Engineering for success

Achkan Bagheri, Eric Bleuset, Renaud Egal, and Marie Simonnet, Fives Cryo, France, examine brazed aluminium plate-fin heat exchangers and modern simulation tools for avoiding failures.

Developed in the 1940s in the aircraft industry, brazed aluminium plate-fin heat exchangers (BAHX) are the most compact and energy efficient heat exchangers for handling a wide range of services, valued particularly for their relatively high thermal efficiency, compactness, low weight and low maintenance. They provide low capital, installation, and operating costs over a wide range of cryogenic applications. Their ability to carry multiple streams, occasionally up to 20 or more, allows process integration in multiple industrial processes and their very large surface per unit volume (up to 2000 m^2/m^3, which is four or five times as many as conventional heat exchangers) is particularly advantageous when low temperature difference apply.

Where it is feasible to use a BAHX, it is usually a cost-effective solution.

BAHX are a unique type of heat exchanger consisting of a stacking of several layers (up to 200), each layer made of corrugated fins inserted between two parting sheets and closed by side bars (Figure 1). Openings in side bars assure inlets and outlets of up to 20 fluids, monophasic and/or diphasic.

Table 1. BAHX limits of use	
Maximum design pressure	Approximately 140 barg
Minimum design temperature	-269˚C – limit of ASME code
Maximum design temperature	Typically specified at +65˚C – ASME limitation for aluminium 5083 for headers and piping – but up to 204˚C with use of different aluminium alloy
Acceptable fluids	■ Clean – filters to be installed upstream of the BAHX ■ Dry ■ Non-corrosive for aluminium
Impurities (H_2S, NH_3, CO_2, SO_2, NO_2, CO, Cl)	Acceptable in low percentages. To be clarified with BAHX's manufacturer
Mercury	■ Can corrode aluminium under specific conditions ■ Presence and concentration to be specified by customer ■ Mercury guard bed should be installed ■ Design of BAHX to be adapted
Maximum difference of T˚ between fluids	■ Around 50˚C for single-phased flow ■ Around 20 – 30˚C for more severe cases: two-phase flows, transient and/or cyclic conditions ■ Induced thermal stresses can damage BAHX

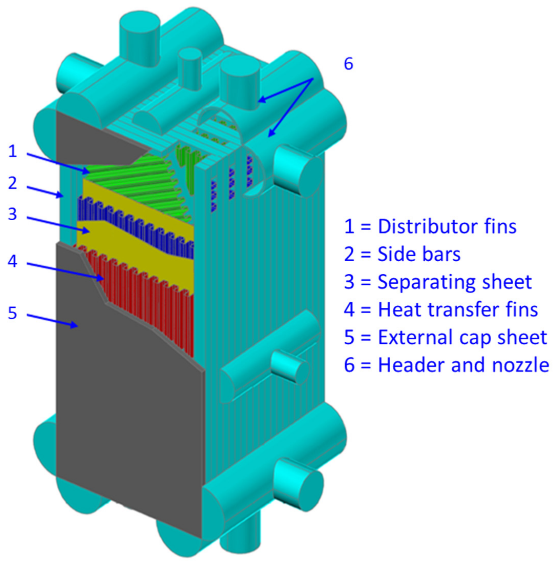

Figure 1. Main parts constituting a BAHX.

Most BAHX have been installed in process plants used to separate a feed gas into its constituents, for example by the partial liquefaction of the feed and subsequent distillation and separation. The products and waste stream are then re-warmed against the feed streams. Condensers and reboilers are associated with distillation columns. Often chillers using standard refrigerants are used. BAHX are well-suited for these and many other services.

Widely used for more than 60 years on the cryogenic separation and liquefaction of air (air separation unit) and on production of petrochemicals and treatment of off-gases (especially on ethylene production), BAHX have been implemented on the whole gas process line from natural gas processing to the liquefaction units. Figure 2 illustrates an example of a cold box during its transportation to a gas treatment unit.

BAHX are a reliable static equipment that can operate for a huge number of years without any maintenance and any failure. Fives has a long history of installing BAHX in many different types of units that worked without any incident for more than 40 years.

Recommended good practices related to the use of BAHX are described in the APEMA Standards and a summary of the main rules for BAHX uses can be found in Table 1.[1]

BAHX are relatively compact and are susceptible to damage if subjected to upset in operating conditions that produce excessive thermal stresses. Thermal stresses can result from the normal presence of streams at different temperatures (above the maximum described in Table 1), as well as stresses that develop due to transient and/or cyclic operating conditions. Transient conditions can be linked to start-up, shutdown, and many different types of trip case. For example, the ALPEMA recommendation is that start-up or cool-down of BAHX should be realised with a rate of 2˚C/min. with a maximum of 60˚C/hr. However, if higher rates are expected, BAHX manufacturers should be consulted for further analysis of the conditions and their impact on the exchanger mechanical integrity.

When operating conditions exist that can subject a BAHX to thermal transients, thermal gradients and cyclic conditions in excess of those described above, a rigorous stress analysis and cumulative fatigue damage study may be necessary in order to estimate the impact of these events on the lifecycle of the exchanger.

Dedicated tool to characterise thermal stress risk

This article will now present an example of the transient calculations study performed for a customer concerned with the thermal stress induced on its BAHX. Thermal stress is a key parameter for the lifespan of plate fin heat exchangers as excessive values can induce either external leaks from the streams to the exterior of the exchanger or internal leaks between the streams.

To realise the study shown here, the customer supplied the streams flowrate and inlet temperature variations with the time expected during transient scenarios.

Thermo-hydraulic transient software

The software used for transient thermo-hydraulic calculations is ProSec-dynamical. ProSec means Program of Simulation of Compact Heat Exchanger. Simulation is performed in two dimensions, according to length (streams circulation) and height (stacking arrangement). The flow and temperature distribution is considered uniform according to the width within each layer. Each type of layer can be described with a high degree of complexity (type of fins, distributors, flows configuration, etc.)

All variables of streams (temperatures, duties, pressure drops, etc.) and sheets (temperatures) can be calculated at any point of the heat exchanger and at any time.

Figure 2. Cold box during its transportation to a gas treatment unit.

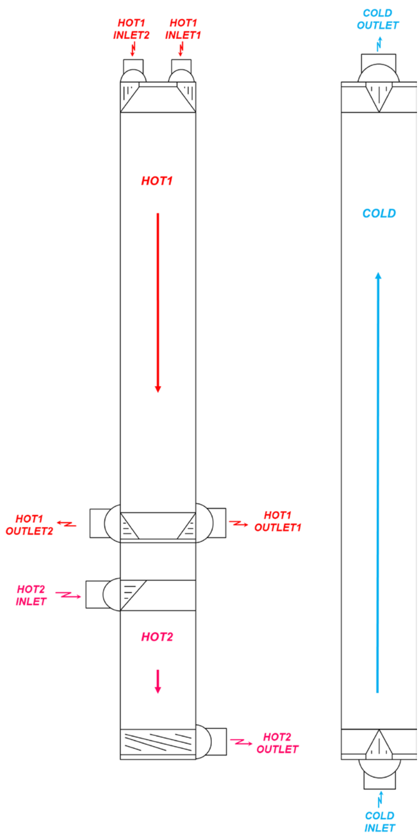

Figure 3. Configuration for transient calculations study: two hot streams in the same layers exchange heat with cold stream located in adjacent layers.

Transient calculations analysis

Due to the nature of BAHX, which are produced by brazing, all internal components are metallurgically bonded to each other. Contraction/expansion of the parts due to temperature change is the main origin of thermal stresses.

To check the mechanical integrity of the exchanger in transient calculations, the values of temperature difference between sheets are tracked:

- Maximum temperature difference (DT) between adjacent sheets, at any given length of the exchanger. 'Adjacent sheets' means sheets that are located side by side, just separated by one stream. The maximum DT between adjacent sheets refers to the maximum temperature difference between sheets located side by side. It can be positioned anywhere in the height.
- Maximum DT between non-adjacent sheets, at any given length of the exchanger. 'Non-adjacent sheets' means sheets that are not located side by side and that can be separated by many streams and other separating sheets. The maximum DT between non-adjacent sheets refers to the maximum temperature difference between all the sheets. It can be positioned anywhere in the height.

The time evolution of those two parameters during transient calculations determines if the process scenario is acceptable or not. Fives subsidiary, Fives Cryo, has achieved maximum acceptable values for those two parameters, due to the development of a dedicated software to study the thermo-mechanical behaviour of BAHX.[1,2]

Configuration of the case study: geometry and process conditions

The geometrical configuration of the exchanger is shown in Figure 3. In this exchanger, two hot streams (HOT1 and HOT2) exchange heat with one cold stream (COLD).

In the process scenario presented here, stream HOT1 is suddenly cut-off due to the spurious closure of a control valve.

Results of the case study

As can be observed in Figure 4 where the streams outlet temperatures are plotted vs time, the closure of this valve is accompanied with a smooth decrease of COLD stream outlet temperature: less hot energy is brought in the upper part of the exchanger when HOT1 disappears. Outlet temperature of stream HOT2 is unaffected by the sudden change in HOT1 flowrate.

Figure 5 illustrates the time evolution of maximum DT between adjacent and non-adjacent sheets calculated during transient scenario. Maximum acceptable values are also indicated. The maximum DT between adjacent sheets decreases at the beginning of the calculations and then increases to reach a constant value after 50 sec. All values always remain below the maximum acceptable values. Maximum DT between non-adjacent sheets also decreases at the beginning of the calculations and then

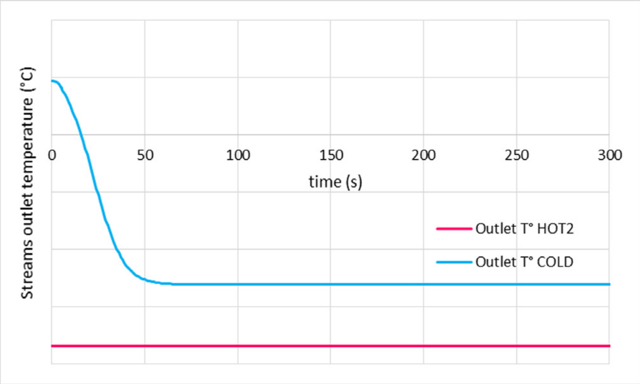

Figure 4. Time evolution of streams simulated outlet temperatures: HOT2 outlet temperature smoothly decrease while COLD value is almost unaffected by HOT1 loss.

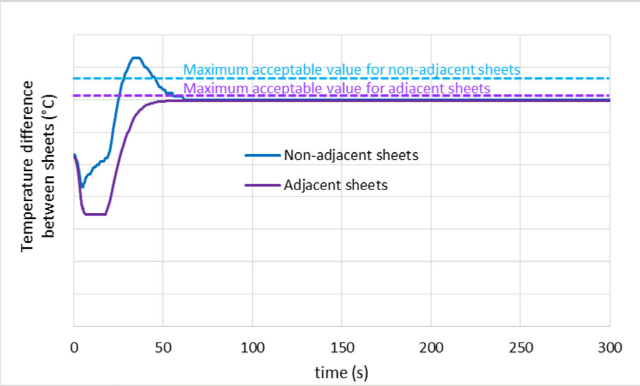

Figure 5. Time evolution of maximum temperature differences simulated between adjacent and non-adjacent sheets: during approximately 25 sec., maximum values between non-adjacent sheets exceed the maximum acceptable criteria.

increases to reach a peak at approximately 35 sec. It finally decreases to stabilise after 50 sec., which is below maximum acceptable value. However, between 25 sec. and 50 sec., DT exceeds maximum acceptable criteria, and during this period the exchanger mechanical integrity could be affected by high stress value. The consequences of high thermal stress will be detrimental for the exchanger: it can initiate cracks in the core which could cause a leak in the future, depending on the number of occurrences of critical conditions and their duration.

In this precise case, as the scenario could not be accepted, a mitigation has been agreed with the customer: thanks to a change in the process control, the sudden closure of the valve leading to the occurrence of this scenario has been modified. Mitigation can cover process modifications such as changes in flowrate, in streams inlet temperature or in valve closure time.

Synthesis: numerical tool to predict unacceptable process conditions

The behaviour of BAHX during transient conditions, such as start-up, shut-down, or some equipment trips phases is an important concern of all end-users in the petroleum, petrochemical, and natural gas industries.[3]

The development of this dedicated software enables Fives Cryo to analyse the impact of thermal transients on the exchanger mechanical integrity. Used during the exchanger conception phase, it can even orientate choices in the design (fins characteristics, layers arrangement, etc.) in such a way that the temperature differences between sheets are minimised in regions where high thermal stress is expected to happen during transient conditions.

Conclusion

BAHX are a perfect equipment for their intended industrial applications providing high energy efficiency, compactness, low maintenance, and exceptional availability rates (99.99%) as long as they are used according to the conditions specified by ALPEMA and/or recommended by the supplier. The 3D numerical modelling performed by Fives Cryo enables the risks of failure to be overcome when the equipment is subjected to transient conditions. Associated to this numerical tool, the best solution to make BAHX operation perfectly safe consists of measuring and analysing the running parameters of the equipment in-situ.

Fives Cryo has developed a digital solution 'CryoSens' to supervise and help its clients to better understand the functioning of BAHX. This solution consists of the following functionalities:

- Installation and configuration: the BAHX (existing or new) is equipped with the relevant instrumentation and the running parameters (temperature, pressure and others) are recorded.
- Visualisation: the ongoing operation is visualised in the control room using Fives Cryo's proprietary data management tool.
- Analysis: the operating data are analysed on a regular basis through in depth data analysis and dynamic dashboards. The operator is alerted when the equipment running conditions exceed set-up limits.

For more than 20 years, Fives Cryo has been a pioneer in the implementation of numerical tools to address problems of stress in the BAHX. Such calculations are now currently proposed to clients. CryoSens is the further stage of this ongoing development: carefully monitoring BAHX to gain a deeper knowledge of operations is essential for the design of future equipment to improve their functions, optimise their maintenance, and maximise their useful life.

References

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2. AVEROUS, D., PICARD, F., and AUBERT, G., 'Ensuring the reliability of aluminum plate-fin heat exchangers', GPA Europe Proceedings, (2010).
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