coil wound exchangers have been designed and manufactured by Air Products for LNG service. Decades of successful operation have proven the mechanical design to be robust. Units fabricated 40 years ago are still in operation.

Evolution of LNG process cycles
That first Air Products’ plant design for Libya utilised the single MCR® Cycle. The precooling, liquefaction and subcooling were all accomplished using a mixed refrigerant in a single coil wound exchanger. Air Products’ second LNG plant design, located in the Sultanate of Brunei, incorporated what would become the mainstay of Air Products’ LNG process technology for decades thereafter. The new cycle was known as the propane precooled MCR® process or C3MR. Mixed refrigerant was still used for liquefaction and subcooling in a single coil wound exchanger, but C3 or propane was used for precooling.

Air Products continued to push the process technology envelope with the development of the AP-X™ LNG process in the early 2000s. The cycle combines pre-cooling using propane, liquefaction in a coil wound exchanger using a mixed refrigerant cycle, and subcooling in a separate coil wound exchanger using a nitrogen expander cycle. The expander cycle is efficient at providing cold refrigeration and uses nitrogen, which is readily available and inert. The cycle runs at high pressure that means low pressure drop losses and compact equipment.

The success of these mixed refrigerant processes and coil wound exchangers has led to the development of other processes such as the dual mixed refrigerant process. This process is similar to the C3MR process with a mixed refrigerant used in a coil wound exchanger for precooling.

The flexibility of the LNG process cycles combined with the robustness of the coil wound exchangers make them amenable to handling a wide range of process conditions. Feed gas compositions can vary from very rich as found in associated gas fields to very lean (>98% methane). Feed gas pressures can exceed 80 bara. Ambient temperatures can vary from the warm temperatures found at most of the existing facilities to much colder temperatures found in arctic climates. In addition, processes utilising coil wound exchangers have been developed for floating service in order to monetise gas fields far from land.

Industry growth
The LNG industry experienced rapid growth in the 1970s when seven grassroot facilities were commissioned. Air Products supplied the process technology and MCHEs for six of those seven sites. Besides Libya and Brunei, facilities at Abu Dhabi, Algeria, and two locations in Indonesia were commissioned in the 1970s. During this time, the C3MR technology became the clear process for the LNG industry.
of choice for liquefaction of natural gas because of the cycle’s high efficiency and ease of operability, as well as Air Products’ expertise in designing and fabricating coil wound exchangers.

The trend continued in the 1980s with global LNG capacity expanding into Malaysia and Australia. Both of those sites and expansions in Algeria and Indonesia use Air Products’ technology. The industry’s growth was sustained in the 1990s with Air Products as part of the grassroots effort in Qatar, Nigeria and Oman as well as numerous plant expansions. With abundant reserves and high demand, the LNG baseload industry continues to grow in the 2000s with plant expansions in Nigeria and Qatar and grassroots sites in Egypt, Yemen, Indonesia and Peru.

Bigger is better

The first liquefaction trains of the early 1970s incorporated a heat exchanger that was able to produce approximately 1 million tpy. The capacity of subsequent trains has followed a steadily increasing trend. By the mid 1970s the 1.5 million tpy per train mark was reached in Algeria. In the 1980s, 2.5 million tpy per train was achieved per train in Malaysia, and in the 1990s, 3 million tpy was surpassed in Nigeria and Qatar. The trend has continued in the 2000s by reaching the 5 million tpy in a single liquefaction train in Egypt. As train production increased to take advantage of economies of scale, the MCHE size also increased. During the four decades of heat exchanger fabrication, the MCHE diameter grew from 3.5 m to over 4.5 m.

Six liquefaction trains, each designed with a nominal capacity of 7.8 million tpy, will catapult Qatar into the global natural gas liquefaction leadership position as the first decade of the twenty first century closes out. In another industry first, the AP-X™ process splits the subcooling from the MCHE and accomplishes it in a separate coil wound exchanger that has an aluminium bundle and a stainless steel shell in order to accommodate the higher nitrogen design pressures. While the output rate is impressively large, the heat exchanger diameter was not increased. This was accomplished by developing an efficient liquefaction process in which the duty of the MCHE is reduced by subcooling LNG in the separate coil wound exchanger. Separator and liquid distributors were designed to accommodate the larger flow rates and were rigorously tested. In addition, the challenges of supporting and transitioning the aluminium bundle to the stainless steel shell were solved using a simple, innovative mechanical design.

The AP-X™ process and equipment can be expanded to enable a single train to produce over 10 million tpy output per train. While this represents a large step in train capacity, the novel design uses proven technology and equipment. Larger capacity liquefaction trains achieve economy of scale by way of fewer individual trains, which leads to fewer piping and control systems and ultimately to reductions in installation, operation and maintenance costs.

Continuous improvement

The engineering and manufacturing methods used to produce the first coil wound tube bundles have evolved tremendously. Years of engineering and fabrication improvements have led to increasingly innovative methods of winding, positioning and installing tubes. Conventional lathes used to wind bundles became winding centres with the addition of sophisticated tensioning devices, computer controls, and automated linear motion equipment.

One of the issues faced by early LNG plants was mercury contamination. As a result of this experience, Air Products and LNG plant operators contributed to the natural gas industry’s understanding of mercury attack on aluminium equipment. Air Products made improvements to the MCHE design that included features intended to minimise the potential for mercury attack on the feed circuit piping. The MCHE is designed so that the tubes and piping are free draining as much as possible. Crevices where mercury could potentially collect have been minimised.

In further design improvements, the external separators and interconnecting piping were included inside the exchanger. This integrated design reduced the amount of separate pieces of equipment and eliminated aluminium field welding.

The bundles of the first heat exchangers depended primarily on friction to hold the coils of tubing in place. To accommodate larger, heavier bundles with higher pressure drops, Air Products’ engineers developed a novel support system that secures each individual tube layer in place. This robust design feature helps to facilitate long service life.

Traditional coil winding was refined into precision programming, where engineered instructions determine the location of each and every one of the thousands of tubes. The tube tails are routed in coherent patterns along the most direct and predetermined paths to the tubesheets. Bends are minimised, as are crossover contacts between tubes. Precision programming not only changes the appearance of the bundle, but improves reliability.

Large bundles are now transported through the fabrication shop quickly and more easily using a state of the art transporter system. Shipping larger heat exchangers from the fabrication shop to the port facility requires the use of specialised equipment such as rail cars with motorised side shifting mechanisms in order to avoid obstructions along the rail route.
Moving forward

Success as a supplier of cryogenic natural gas liquefaction technology and equipment results from the creativity and technical capability of the many people who have dedicated their careers to this objective. Years of process technology effort have yielded efficient cycles with large capacity capabilities. From a fabrication standpoint, Air Products sets the standard for world class welding and coil winding technology. These attributes put Air Products in a leadership position for taking on new LNG baseload ventures, one of which is floating, production, storage and offloading (FPSO).

The desire to capitalise on remote gas fields has fuelled research and business development activities towards taking the liquefaction train to the source of the gas. A project to build an FPSO plant for LNG has yet to come to fruition, but Air Products has completed a comprehensive research and development programme to prove the viability of LNG liquefaction technology at sea. Air Products partnered with maritime engineering consultants to determine the design basis. A scaled version of a coil wound exchanger was tested at a prominent university for the effect of harsh wave motion conditions. Additional cyclic load testing at an Air Products research facility rounded out the validation process. The result of the findings is that Air Products possesses the process technology, mechanical design capabilities, and the manufacturing expertise to successfully implement FPSO projects. The fabrication experience gained from the AP-X™ subcooling exchanger will lend itself to the FPSO application because the stainless steel shell will have the strength to withstand the motion of the platform while maintaining the heat transfer benefit of the aluminium tube bundle.

Air Products continues to change the LNG landscape with new MCHE product development efforts such as modularisation of equipment, higher design pressures, and larger diameter exchangers. Upgrades to shop equipment and improvements in rail shipping clearances have paved the way towards the ability to produce the largest coil wound heat exchangers in the world; exchangers that are 5 m in diameter and weigh 430 t.

Conclusion

Air Products’ unique ability to integrate the liquefaction process design, the mechanical design and the fabrication of the main cryogenic heat exchanger leads to an optimisation of performance and reliability that has become the benchmark of the LNG industry. Air Products lives a culture of continuous improvement, which is evident in the design and fabrication processes used to make coil wound heat exchangers. Forty years of commitment to ever evolving coil wound heat exchanger technology continues to fuel the drive toward liquefaction cost reductions. LNG

References

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