# A KEY TO LNG

**Doug Ducote, Joe Belling and Paul Shields, Chart Industries Inc., USA,** explore how brazed aluminium heat exchangers optimise processes for natural gas liquefaction.

Brazed aluminium heat exchangers (BAHXs), also referred to as plate fin heat exchangers, are at the heart of many of the processes used for the liquefaction of natural gas. They are deployed across the world on plants of all sizes, from world-scale base-load facilities down to facilities that produce much smaller quantities of LNG for local use. They are also proven, both onshore and offshore. This article will explain how the characteristics of BAHXs are instrumental in the development of standard and modular plant solutions that have enabled small and mid scale LNG to become economically feasible.

## What is a BAHX and how does it work?

BAHXs are highly efficient, custom designed compact heat exchange devices that offer distinct advantages vs other heat

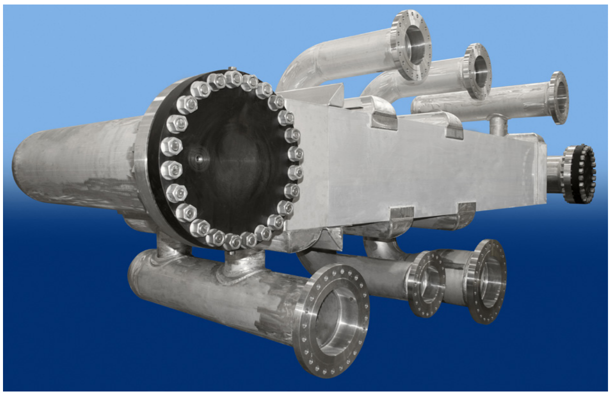


**Figure 1.** A BAHX complete with manifolds and flanged terminations.

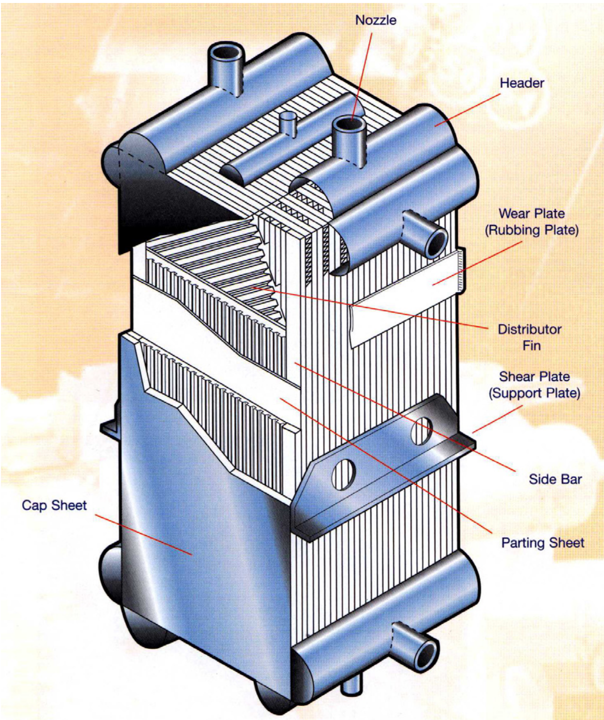



**Figure 2.** BAHX components and nomenclature.

exchanger types. They are manufactured as an all brazed and welded pressure vessel with no mechanical joints and are designed in accordance with major pressure vessel codes across the world. BAHXs are applied in a variety of cryogenic and non-cryogenic heat transfer applications, ranging from LNG production, industrial gas production, petrochemical and hydrocarbon processing, as well as hydrogen and helium liquefaction. Given their high surface area, compactness and the high heat transfer capability that is inherent to aluminium, BAHXs are a cost-effective solution for processing non-corrosive liquids and gases.

Originally adapted from aerospace applications shortly after World War 2, BAHXs were commercially deployed in cryogenic air separation processes during the 1950s and first used for the liquefaction of natural gas in the 1970s. Today, there are tens of thousands of units in operation across the world. However, despite such extensive use, the characteristics of BAHXs, and especially those that make them pertinent for cryogenic processes, are still not widely understood, hence articles of this nature typically require an introduction.

## Construction

The principal components of a BAHX are: parting sheets (primary heat transfer surface); fins (secondary heat transfer surface); and side bars (pressure retaining wall). The components are stacked in an alternating pattern of hot vs cold.

The key to bonding the structure together is the brazing process. An aluminium alloy is applied to the surface of the parting sheet. Once the core is stacked and heated in the vacuum brazing furnace, the alloy melts, whetting the surface of adjacent components. When cooled, the alloy returns to solid state, effectively sealing the components together.

A major milestone in the development of BAHX occurred in the 1980s with the introduction of vacuum brazing, which replaced the previous salt bath process. Vacuum brazing has enabled manufacturers to develop the size, complexity and upper pressure limits of the plate fin units needed in industry today.

Heat transfer within the BAHX takes place almost entirely through convection between the fluid and metal surfaces.

BAHXs are generally oriented with the warm end up. This is a preferred arrangement for process efficiency and also affords reduced thermal stresses during shutdown as it prevents cryogenic fluids flowing to warmer surfaces.

There are four main fin types that provide the secondary heat transfer surface. They are one of the main contributors of the high thermal efficiency of BAHXs.

Plain fins are typically used in the distributor section, where the fluids are moved and turned from the inlet ports into the heat transfer section. Perforated, herringbone and serrated fins are used in the heat transfer section and their primary function is to break up the boundary layer of the fluids as they move through the unit. The boundary layer is essentially resistant to heat transfer, so the more often that is broken up, the more effective the heat transfer surface will be. However, this also results in more pressure drop, hence the skill of the design engineer is to find the optimal balance between thermal and hydraulic performance and, at the same time, ensure that the mechanical design requirements are met.

To illustrate the compactness of the BAHX for natural gas liquefaction, the design provides a heat transfer area density of approximately 1000 – 1500 $m^2/m^3$, which is 6 – 10 times greater than a coil wound heat exchanger and at least 20 times greater than conventional shell-and-tube technology. This characteristic advantage of a BAHX, coupled with the enhanced heat transfer performance of aluminium plate fin construction and optimised heat transfer fin designs, results in 25 – 50% lower costs and substantially lower weight.

When process UA requirements exceed what can be delivered in a single core block, several BAHXs can be piped or manifolded together in parallel or series to accommodate nearly unlimited flow or duty requirements. BAHXs are generally supplied in a carbon steel modular structure called a cold box for ease of insulation, support and installation.

The flexibility of BAHXs allows for multiple heat exchange services (10 or more streams in a single block) to be combined into a single compact application. BAHX technology enables application of pinch technology along with all the energy minimising benefits. This feature significantly reduces installation and operation costs, engineering, insulation, support systems, testing, documentation, transportation and site arrangements.

Key features of a BAHX include the following:

- Multi-stream capability: meaning that the entire cooling requirement can be contained in a single unit or a series of single units manifolded in parallel for larger plants.
- Aluminium's greater thermal conductivity compared to steel. Aluminium also gets stronger at cold temperatures.
- Increased thermal efficiency through tight approach temperatures.
- Hydraulic performance, which affords excellent turn down capability.
- High heat transfer surface area per unit volume.

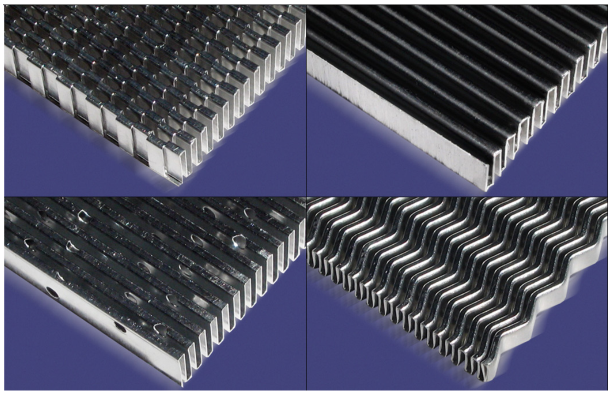


**Figure 3.** Fin types: top left, serrated; top right, plain; bottom left, plain perforted; bottom right, herringbone (wavy).

**Figure 4.** An LNG cold box being raised into position.

## BAHXs in the liquefaction process

Aluminium plate fin exchangers offer advantages in most LNG processes. Minimising power consumption (or maximising LNG production for a selected turbine/compressor model) is a key design criterion for liquefaction processes, creating an inherent requirement for highly efficient heat exchange. Process efficiency is gained by minimising temperature approach between the hot and cold streams. As the temperature approach decreases, the required surface area increases. As such, the heat exchanger of choice must offer high surface area economically, as can be accomplished with a BAHX.

There are several refrigeration cycle configurations that can be utilised to liquefy natural gas, but this article will principally focus on two: nitrogen cycle and mixed refrigerant cycle. Each cycle has its advantages and disadvantages when evaluated for use in a specific application. Designers tend to study the trade-offs between power consumption and equipment utilisation. This analysis allows them to optimise the liquefier for the total plant cost (capital plus operating costs). Comparison of operating costs should focus on the energy consumption of the refrigeration system, as the balance of plant should be essentially the same for all processes.

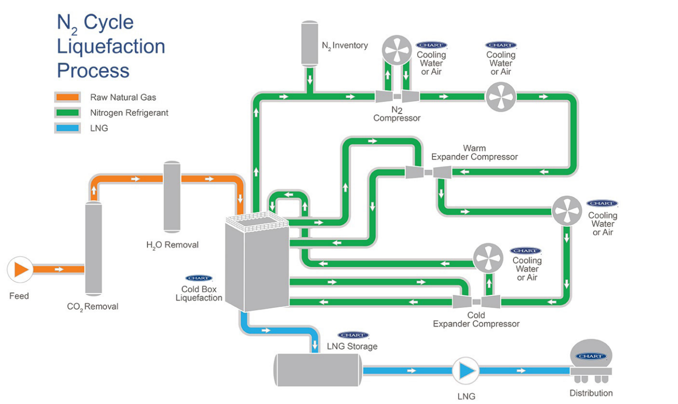



**Figure 5.** Nitrogen cycle process scheme.

### BAHXs in nitrogen cycle liquefaction processes

Nitrogen cycles are simple to operate and eliminate the need to use and store hydrocarbons as refrigerants. They offer advantages to operators that do not want to spend capital and energy to extract their hydrocarbon refrigerants from the treated feed gas and are ideally suited to remote areas that do not have easy access to hydrocarbons for refrigerants. However, simplification comes at the expense of higher specific energy consumption.

Consequently, the nitrogen cycle process is a good fit for small scale LNG when bringing LNG to market quickly is a key driver for project success. The liquefaction technology and design flexibility of BAHXs are entirely consistent with standard plant solutions, which entails

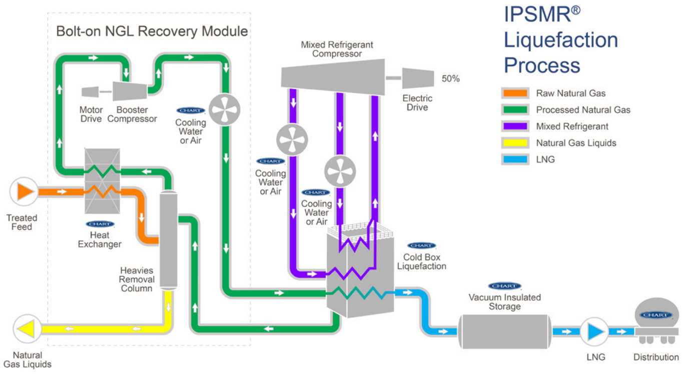



**Figure 6.** IPSMR® mixed refrigerant process technology scheme.

maximising equipment, including BAHXs, with a fixed design for a portfolio of capacities.

BAHXs offer a distinct advantage when a nitrogen cycle is employed as they allow for tighter approach temperatures, which enable increased cycle efficiency and lower power consumption. The compact design and multi-stream capability allows the BAHX to contain the entire cooling requirement in a single exchanger service. This significantly reduces plot space requirements and eliminates the need for interconnecting piping between multiple pieces of heat exchange equipment.

Nominally, a standard liquefaction plant solution incorporating nitrogen cycle technology is suited to small scale plants producing between 60 000 and 250 000 gal./d of LNG.

### BAHXs in mixed refrigerant liquefaction processes

As plant capacities increase, most technologists recommend a mixed refrigerant (MR) process. MR processes are based on mixtures of light hydrocarbons and nitrogen, normally a single mixture system with or without pre-cooling. In some instances, the processing scheme utilises dual mixture systems.

Process optimisation is achieved by varying the mixture of refrigerant components and operating pressures in a manner that essentially allows the heating curve of the refrigerant to mirror the cooling curve of natural gas in a tight temperature approach. The brazed aluminium exchanger accommodates the surface area requirements resulting from the tight approach temperatures and log mean temperature difference (LMTD). Its inherent multi-stream capability also allows the process engineer to add or remove refrigeration along the process thermal gradient, wherever needed, to optimise process efficiency. A single service main liquefaction BAHX has been an integral part of MR base load, mid scale, and peak shaving plants since the early 1970s. Another advantage to the process is the use of a single service compressor to provide the refrigeration pressure boost.

Chart's Integrated Pre-cooled Single Mixed Refrigerant (IPSMR®) process is comparable to dual mixture processes, but less complicated. It was designed specifically to minimise operating differential temperature in the BAHX, which significantly reduces the possibility of overstress from plant upset conditions and also improves process efficiency.

Another advantage of using BAHXs in MR processes is the ability to scale capacity. BAHXs work well in both small and multi-train mid scale LNG applications as capacity can be easily managed for increasingly larger flow volumes. The construction of BAHXs allows for scaling heat transfer requirements from a single exchanger to multiple exchangers connected in parallel. Because the designer has the ability to manage heat transfer and pressure drop and solve two-phase complexities in multi-BAHX trains, it makes them the ideal solution for the entire range of small and mid scale MR process capacities.

## Design validation

To ensure the robustness of the BAHX for LNG applications, state-of-the-art software is coupled with in-house engineering expertise and experience to perform advanced transient thermal analyses. Chart has developed proprietary in-house transient thermal analysis software that can utilise operating data or dynamic simulation process data to determine the internal fluid and metal heat exchanger temperatures and the associated thermal stresses imparted on the exchanger. These analyses can be carried forward to predict potential fatigue damage and life expectancy of the equipment. Dynamic simulation is used to simulate operation of the BAHX and plant upset conditions to ensure process technologies are designed with proper controls to mitigate situations that introduce thermal stresses.

## The cold box

The cold box has traditionally been dismissed as a carbon steel enclosure that houses a BAHX or, more typically, a series of BAHX units. However, with an increased drive towards maximum prefabrication for minimised field construction, the cold box has emerged as a key component in this effort. Consequently, it is prudent to include a short summary of what a cold box includes and the advantages it provides.

The composite construction of a cold box comprises of the following:

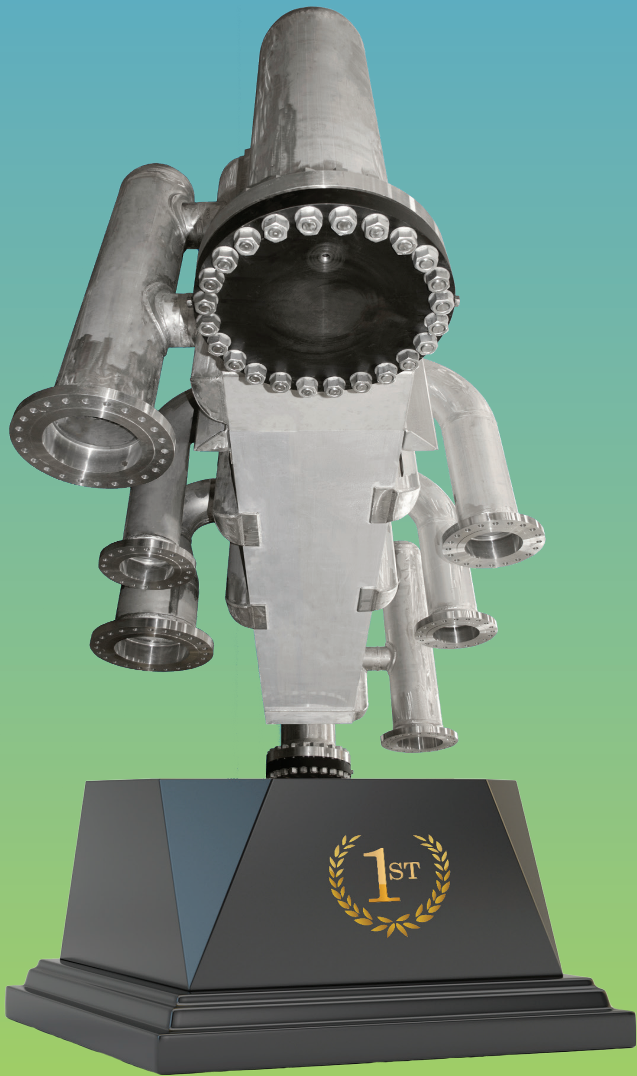
- BAHXs, which can be a single unit or multiple units manifolded together in parallel and/or series.
- Interconnecting pipe work.
- Process and separator vessels.
- Nitrogen purge and pressure relief safety systems.
- External flanged connections for easy hook up to process pipe work.
- Instrumentation.
- Insulation.

A modular structure provides simplified transportation and installation, minimised on-site construction, and reduced overall project schedule, complexity and cost.

## Conclusion

The highly efficient and versatile BAHX makes it possible to design and optimise liquefaction systems to minimise capital and operating cost over a wide range of plant capacities. BAHXs and cold boxes are well suited to all common process cycles, reducing the cost of LNG production without compromising safety or reliability.

# Chart Brazed Aluminum Heat Exchangers




## First to Produce LNG On-board a Floating Facility

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