LNG APPLICATIONS OF DIFFUSION BONDED HEAT EXCHANGERS

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Abstract

In industrial processes energy is transferred between process streams by a variety of methods, including conduction and conduction-convection in exchangers. Often exchangers operate under steady-state conditions, but in certain processes they operate cyclically, as in regenerative furnaces and some cryogenic processes.

Brazed aluminum plate fin heat exchangers have been widely used in the LNG industry where their compact size and cost competitiveness are beneficial. However, they are not suitable for services with large temperature differences between cold and hot fluids.

Diffusion bonded heat exchangers are compact, high integrity exchangers that have been widely used on offshore platforms for many years. They are typically just 20% of the size of equivalent shell & tube heat exchangers, but unlike other compact exchangers, they can be designed for pressures up to 9000psi (620bar).

A diffusion bonded stainless steel construction allows far greater temperature differences than permissible with brazed aluminum plate-fin technology, and it's also not subject to the stringent warm up / cool down rate limits associated with brazed construction.

This paper discusses the technical design features of diffusion bonded heat exchangers and their application to the LNG industry, and it also addresses some of the associated technical/operational aspects of these exchangers.

Introduction

Heatric has been involved in the commercial design and manufacture of diffusion bonded heat exchangers for over 20 years and there are now thousands of tons of such exchangers in operation on hundreds of different projects around the world. Many of them are installed on offshore oil & gas platforms where the size and weight advantages of such compact exchangers are of obvious benefit. Typical applications include gas compression cooling at pressures up to 9000psi (620bar) and gas/gas exchangers in dewpoint control systems.

More recent work in the LNG industry has highlighted a number of areas where such diffusion bonded exchangers may prove beneficial and commercially attractive and we shall investigate these further in this paper.

Diffusion Bonding Technology

Diffusion bonding is a high temperature, solid state joining process that promotes grain growth across metal boundaries, resulting in a join exhibiting parent metal strength and ductility.

This joint is significantly stronger than a brazed joint in an aluminum plate fin heat exchanger, and hence stainless steel, diffusion bonded exchangers can be designed for much higher pressures. In addition, they are far less susceptible to thermal shock and thermal fatigue than a brazed aluminum plate fin heat exchanger.

Heat Exchanger Core Construction

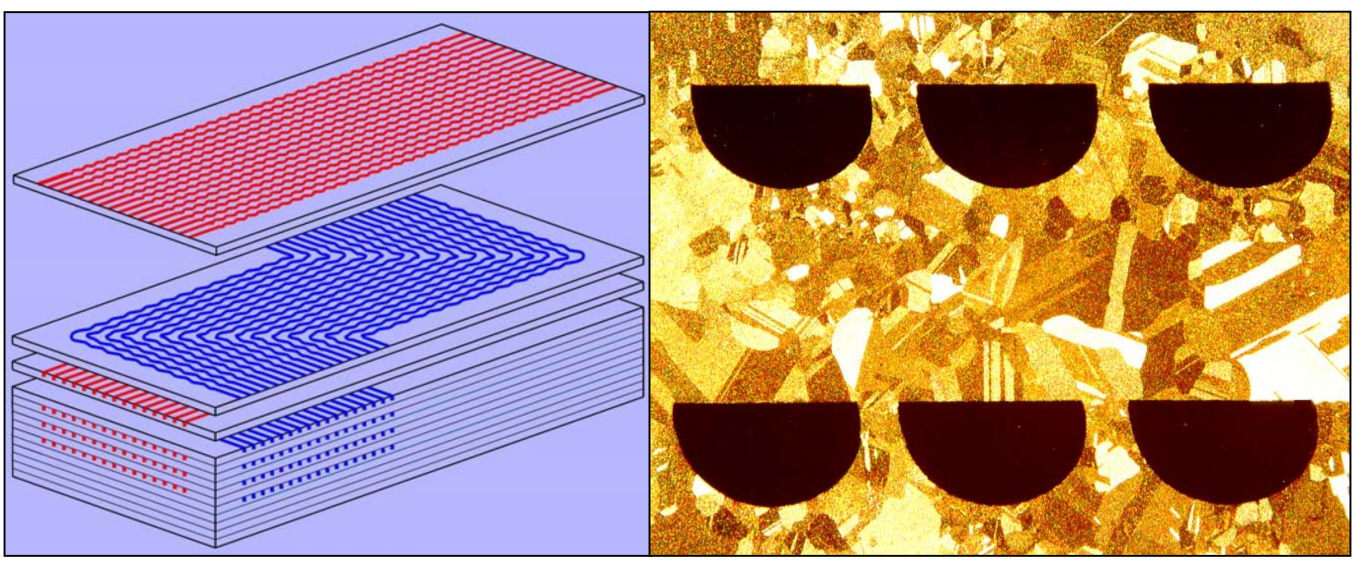
The high specific surface core of a compact, diffusion bonded exchanger is constructed using one of the following methods:

a) Printed Circuit style

Flow channels are created along flat metal plates using a photo-chemical milling technique analogous to that used for the manufacture of electronic printed circuit boards, giving rise to the name “Printed Circuit Heat Exchanger” or PCHE.

The plates are commonly 1.6 or 2mm thick (0.063 or 0.079”), and the chemical milled flow channels are typically semi-circular in cross-section, having a diameter of about 2mm (0.079”).

Different flow geometries are designed for each stream in order to optimize heat transfer and pressure drop performance. The resultant plates are then stacked ready for diffusion bonding.



b) Plate Fin style

This form of construction is very similar to that of a brazed plate fin heat exchanger having alternating layers of corrugated fins separated by flat metal plates.

However, in this case there is no braze alloy involved and instead the peaks and troughs of each corrugated fin are diffusion bonded to the adjacent separating plates.

Many different corrugations are available with various fin densities, thicknesses and corrugation styles (plain, perforated, herringbone).

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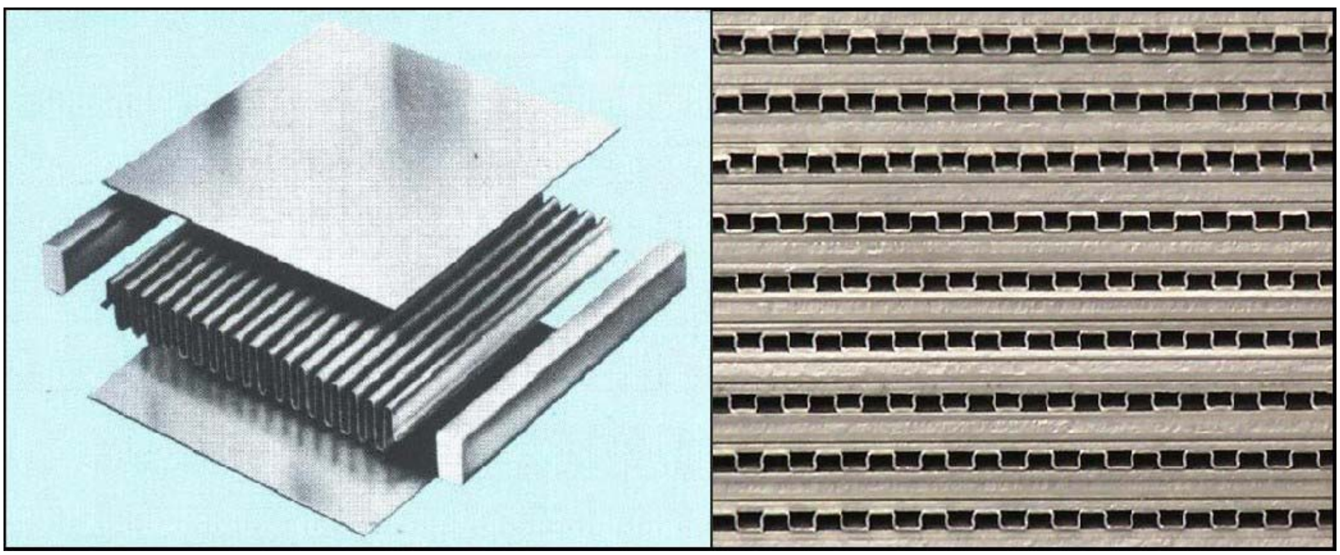


Irrespective of the chosen core construction method, the result after diffusion bonding is a solid block of metal with engineered flow channels passing through it.

Plate Fin style cores are generally more suited to lower pressure services up to around 3000psi (207bar), and Printed Circuit style cores are used for higher design pressures.

Completion of Manufacture

Multiple diffusion bonded exchanger blocks may be welded together to form larger cores. Then headers, nozzles and flanges are welded on to complete the exchanger.

Single complete exchangers can weigh up to 80,000 lb (36,000 kg) each. This may not sound like a large exchanger, but consider that Heatric exchangers are typically just 20% of the size and weight of shell & tube type exchangers. Hence this is equivalent to 400,000 lb (181,000 kg) of shell & tube in a single compact unit.

Limitations of Brazed Aluminum Plate Fin Heat Exchangers

Firstly it is worth noting that aluminum is both a cheaper material and a more thermally conductive material than the stainless steel most commonly used in diffusion bonded exchangers. Hence if brazed aluminum is considered fit for purpose then it will usually provide a cheaper exchanger solution than stainless steel.

So let us first consider the limitations of aluminum exchangers:

a) Design Temperature
In theory heat exchangers manufactured in aluminum can be designed for temperatures as high as 400F (204C). In practice however, except for very low-pressure applications, this must be limited to 150 F (65C) which is the maximum ASME design temperature for the preferred high strength alloy “5083”.

b) Design Pressure
The low mechanical strength of aluminum limits the maximum design pressure to about 1750psi (120bar) according to manufacturers' current literature (although this is significantly reduced if design temperatures exceed the 150F noted above). Fin choices are severely limited at this pressure and multiple nozzles are often required per header.

c) Corrosion
Mercury is a common contaminant found in hydrocarbon feed gases, and in it's liquid form it attacks most aluminum alloys, particularly the high strength Al / Mg alloys used for headers or nozzles. Manufacturers talk of mercury tolerant construction, but in reality this only reduces the rate of destruction by limiting the potential sites likely to be attacked. Aluminum exchangers are most susceptible to mercury corrosion during plant shut downs when mercury liquid beads collect in the non-drainable dead areas.

d) Fatigue
Due to the weak nature of aluminum and particularly the brazed joints, it is very important to limit the cyclic or frequently repeated temperature fluctuations of any stream to ±1C (±1.8F) per minute, otherwise leakage can occur.

e) Temperature difference between streams
The ALPEMA guide states that for a typical geometry of brazed plate-fin exchanger under steady state conditions, the maximum permissible temperature difference between streams is approximately 50C (90F), although some manufacturers suggest even lower figures. In more severe cases such as two-phase flows, transient and/or cyclic conditions, this temperature difference should be lower, typically 20 - 30C (36 – 54F).

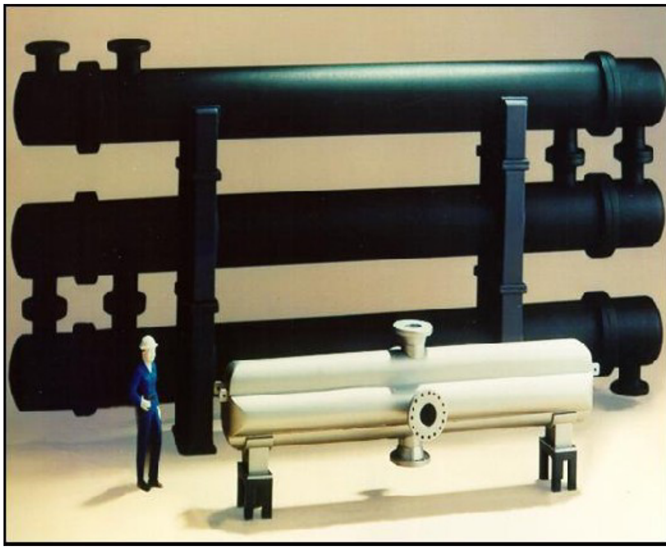
Capabilities of Diffusion Bonded Exchangers

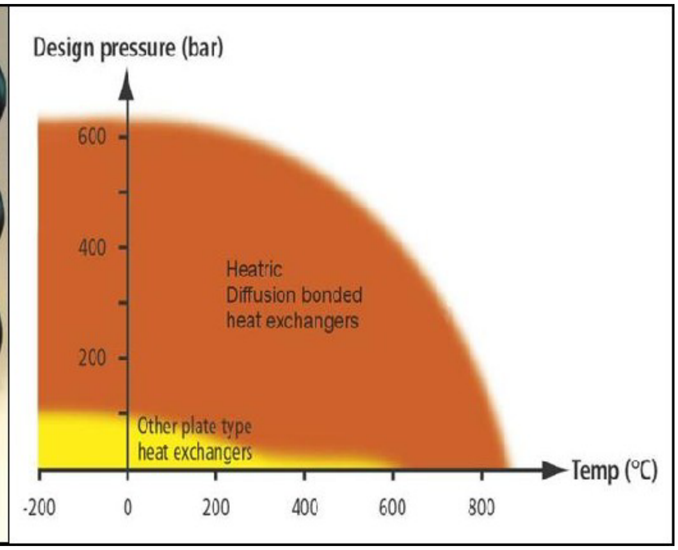
In comparison, a diffusion bonded structure has far greater integrity than a brazed construction. Use of stainless steel allows design temperatures up to 1500F (815C), and design pressures up to 9000psi (620 bar) are achievable.

Much larger temperature differences are possible with diffusion bonded exchangers, including the 400F (222C) often required for LNG vaporizers.

Stainless steel is not susceptible to mercury attack, and it is much more resistant to thermal fatigue than aluminum due to its lower coefficient of thermal expansion. Hence, Heatric diffusion bonded exchangers do not have tight constraints on rates of temperature change.

Whilst frequent large temperature transients are best avoided with any compact exchanger, Heatric exchangers can accommodate several controlled start-ups and shut-downs every day over a 30 year life in the example of an LNG regasification service.





Applications for Diffusion Bonded Exchangers in the LNG Industry

Diffusion bonded exchangers offer many of the same advantages as brazed plate fin exchangers but with far greater mechanical integrity. Hence they often prove attractive where operating conditions fall outside brazed exchanger capabilities, but where the process would benefit from close temperature approaches or multiple process streams in a single exchanger.

a) LNG Regasification

Regasification of LNG can be achieved using a variety of different heat media, and diffusion bonded exchangers are best suited to intermediate fluid regas systems.

Propane and other such refrigerants result in the smallest and cheapest exchangers as the majority of the heat supplied is latent heat released as the refrigerant condenses. As a result significantly lower flow rates are required than with single phase heat media which reduces pumping costs and keeps exchanger size to a minimum.

However, propane has not been historically favored in LNG terminals to date due to its greater flammability than LNG. But consider plants where NGL extraction is being considered in addition to vaporization. Here a propane rich stream is typically one of the resulting products and the facility would have to be designed to handle the additional risk anyway.

Due to the high thermal efficiency of compact exchangers, more care is required where the heat medium can freeze, and in such cases the cold end of the regasification duty is often designed in co-current flow. However, compact exchanger designs are not always appropriate where freezing can occur and careful analysis of wall temperatures within the exchanger is required in each case. As a general observation, compact exchanger design becomes easier with increased heat medium inlet temperature.

Water/glycol mixtures are commonly used in the large shell & tube type vaporizers, but it's worth noting that the glycol has a negative impact on the heat transfer coefficient resulting in very large exchangers. Potassium formate based solutions offer greater protection from freezing with coefficients approximately twice that of glycol solutions.

The freezing mechanics of both potassium formate and glycol based solutions are unlikely to damage a diffusion bonded exchanger in the event of a power outage and sudden stoppage in heat medium flow.

(NB Refrigerant suppliers caution against using potassium formate solutions in installations containing aluminum, zinc or galvanized steel.)

b) LNG Superheating

Irrespective of the chosen method of regasification, diffusion bonded exchangers are well suited to subsequent natural gas superheating / trim heating duties.

This is especially true for some of the floating LNG receiving terminals being considered with size and weight restrictions. Here it’s common for a closed loop intermediate fluid to be used such as a water/glycol heat medium. The duty is post vaporization and gas side temperatures are not usually cold enough to cause freezing of the heat medium.

In addition, the closer temperature approaches possible with compact exchangers allow greater heat recovery and a corresponding reduction in required heat medium flow rates compared to traditional shell & tube technology.

c) NGL Extraction

Certain LNG liquefaction plants (for example in North Africa) produce LNG streams which are heavier in NGLs than other plants. These “heavies” must be removed at the LNG receiving terminal in order to meet pipeline gas specification.

In some areas these NGLs are a nuisance, but here in the United States and in Canada they can be a valuable feedstock for the petrochemical industry, and as North American stocks of NGLs are depleted, demand from LNG is expected to grow.

Sizeable exchangers are required for such NGL extraction, and diffusion bonded construction is well suited to the thermal duties involved.

In one particular duty the LNG feed stream (rich in NGL) exchanges heat with the lean return gas (post NGL extraction) and brazed aluminum cannot be selected due to the temperature differences involved and two phase nature of the streams.

Spiral wound exchangers could be used, but evaluation work done by a well known engineering contractor suggests that diffusion bonded exchangers are a much more cost effective solution.

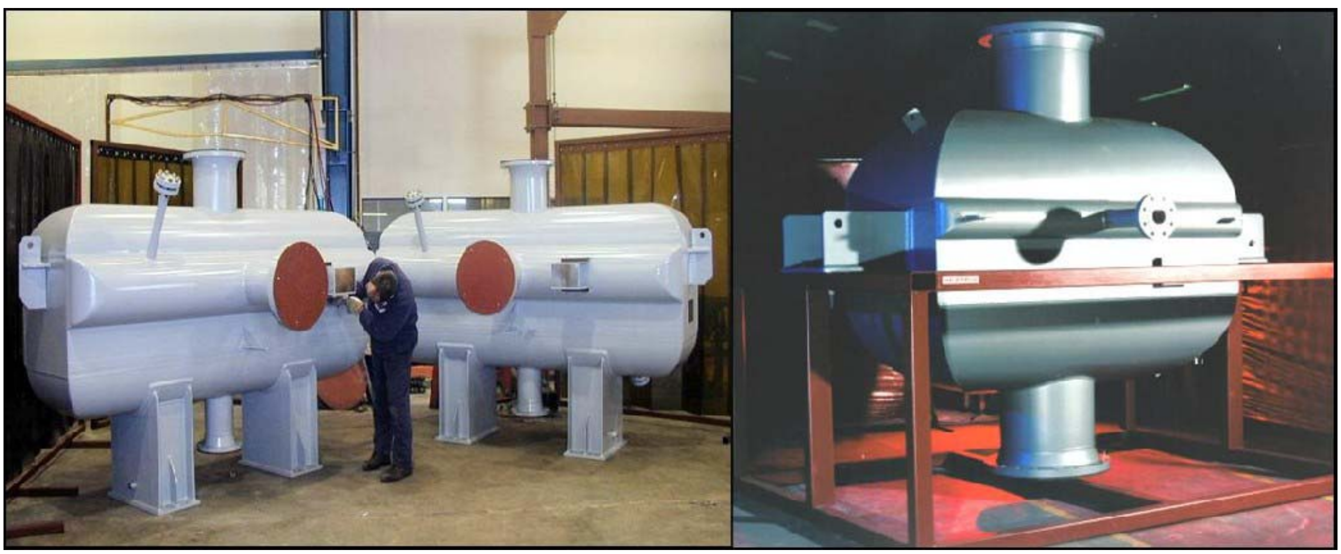
Other NGL extraction processes utilize intermediate fluids such as the potassium formate solutions mentioned above. And in some cases the extraction is done at elevated pressure (2160 psig design) so that the final product streams of methane, ethane and propane+ are at sufficient pressure to avoid the need for further compression. In these cases diffusion bonded exchangers prove attractive as pressures exceed the capabilities of brazed technology.

d) LNG Liquefaction

Heatric has supplied a number of diffusion bonded exchangers for End Flash Gas / Light Mixed Refrigerant duties where higher integrity construction was required.

Separately, a number of companies are considering offshore LNG liquefaction and diffusion bonded exchangers look attractive for nitrogen and methane compression cooling services especially from a size and weight perspective.

In closed loop refrigerant circuits, diffusion bonded exchangers may allow a greater settle-out pressure to be accommodated than possible with brazed aluminum. The resulting reduction in low pressure suction drum volume would be particularly attractive offshore where the size and weight of equipment is so important.



Conclusion

Diffusion bonded heat exchangers have been widely used offshore for many years, but they are still relatively unknown in the LNG industry.

They offer many of the same advantages as brazed plate fin heat exchangers but with far greater mechanical integrity. Hence there appears to be significant opportunity for process engineers to exploit this technology where operating conditions fall outside brazed exchanger capabilities, and where the process would benefit from close temperature approaches or multiple process streams in a single exchanger.

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Biography of Speaker

Tony Bowdery is responsible for Heatric’s technical sales activity in North & South America, and he has over 10 years experience working with compact heat exchangers. He graduated in 1995 from Loughborough University in the UK with a Bachelor’s degree in Chemical Engineering. Prior to joining Heatric he was an exchanger design engineer and worked on many cryogenic & industrial gas projects. Tony lives and works in Houston, Texas and he is happily married with a son aged 3.

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