BUILT TO PERFORM

William P. Schmidt, Damian Vujcich, and Christopher R. Butler, Air Products, discuss which type of heat exchanger is best for producing LNG, outlining the advantages of each.

All LNG plants require cryogenic heat exchangers to liquefy natural gas. This article compares the two most common heat exchangers used in LNG liquefaction: coil wound heat exchangers (CWHE) and brazed aluminium heat exchangers (BAHX). Air Products has extensive experience with each of these heat exchanger technologies across its industrial gas plants and LNG equipment projects.

Both BAHXs and CWHEs have high efficiency; however, the CWHEs have three clear advantages in LNG:

- High throughput in a single exchanger with a small footprint.
- Better resistance to thermal stresses, which reduces the likelihood of a leak. In the unlikely event of a tube leak, the CWHE has double containment, nearly eliminating the possibility of an external release of flammable fluids, therefore increasing safety. The plant can run until the next scheduled shutdown, where the leak can be repaired, which increases availability.
- Air Products' CWHE designs are already highly modularised, containing interconnecting piping and internal vapour and liquid distribution systems, all within a single pressure retaining shell. This design facilitates maintenance from the outside and without the need for confined space entries.

These features contribute to the use of CWHEs in the vast majority of LNG baseload facilities.

What is a CWHE?

A CWHE consists of a shell containing one or more tube bundles (Figure 1). A bundle is made up of tubes wound around a mandrel in concentric layers (Figure 2), with the layers being separated by spacers to ensure flow area for the shell side fluid outside of the tubes (Figure 3). The number of bundles within a CWHE and the specific design of the bundles depend on the process requirements for the LNG plant.[1,2]

The flow directions are sketched in Figure 1. The streams that are cooled (natural gas and high-pressure warm refrigerant) flow upward through the tubes in their respective circuit, with the natural gas leaving as LNG. Cooling is provided by boiling the cold refrigerant as it cascades down the outside of the tubes in an evaporating thin film. In mixed refrigerant (MR) processes, the refrigerant composition can be adjusted during operation to maximise plant efficiency, by blending nitrogen and low molecular weight hydrocarbons (C1 through C5).

The tube bundles are small-bore aluminium tubing, which provides a large amount of heat transfer area in a small footprint. A single tube bundle may contain hundreds of kilometres of piping. The vessel shells are manufactured from aluminium or stainless steel, depending on:

- The design pressure requirements of the liquefaction process.
- Whether it will be installed in an onshore or offshore LNG facility.

All interconnecting piping between bundles and the flow distribution systems are inside the shell, which greatly simplifies installation and field construction.

CWHEs are widely used in the LNG industry. For over 50 years, Air Products has manufactured LNG heat exchangers installed in over 120 LNG trains at LNG facilities in 20 countries around the world.

BAHX explained

A BAHX consists of many layers of fluid passages that are separated by parting sheets (Figure 4). Side bars seal the sides of each passage, and within each passage are corrugated fins, serving two purposes:

- They separate the parting sheets while providing the mechanical integrity to hold the heat exchanger together.
- They promote heat transfer between the fluids.

The BAHX contains passages of differing fluids. At the ends of the exchanger, the fins are angled towards a specific point to introduce and remove the streams from each passage. A half-pipe header is welded over the opening to collect the fluid.

Requirements of cryogenic LNG processes

Cryogenic LNG processes have special requirements for their heat exchangers:[3,4,5,6,7]

Process

- High thermal efficiency, produced by large temperature changes from inlet to outlet, while simultaneously achieving very close ΔTs between the hot and cold streams.
- Simultaneous heat transfer between three or more streams.
- Streams enter and exit partway through the heat exchanger.
- Many streams are two-phase, which requires special features to ensure even and steady flowrates.

Mechanical

- Both the hot and cold streams can have high design pressures.
- Heat exchanger designs are such that there is very little chance of experiencing flow-induced vibration.

Differences between CWHE and BAHX

Although they share many characteristics, each has particular strengths:

- Thermal stresses – LNG liquefaction exchangers can experience rapid temperature changes due to the nature of liquefaction processes. These lead to uneven temperature profiles within the exchanger. BAHXs are rigid, with components welded and brazed together, so uneven temperature profiles can cause high stresses. CWHE bundle construction provides more mechanical flexibility due to the lack of welded components, which minimises the thermal stresses during temperature changes.
- Design pressures – CWHE tube circuits can be designed to >100 barg, and the shells to 10 – 40 barg. BAHXs can be designed to >100 barg, although at above 60 barg, the fins become less effective and the heat transfer/pressure drop performance decreases. Higher feed pressure allows higher liquefaction efficiency and throughput. For example, increasing the feed pressure from 50 to 100 barg increases production by 10% and improves efficiency by 4%.
- Heat transfer – Both exchangers (BAHXs and CWHEs) have a high heat transfer area per unit volume. Due to the internal fins, the area/volume ratio for BAHXs is higher.
- Single unit throughput – CWHEs have a larger throughput, with a single exchanger processing over 5 million tpy of LNG. BAHXs require multiple exchangers in parallel, requiring manifolding to distribute flows. This can be problematic if two-phase flows need to be introduced.
- Footprint – The CWHE footprint is significantly smaller, due to its ability to process large flows in a single unit. The footprint is essentially the exchanger diameter of 3 – 6 m.
- Consequence of leaks – Repeated thermal stresses can lead to leaks caused by metal fatigue. BAHX leaks can either be passage-to-passage or passage-to-environment. The latter requires immediate shutdown to repair. In a few cases, there have been catastrophic loss of containment events.[8] A CWHE provides dual containment of the tube circuits; any leakage is contained by the shell and does not leak to ambient. Tube leaks are infrequent; however, if they occur, the leak can be managed, and operation continues until the next regularly scheduled maintenance outage.

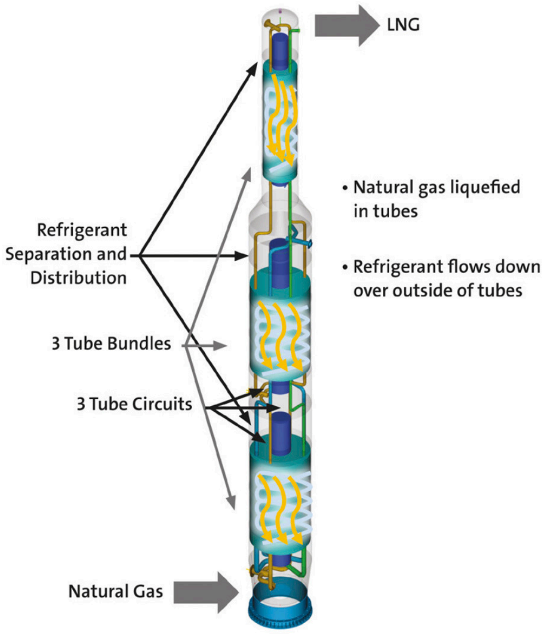

Figure 1. Main cryogenic heat exchanger.

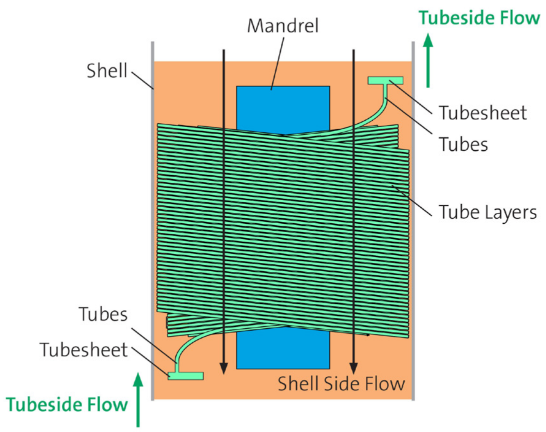

Figure 2. CWHE tube bundle – side view.

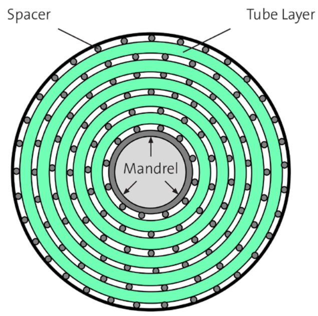

Figure 3. CWHE tube bundle – cross-sectional view.

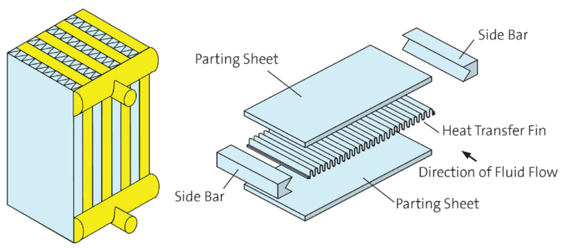

Figure 4. BAHX construction.

- Ease of repair – If leaks occur, each exchanger type has specific repair strategies:
  - BAHX leaks are repaired depending on the location:[8]
    - » External leaks through the sidebars – Aluminium is removed from the area of the leak by grinding. Fresh weld material is put down to seal the leak.
    - » Internal leaks between passages – The leaking passages are removed from service by welding the inlet and outlet openings. However, it should be noted that removing even a few passages can radically alter the temperatures within the BAHX. An engineering analysis is needed to ensure that the resulting thermal stresses are acceptable. This prevents the repair from leading to further thermal stresses and potential future leaks.
  - CWHE tube leaks are repaired by plugging both ends of the leaking tube. CWHEs are designed so the tube sheet can be accessed without an entry into the shell. Eliminating these tubes from the circuits has a negligible impact on the temperature profiles within a bundle.
- Resistance to plugging – The CWHE tube diameters are large, between 5 – 20 mm. The internal spaces within a BAHX are 0.2 – 1.6 mm, making the BAHX more susceptible to plugging with debris.
- Turndown – CWHEs operate stably at flows of >50% of design with minimal operator attention and between 5 – 50% of design flow with some operator attention. This is because in a CWHE, the tubes are close to horizontal, only slightly inclined, making flow stability much easier to maintain in a CWHE. On the shell-side of a CWHE, liquid flows downwards over the outside of the tubes. Gravity is moving the fluid in the desired direction, so the two-phase flow is stable in virtually all conditions.[9] In BAHX exchangers, turndown is limited to approximately 60% of the design because the boiling two-phase streams that flow upwards become unstable.

Modularisation is the name of the game

Modularisation is an execution strategy which enables the transfer of construction work from the jobsite to one or more local or distant fabrication shops or yards with the aim to improve the overall cost, schedule, and risk profiles. CWHEs and BAHXs can be modularised, which moves work offsite to improve access to labour markets, minimise work at heights, and improve security, just to name a few benefits.

When modularised, much of the construction will take place in a controlled environment, and then the fully assembled unit is shipped and erected. For BAHX, all the cores, piping, controls, and instrumentation can be contained in a shop-fabricated cold box. The box is shipped to the site, where it is erected, and insulation is installed. Once insulated, the box must be purged with an inert gas (usually nitrogen) during operation. This is to maintain a dry, inert atmosphere surrounding the cryogenic equipment and piping.

CWHEs are modularised by their very nature. The interconnecting piping between bundles and flow distribution systems are contained within the shell, so only the inlet and outlet piping need to be attached. The execution strategy for CWHE is often field installation, where the exchanger is installed, and then piping, platforms, and insulation are added in the field.

When CWHEs are fully modularised, they are installed in a frame; piping, instrumentation, and insulation are added; and then the entire module is transported to the field and installed. This decreases the requirement for on-site labour and aims to eliminate on-site scaffolding, thereby reducing the construction costs and increasing the schedule certainty of the proposed project.

Figure 6 shows a fully modularised CWHE.

CWHEs in other LNG services

CWHEs can be used in other LNG processing applications in addition to the main cryogenic heat exchanger (MCHE). These include:

- Pre-coolers in dual mixed refrigerant cycles, where the natural gas feed is cooled from ambient to between -30˚C and -60˚C, using a mixed refrigerant. All of the benefits described above apply to these pre-coolers.
- End flash exchangers, which increase LNG production and efficiency by recovering refrigeration from cold vapours by cooling and/or liquefying a warm stream, typically either natural gas or refrigerant. The cold vapours are most often from the end flash unit, but they can also come from the LNG storage tank. These exchangers are often subjected to sudden flow changes, which can create high thermal stresses. CWHEs provide the most robust and reliable heat exchanger for this demanding thermal cycling service. CWHEs minimise the thermal stresses that can lead to leaks, and their double containment greatly reduces the consequences of leaks.
- Further savings are possible by combining the end flash CWHE and end flash drum into a single piece of equipment. This reduces CAPEX and footprint compared to alternative heat exchanger designs. It also eliminates a significant length of large diameter piping and the associated pressure drop.
- Floating LNG (FLNG) plants, including those in operation and several in the project development phase. CWHEs are ideal in FLNG service, due to their small footprint, high efficiency, and robustness.[2] CWHEs are modified for shipboard service by:
    - Designing the CWHE internals to mitigate the effect of motion on liquid flows, including sloshing.[10]
    - Making the MCHE shell out of stainless steel to withstand the high blast loads from the compact environment and the fatigue loads caused by sea waves. Stainless steel also helps to mitigate the marine environment.
- CWHEs have been designed for and are operating in other severe environments, including the cold arctic conditions and the high hurricane loads of the US Gulf Coast and Australia.[2]

Conclusion

This article has shown that CWHEs are ideal for producing LNG. They meet all requirements for cryogenic heat exchangers. In addition, they can process a large flow in a small footprint, are resistant to leaks, they intrinsically have double containment to virtually eliminate loss of containment, and can be readily modularised. **LNG**

References

A comprehensive list of this article's references can be found on the *LNG Industry* website at: www.lngindustry.com/special-reports/

Figure 5. An Air Products CWHE being loaded onto a ship for transport.

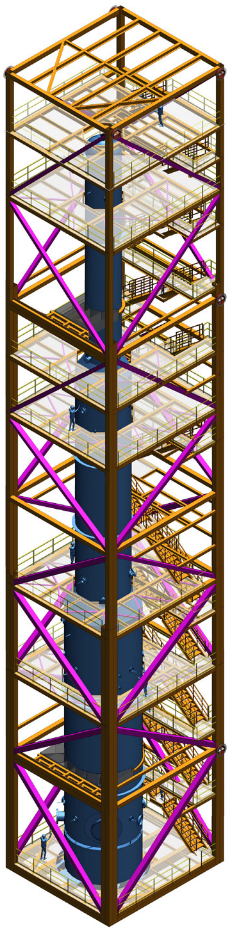

Figure 6. Modularised CWHE.