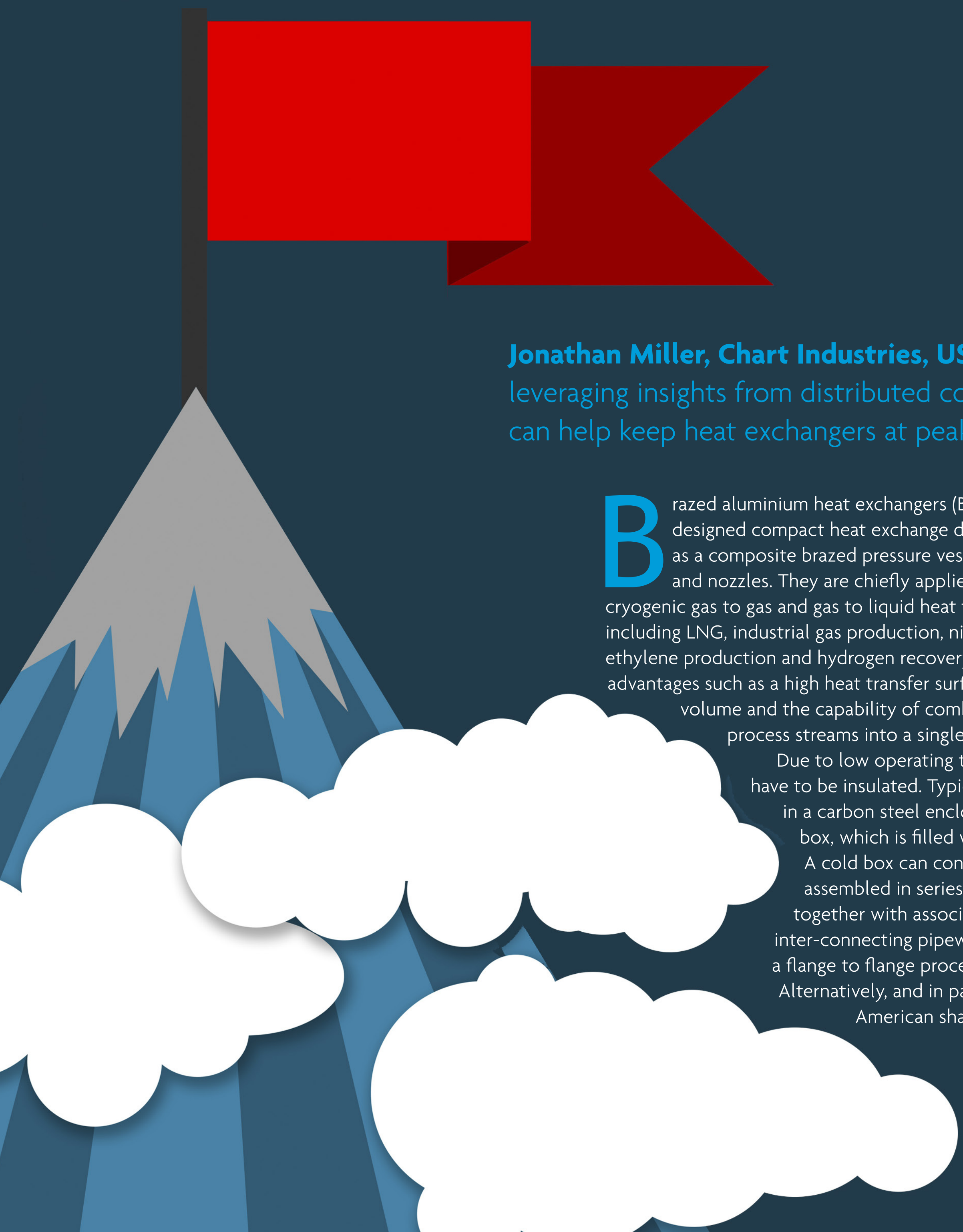
PEAK PERFORMANCE



Jonathan Miller, Chart Industries, USA, advises how leveraging insights from distributed control systems can help keep heat exchangers at peak performance.

Brazed aluminium heat exchangers (BAHXs) are custom designed compact heat exchange devices manufactured as a composite brazed pressure vessel with welded tanks and nozzles. They are chiefly applied in a variety of cryogenic gas to gas and gas to liquid heat transfer processes, including LNG, industrial gas production, nitrogen rejection, NGL, ethylene production and hydrogen recovery. They offer advantages such as a high heat transfer surface area per unit volume and the capability of combining multiple process streams into a single unit.

Due to low operating temperatures, BAHXs have to be insulated. Typically they are supplied in a carbon steel enclosure, called a cold box, which is filled with perlite insulation. A cold box can contain multiple BAHXs assembled in series and/or parallel together with associated vessels and inter-connecting pipework, and is essentially a flange to flange process module. Alternatively, and in particular with North American shale gas processing, it is

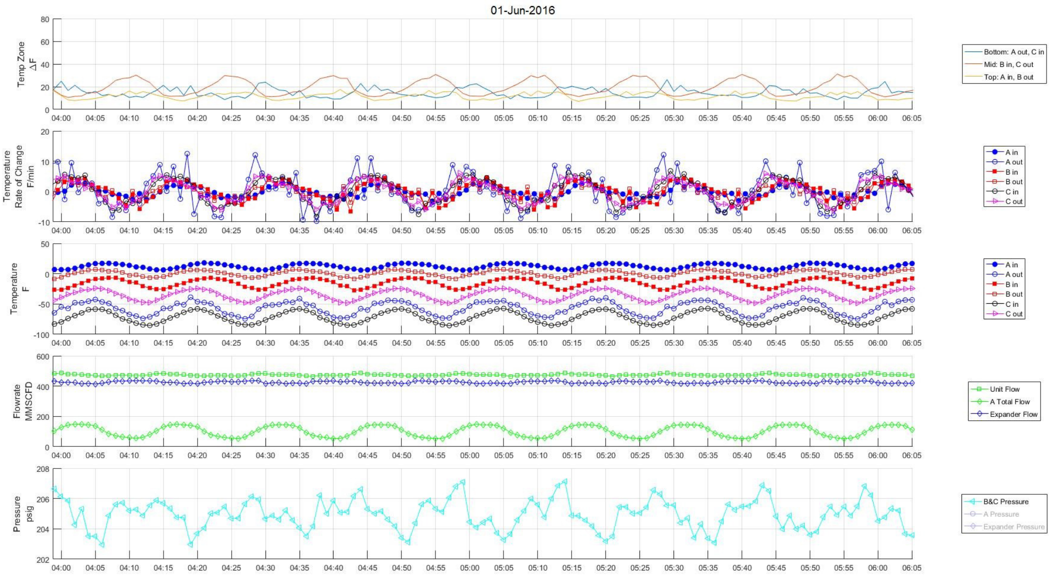


Figure 1. An example of cyclical behaviour due to interacting controllers.

commonplace to see single BAHXs that use slab insulation instead of a cold box.

A BAHX typically provides in excess of 20 years uninterrupted and wholly reliable service. Its ultimate lifespan depends entirely on the care with which it is operated and maintained, especially with respect to thermal gradients. Where there is a high frequency of temperature excursions beyond ALPEMA guidelines, the gradual accumulation of stress events can lead to fatigue fractures in the field.

However, aided by developments in technology, increased awareness and operator training, analysis of distributed control system (DCS) data direct from the heat exchangers can highlight temperature excursions and other events with the potential to limit the unit's lifecycle. Operating procedures can be modified and instances where unexpected external leaks require unplanned shutdowns and expedited delivery of a replacement BAHX significantly reduced.

Plugging and fouling

Plugging is the introduction of particulates or other solid objects into the exchanger. Pipe scale and molecular sieve dust are the most common plugging agents, though coke can be an issue if it forms in the upstream process. Smaller debris will show up in the DCS data as a high pressure drop with mildly decreased heat transfer – there is less flow area, but where it does flow heat transfer coefficients remain high.

Fouling is the build-up of some type of residue along the heat transfer surfaces of the exchanger. The main causes of this type of build-up in a BAHX are heavy hydrocarbons, hydrates, and carbon dioxide (CO_2). The build-up primarily shows up as a decrease in heat transfer performance, though the reduced area and reduced boiling/condensing will affect the pressure drop across the exchanger as well.

Hints that fouling is the issue include a worse heat transfer coefficient, whereby the temperature approaches are wider than in the past or temperature approaches remain the same but flowrates are limited. A more conclusive method is a comparison of the expected performance of the heat exchanger to actual performance. For simpler exchangers, this may be possible with an ordinary process simulator. For more complex exchangers, it is best to work with the equipment manufacturer. A rerating of the exchanger will help identify which specific pass is the source of the issues and can also identify if other factors are a more probable cause – new compositions, refrigerant pressures, and other factors which can shift heating and cooling curves in key parts of the exchanger.

The key to preventing both of these lies in the upstream process. Most plants containing a BAHX include an amine system to pull out CO_2, molecular sieves to pull out water, dust filters to remove mole sieve dust, and strainers just upstream of the exchanger inlets to catch anything remaining. If these work properly, there will be no plugging issue within the exchanger itself.

Taking the time during commissioning to blow out the lines in the plant has the potential to save a lot of time during start-up or issues down the line with the plant.

Keeping an eye on pretreatment analysers – not only that they are reaching acceptable levels of CO_2 and water removal but also that the analyser itself is telling the truth – are key to preventing freezing components passing along to the cryogenic portion of the process.

Dual dust filters are an excellent solution in order to keep the exchanger permanently online. If there is a bypass loop around a given dust filter, it is best to put the bypass valve in a vertical rise in the pipe to prevent dust from accumulating behind it and passing downstream to the exchanger once it is opened. If the differential pressure reading across one is zero, there may no longer be a dust filter in place.

If caught early, plugging and fouling are not catastrophic. Generally, most if not all of the performance of the exchanger can be restored through simple cleaning activities.

However, it is important to address the issue as early as possible. The longer material accumulates in the exchanger, the harder it is to dislodge it because it becomes harder for the cleaning fluid to flow past the contaminant to convey it out of the exchanger.

The three main options for cleaning are deriming (which removes fouling components by heating the exchanger until they boil off), backpuffing (which removes plugging components by jostling them and sweeping them out opposite the normal flow direction with a wave of pressure), and chemical cleaning (which uses a solvent to dissolve pernicious fouling or plugging components, but requires

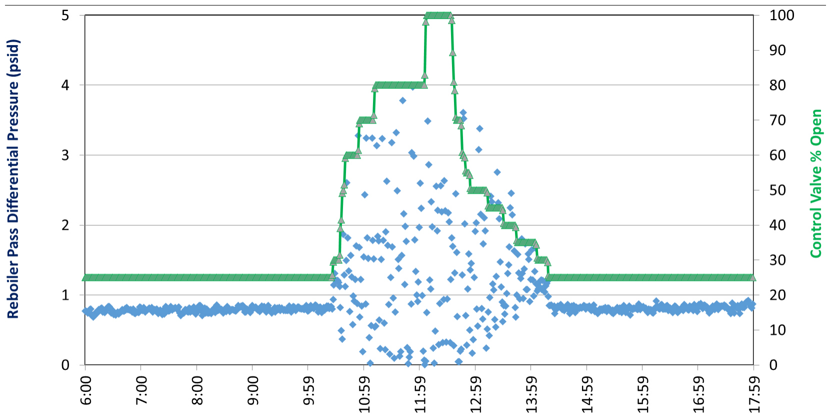


Figure 2. A graph of differential pressure (blue) vs the thermosiphon pass' control valve percentage open (green). As the valve opens, flow and pressure drop across the thermosiphon pass in the exchanger become unstable. Throttling the valve stabilised the process.

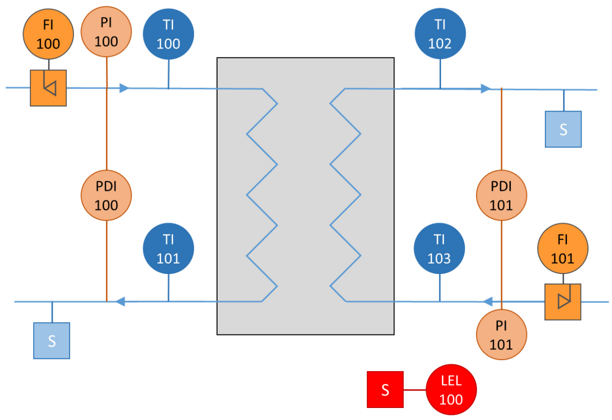


Figure 3. Recommended instrumentation for a BAHX. Temperature measurement at every inlet and outlet is critical in evaluating the performance of the exchanger.

careful solvent selection and proper post-cleaning flushing before returning to service).

Feedback loops

Feedback loops are the sinusoidal behaviour observed when a process oscillates around a setpoint rather than converging toward it.

They are generally caused by either a single improperly tuned controller overshooting its setpoint or can be caused by the interaction of two or more controllers, e.g. the split of feed gas between heat recovery from a column's condenser and duty for its reboiler.

The main concerns with loops are that they can fatigue the exchanger, reduce the efficiency of the process (generally every type of process equipment prefers stability), and leave the process sensitive to any upsets.

Cyclical behaviour tends to be very distinctive to the human eye due to its repeated waves, as shown in Figure 1.

Dynamic simulation of the process can give insight into the expected performance of a set of controllers on a process and can give a sandbox to tune controllers to handle a wide variety of conditions and upsets before they become an issue in the real world.

However, particularly in the case of complex plants, the issue may have less to do with the controllers themselves and more to do with how their actions influence other controllers. Often, the solution to these kinds of problems is as simple as offsetting the reset times on a pair of controllers so that they will gradually converge.

When the issue is clearly a single controller, then the standard methods for tuning controllers will work. It may be that the oscillations are due to the plant's operating modes such as running a column in ethane rejection vs ethane recovery modes. In these cases, the controller may need a different set of tuning parameters for each operating mode.

Unstable thermosiphon flow

While thermosiphons normally operate with excellent stability once successfully started up, thermosiphon loops that are operating far away from their original design conditions can begin behaving erratically. This could be due to a change in composition, extreme turndown, or instability in the heat source.

In some cases, the instability in outlet piping leaving the exchanger and returning to the column causes slug flow to occur in the line. As with many other cases, this not only leaves the column subject to upsets but can also cause significant damage to equipment.

One of the most telling signs of unstable flow is that differential pressure will bounce back and forth, as shown in Figure 2.

If the exchanger does not have differential pressure measurements across the reboiler pass(es), then changes in temperature, especially at the inlet of the reboiler pass, are also signs that there is a problem.

To prevent this, the best steps are to configure the thermosiphon loop for adaptability. Two features that help with this are a modulating valve on the line from the column to the reboiler inlet, which provides a pressure drop that helps stabilise the loop, and a lift gas connection, which provides additional vapour to push flow through even at extreme turndown.

Addressing instability in anything tied into a column can be difficult, but a good starting place for these issues is to ask if there is anything different about current operating conditions that could explain the instability. Is the plant turned down significantly? In that case, adding lift gas (if available) may push the loop back into stable flow. Is the heat source stable? If not, putting the relevant controller in manual can stabilise the reboiler and allow time to tweak the controller.

Over longer timeframes, modelling the current operation of the plant using a flow regime map applicable to vertical lines, such as that of Aziz et al., can give insight into what factors can be changed to move the flow regime into a more stable state.[1]

In extreme cases, such as continued operation at turndown, modifications to the plant piping may be in order, such as

Figure 4. A BAHX undergoing final inspection.

Figure 5. Cold boxes being prepared for dispatch.

swapping out reboiler return lines if turndown is expected to persist for months or years.

Thermal stress

Thermal stress is stress in the exchanger caused by uneven expansion and contraction of exchanger components due to uneven heating and cooling.

The most common causes are temperature differences between layers in the exchanger and abrupt changes in temperature which bring the thin heat transfer components (parting sheets and fins) to the new temperature while thicker structural components (bar column and headers) lag behind.

The largest thermal stresses are typically encountered during start-ups, shutdowns, and transitions between operating modes, such as between ethane rejection and recovery in a natural gas processing plant. Additionally, many of the issues described in other sections can also induce thermal stresses in the exchanger if allowed to go unchecked.

The issue with these thermal stresses is that they can lead to an exchanger leak. Large thermal stresses can cause plastic deformation leading to leaks from one event, but the more commonly observed problem in industry is fatigue due to repeated stresses eventually culminating in a leak.

The best indications within the DCS of the possibility of thermal stresses are high rates of temperature change of a stream entering or exiting the exchanger and temperature differences between streams where they contact each other in the exchanger, e.g. between a warm stream entering the exchanger and a cold stream exiting the exchanger.

For both of these, a simple calculation in the DCS measuring the change per minute of each temperature in and out of the exchanger, and a calculation of streams entering and exiting the exchanger at the same position on the exchanger, provide operators with the ability to discern whether guidelines for the exchanger are being exceeded.

Chart's guidelines to maximise exchanger lifespan are to keep temperature differences between adjacent layers within 28˚C (50˚F) and rates of metal temperature change to less than 1˚C/min. (1.8˚F) during normal, steady-state operations, and less than 2˚C/min. (3.6˚F) during transient events and upsets while maintaining an average of 60˚C/hr (108˚F). Since direct measurement of metal temperatures are difficult to measure in operation, fluid temperatures are used as a proxy. The higher the heat transfer coefficient of the fluid, the more readily it will cool or heat the metal and so the more important it is to change its temperature slowly.

For start-ups, shutdowns, and transitions, each plant and each case will be different. The key to controlling in any of these cases is to make a plan before the event, taking into account how temperatures at each exchanger inlet and outlet will change in response to process changes. A good dynamic model is invaluable in this process, but it can also be done based on engineering judgement, operator experience, and historical DCS data.

A few basic questions to serve as a starting point include:

- Is there any way to ensure that flows remain balanced, either stopping or starting as close to simultaneously as possible? Unbalanced flows that unevenly heat or cool the exchanger can easily occur during shutdowns if the other streams are not also stopped.
- Are any valves sticking or have trims which make control during the event difficult or impossible?
- What happens when a compressor starts or stops? Is there any way to dampen the pressure (and therefore temperature) changes of the refrigerant at the exchanger if they will be significant?

Finally, after the event in question occurs, take the time to go through the historian and see where the plan succeeded and where it still needs improvement.

Conclusion

The DCS can provide the data to catch issues before they become problems.

The vast majority of the thousands of BAHX in operation around the world will provide approximately 20 years of reliable and trouble-free service. Issues can occur but, through increased instrumentation, careful analysis of operating data and improved operator training, the extent to which such issues propagate and lead to equipment failure can be significantly reduced.

Chart recommends that reviewing DCS data is established as part of a proactive preventative maintenance programme and not just as a reaction to an operating event. Particular attention should be paid after major operating events such as a start-up, shutdown, or transition between operating modes.

Reference

1. AZIZ, K., GOVIER, G.W., and FOGARASI, M., 'Pressure Drop in Wells Producing Oil and Gas', *Journal of Canadian Petroleum Technology*, (1972), pp. 38 – 48.