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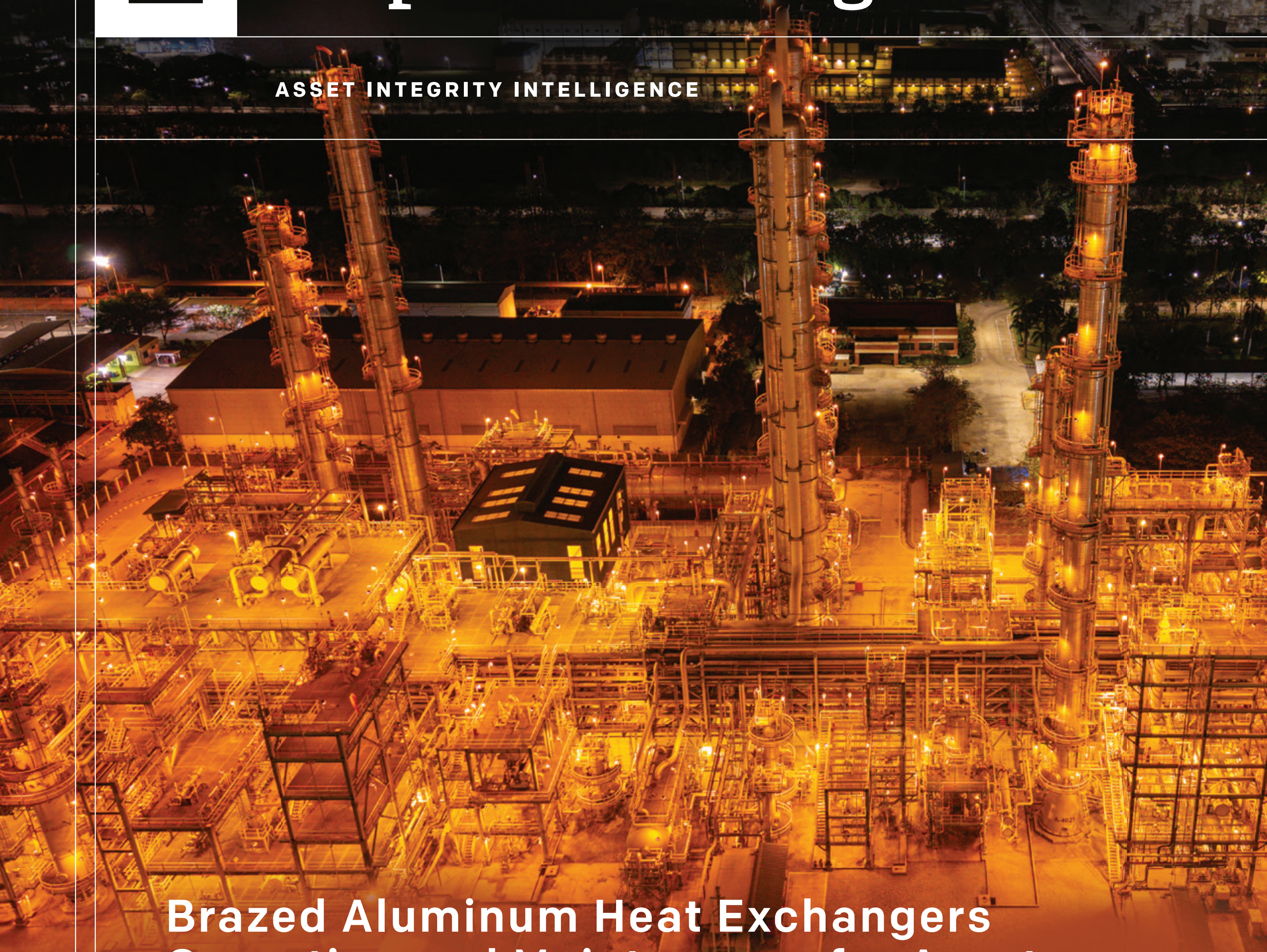

Brazed Aluminum Heat Exchangers Operation and Maintenance for Asset Integrity

Douglas Decker, *Fellow at Chart Industries*

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Introduction

Brazed aluminum heat exchangers (BAHX) serve a critical role in various industrial cryogenic processes, including processing and liquefaction of natural gas, air separation, hydrogen and helium liquefaction, and petrochemical applications around the world. While there is a significant body of literature on how to operate and maintain a BAHX, personnel in mechanical integrity roles often have difficulty locating and implementing this information. This article addresses many of the operation and maintenance issues associated with BAHX units and provides a helpful reference for further reading.

Operation Basics

Since a BAHX typically operates cryogenically, it is usually covered with slab insulation or installed in a cold box and buried in insulation. The insulation shrouds the BAHX, making what is covered by it unfamiliar to those operating the equipment.

There is a simple mantra for properly operating a BAHX: keep it clean, keep it dry, and manage thermal gradients. While a myriad of issues can lead to premature equipment retirement, these three are the main culprits.

Keep It Clean

BAHX units can be cleaned, but it is not easy, and the result may not restore the unit to "like-new" conditions. To avoid this issue, it is best practice to use proper filtration. ALPEMA Standards recommend a 177-micron screen, equivalent to 80 mesh Tyler filters.

Keep It Dry

BAHX units typically operate at temperatures below the freezing point of water. Water expands when it freezes, leading to potentially detrimental effects on the brazed joints and pressure retaining ability. It is important to minimize the time between when the unit is opened, which releases the dry shipping purge, and when it is connected to the plant piping. Covering the unit to limit or eliminate any debris or water ingress is critical. Finally, the unit should be purged with warm, dry gas at -40°F dewpoint to dry out all moisture before start-up.

Manage Thermal Gradients

To avoid the ramifications of thermal fatigue and stress, it's critical to follow ALPEMA standards on operating a BAHX. Below are some suggested guidelines to minimize thermal fatigue:

1. Limit the temperature difference between the streams at any point along the exchanger length to 50°F (28°C) (See **Figure 1**).
2. If a stream temperature difference at introduction exceeds 50°F (28°C), introduce the flow slowly (crack the valve) until the stream temperature difference is within 50°F (28°C) and then slowly ramp the flow rate to full flow.
3. For frequent events (what could be labeled steady state flow) limit the cyclic stream temperature fluctuations to 1.8°F (1°C).
4. For infrequent events like startup and shutdown, limit the stream inlet and outlet temperature rates of change to less than 108°F/hour (60°C/hour) with allowance up to 9°F/min (5°C/min).

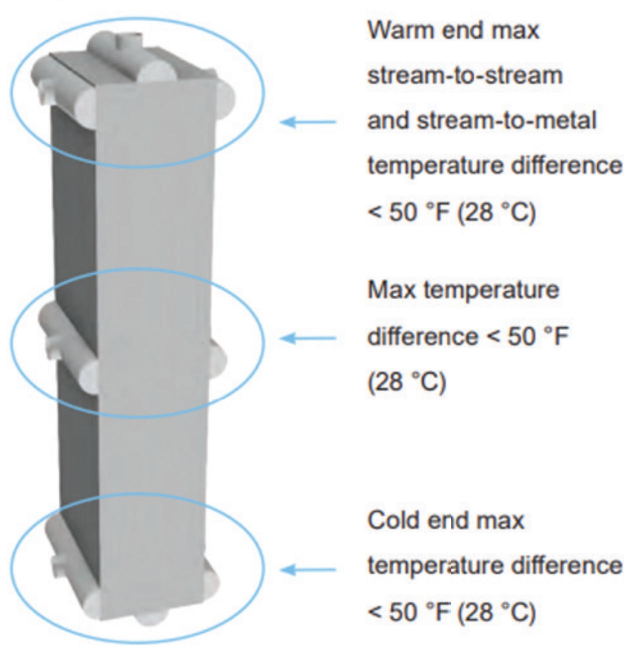

Figure 1. Temperature Difference Recommendations

Possible Problems

This section discusses some possible problems an operation may experience with a BAHX, as well as how to detect and prevent them from occurring.

Plugging

Plugging is when particulates such as pipe scale and molecular sieve dust are deposited inside a brazed aluminum heat exchanger. Construction debris such as cardboard, hand tools, and welding dams left in pipes can also become lodged inside the inlet headers. This issue can arise during initial commissioning or after maintenance has been performed. The result of plugging most often manifests as an abnormal increase in pressure drop across the exchanger. It is recommended to have a baseline of three times the design allowable pressure drop.

Using upstream filters with a 177-micron screen—equivalent to 80 mesh Tyler—is the best way to prevent a heat exchanger from plugging. These issues can arise during initial commissioning or after maintenance has been performed; special care should be taken at these times to ensure no debris is left where it may contribute to plugging.

Fouling

Fouling is when a substance coats the fin matrix and enters the BAHX. Sources of fouling can include oils, heavy hydrocarbons, and waxes (such as paraffin, TEG). In addition to an increase in pressure drop, fouling may also result in decreased thermal performance (i.e., heat exchanger temperatures are not as close as they used to be), which can reduce plant throughput. A pre-treatment system that targets removal of the fouling agent before it enters the BAHX is needed to prevent fouling.

Hydrates

Hydrate accumulation is caused by hydrate formation upstream or inside BAHX units, typically in natural gas feed streams. Hydrates can form at high pressure and warmer temperature regimes that vary with the stream composition and are problematic due to their propensity to freeze inside the BAHX. In addition to an increase in pressure drop, high concentrations of hydrate formation can even cause thermal distortions that damage the BAHX. A pre-treatment system, like a glycol contactor, can be used to remove hydrates before they enter the BAHX.

CO_2

CO_2 ice formation is caused by streams with high CO_2 concentrations. The critical concentration of CO_2 depends on the stream composition and operating temperatures and pressures. Similarly to hydrate formation, this can cause an increase in pressure drop and thermal distortions that damage the BAHX. Amine systems are commonly used to remove CO_2.

Ice Formation

Similarly to CO_2, liquid water can form ice inside a BAHX, for most services operate in temperature ranges below the freezing temperature of water. The volume of water expands 9% when it freezes from a liquid to a solid, which can damage the BAHX fin matrix. Thus, removing liquid water is of critical importance. When a service oscillates between freezing and thawing temperatures, it will distort the fin legs. If left to progress, the fins may rupture, and the rupture may proceed to the outside of the core matrix, which will appear as a bulge on the cap sheet and eventually lead to an energy release. In addition to an increase in pressure drop, ice formation may also result in decreased thermal performance (i.e., heat exchanger temperatures are not as close as they used to be, which can reduce plant throughput).

An effective derime is the first line of defense in removing moisture from the heat exchanger. Oxygen-free nitrogen with a dewpoint of -40°C or lower should be used. After the unit is derimed, a pre-treatment water removal system like a molecular sieve bed should be used to prevent water from entering the heat exchanger.

Corrosion

Exchangers exposed to corrosive fluids can irreparably damage a BAHX. Some common fluids are listed below, but this is not an exhaustive list.

- Chlorides
- Amines
- Acids / Bases
- Cleaning Agents
- Mercury

Corrosive fluids will thin pressure-retaining parts (e.g., fins), which can result in a catastrophic energy release. Monitoring the stream composition and the pH level of streams to detect undesirable components is good practice. Operations must have pre-treatment systems to avoid corrosive fluid exposure to BAHX. For example, mercury guard beds installed upstream of the BAHX to safeguard against mercury corrosion are invaluable in applications where mercury may be present.

Exceeding Thermal Guidelines

Exceeding thermal guidelines can cause damage to the exchanger through repeated cycles of thermal shock, introducing fatigue into the material components. For many situations, exceeding the stream temperature rate of change will not damage the heat exchanger, but this cannot be guaranteed without analysis of the specific situation. The greater the thermal excursion and the more frequent the number of events, the more likely the sheets will fatigue and crack, which in turn will become fluid leaks.

The plant should be instrumented with temperature probes on the inlet and outlet of each stream, allowing for direct monitoring of temperatures entering and exiting the BAHX. Note that all temperature rates of change should be calculated using the time interval specified in the rate of change time unit (i.e., use one-minute intervals when calculating temperature rates of change against rates of change per minute and use one-hour intervals when comparing against rates of change per hour). Instantaneous rate of change calculations should be avoided. Having flow rate measurements is useful in determining if the temperature change is significant in terms of energy.

Of the methods that can be utilized to mitigate exceeding thermal guidelines, the simplest is typically improving process controls. This can be difficult for operators due to the lack of access to thermal gradient information in the field. Thermal stress is determined by thermal gradients in the heat exchanger metal, and some guidelines are conservative to account for variations in designs and potential circumstances.

Unstable Flow

Unstable flow should be avoided. Operations can detect unstable flow by monitoring the differential pressure across the boiling pass. Unstable flow can instigate high-cycle fatigue, which manifests as cracks in the sheets, which then leak. Pressure drop measurement is a huge help in diagnosing issues, especially in the case of a thermosiphon loop.

In **Figure 2**, the impact of valve position (in green) is compared with the pressure drop (in blue). As the valve is opened, there is no

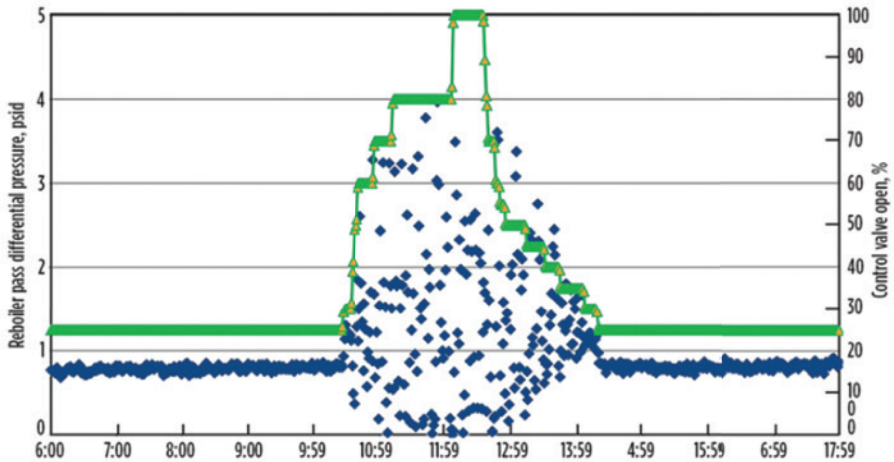

Figure 2. Unstable flow data.

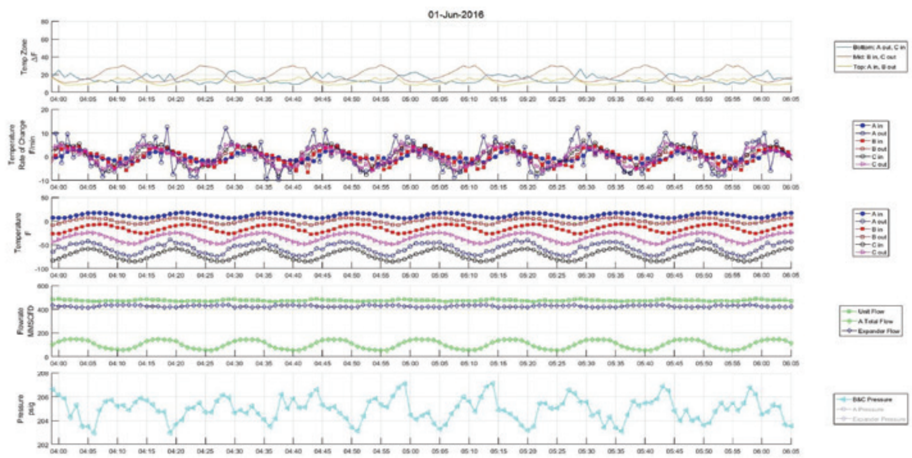

Figure 3. Oscillating flow and temperature data.

longer sufficient dampening on the system, and the flow becomes unstable. The unstable flow can be mitigated by closing the flow control valve until it becomes stable (as shown in the example).

Assessment

This section discusses how to assess the health of a BAHX both while it is in service and when it is out of service.

In Service

The following are tasks that can be performed while the unit is operating.

- Visual Inspection: While the unit is operating, the exterior of the unit or insulation covering should be inspected for anomalies such as frost spots, dripping fluids, and vapor clouds. These indicate that external leaking is occurring. This inspection should be performed every shift.
- Fluid Composition Testing: The fluid composition of the streams should be monitored, both upstream and downstream of the unit. Changes in purity from upstream to downstream of the BAHX indicate internal cross-pass leaking. In a closed-loop system, gradual changes in composition over time may also indicate cross-pass leaking. The interval of this test depends on the variation patterns of the streams and the industry norms for the specific application.
- Monitoring Operating Data: The operator of a BAHX should continuously monitor the real-time temperature, pressure, and flow rate operating data. Watch for indications of:
    - High local stream temperature differences.
    - High rate of change of stream temperatures.
    - High pressure drop.

In **Figure 3**, one stream's flow rate oscillates, causing the heat exchangers' temperatures to fluctuate and exceed the temperature rate of change guideline. The cause of the flow oscillation should be investigated. In this case, the flow controller required tuning.

Out of Service

When the unit is out of service, more tasks can be performed. For some of these tasks, insulation will have to be removed.

- Visual Inspection: A visual examination of the exterior of the exchanger for bulges in the cap sheets or other anomalies, such as cracks, should be performed. Bulges in the cap sheets indicate ice formation has occurred (see **Figure 4**). Cracks likely indicate thermal fatigue or thermal shock damage. Dye penetrant tests on all external welds should be performed.

Figure 4. Cap sheet bulge due to ice formation.

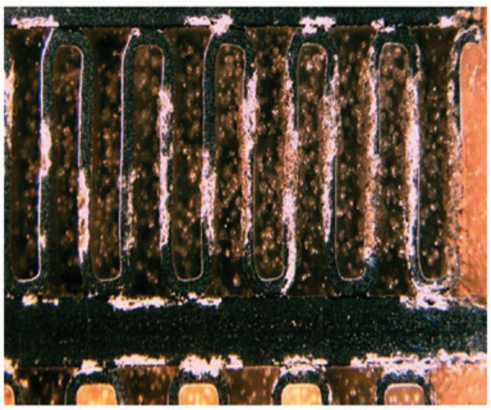

Figure 5. Plugged Distributor Fin

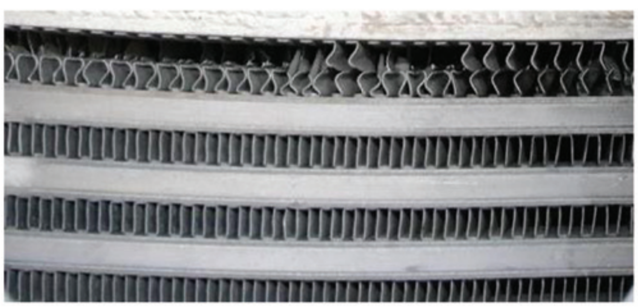

Figure 6. Cracked Distributor Fin

Cracks most likely indicate thermal fatigue or thermal shock damage. Brazed surfaces should not be dye penetrant tested, as the results will not be meaningful. A borescope should be inserted into the header bodies to inspect the port fins. Debris or particulate indicates plugging, discoloration, or residue may indicate corrosion or fouling (see **Figure 5**), and cracks may indicate thermal fatigue or thermal shock damage (see **Figure 6**).

- Pressure Test: A pressure test will confirm the pressure-retaining capability of the BAHX. Pressure tests should be considered after any repairs have been made, or if chemical attack or corrosion is suspected, or if thermal shock or thermal fatigue is suspected.
- Leak Test: A soap bubble leak test can detect external or internal cross pass leaks. Leak tests should be considered:
    - After any repairs have been made.
    - If cross-pass or external leaks are suspected.
    - If a chemical attack or corrosion is suspected.
    - If thermal shock or thermal fatigue is suspected

Cleaning

Cleaning a BAHX is possible, but it will likely not restore the unit to "like-new" condition. Chemical cleaning and backpuffing are common methods of cleaning a BAHX.

Chemical Cleaning

If operations suspect plugging or fouling:

- Operations should attempt to identify the potential blockage to best match the cleaning approach/best solvent to dissolve the blockage.
- If feasible, perform a borescope inspection of the inlet header/nozzle.
- Hydrates can be an issue as well, often deriming is recommended as a first step.
- Often, operations are unable to identify the plugging agent, so a general-purpose solvent is recommended.

Figure 7. Debris in header/nozzle.

Figure 8. Fouling in header/nozzle.

Figure 9. Backpuffing (notice black cloud of particulate)

- If both solvent cleaning and backpuffing are planned, it is recommended that backpuffing be performed before solvent washing.

Backpuffing

One technique for removing particulate matter is backpuffing (or back blowing). Backpuffing is very aggressive, so take this into account for planning purposes. A rupture disc is placed at the inlet of the BAHX. The stream is pressurized until the rupture disc releases the lodged particulate (see **Figure 9**). The rupture sounds like a cannon, and anything close to the rupture disc is in a precarious location.

Repair

BAHX repair primarily involves blocking layers. Blocking layers is primarily performed when there is a sheet leak either externally or internally. Similar to blocking leaking tubes in a shell-and-tube heat exchanger, layers can be blocked in a BAHX.

Figure 10 shows a blocked layer. The distributor opening for one layer is welded shut, while the other distributor openings are open to fluid flow. The repairs must be performed by an authorized repair organization. For ASME vessels, these would be organizations with a certified "R" stamp. The repairs should be in accordance with the code authorities, such as the National Board Inspection Code, the ASME Code, and local requirements.

Figure 10. Blocked Layer (encircled in red)

When to Replace

ALPEMA (ALPEMA®, 2024) says:

To achieve maximum life expectancy of the heat exchanger, root cause analyses of leakage/failure events should be conducted. This may involve metallurgical analysis and/or review of past operating history. If thermal fatigue is suspected as causing the leaks and the repair under consideration is the second repair due to thermal fatigue, it is recommended the customer replace the heat exchanger within a reasonable time frame.[1]

Conclusion

BAHX units are extremely reliable and safe when properly installed, operated, and maintained. They have an incredibly low incident rate, and they stay that way by following industry guidelines, as well as those specific to a custom solution. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

REFERENCES

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CONTRIBUTING AUTHOR

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As a Fellow for Chart Energy and Chemicals, Douglas Decker is focused on enhancing brazed aluminum plate fin heat exchangers so that customers prefer Chart products. He has engaged in the design, manufacture, service and education efforts at Chart. He was a member of the API 668 committee that published the 2018 standard. He was a member of the committee that edited the GPA Midstream Technical Bulletin – Brazed Aluminum Heat Exchangers GPA-TB-001, December 2020. He has been a speaker at AICHE, MTI and API. He holds a BS degree in mechanical engineering from South Dakota State University.