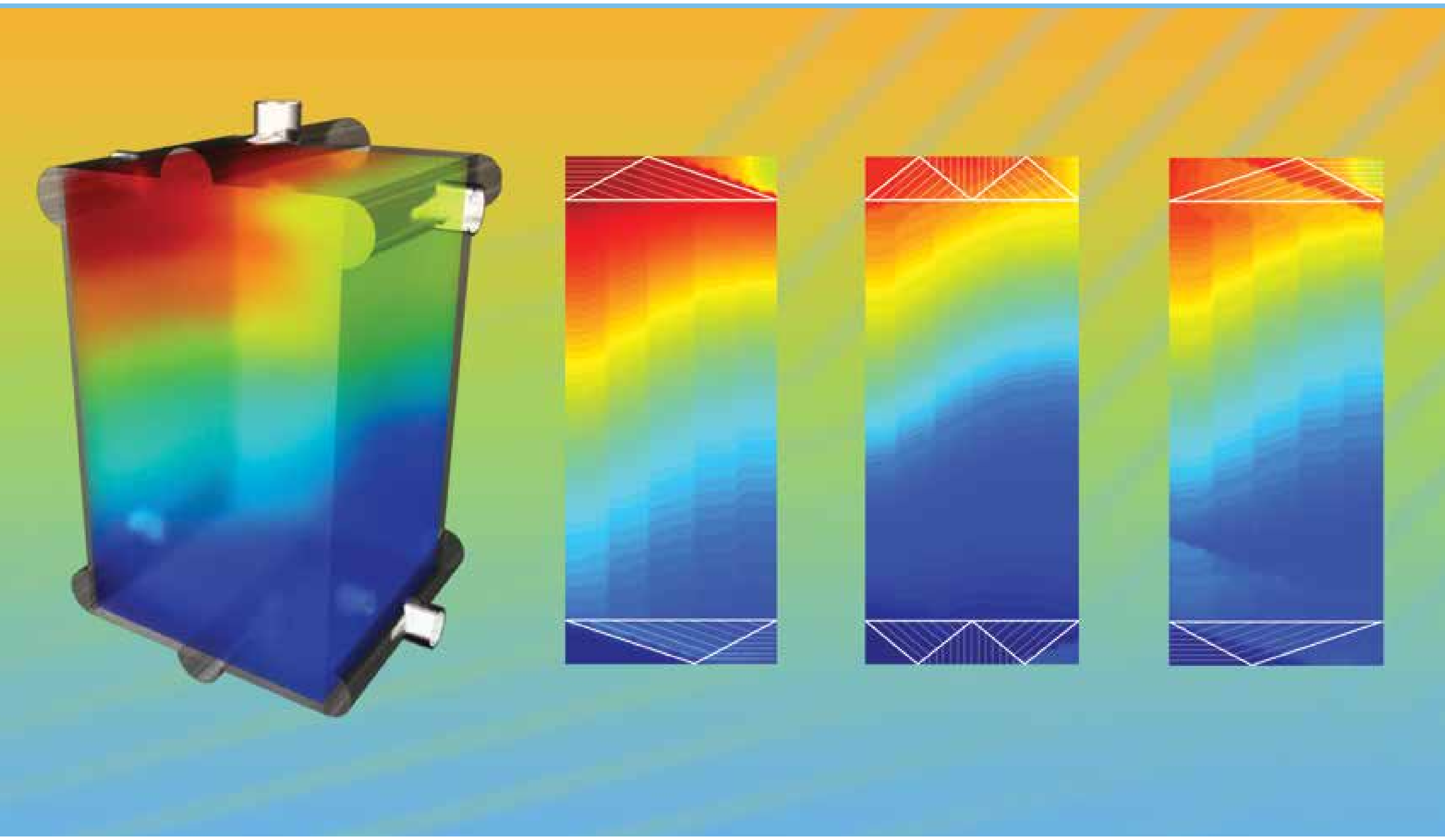

BAHX PRODUCT BULLETIN

Cooler By Design.®

Issue 2 - January 2021

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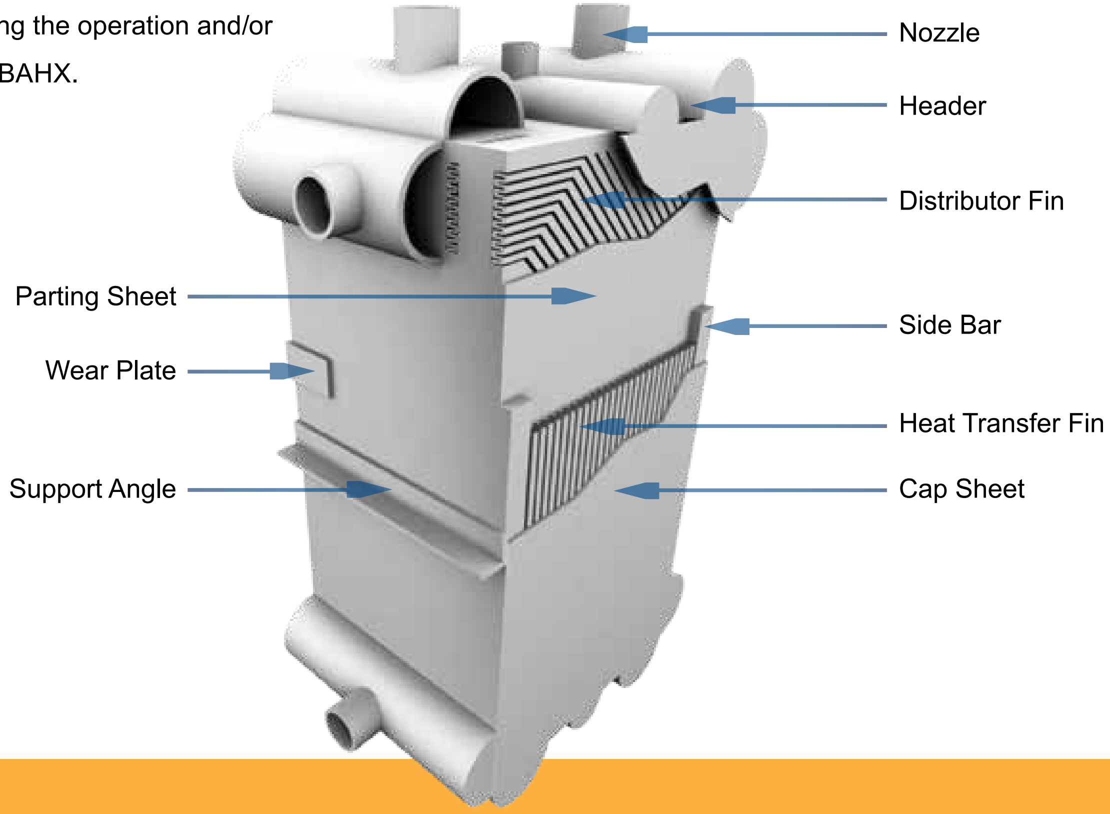
INTRODUCTION

Chart Energy & Chemicals, Inc. (Chart) is committed to assisting our customers in getting the most out of their Chart Brazed Aluminum Heat Exchangers (BAHX). To that end, Chart has developed this bulletin to help educate users by outlining what they should and should not do with respect to operating, inspecting, and maintaining their BAHX.

Chart's BAHX heritage dates back to the 1950's when, under the Trane name, the company was the first to adapt plate fin heat exchanger technology from aerospace to industrial applications, beginning with the separation of air. Trane eventually became ALTEC and Chart's 'Heat Exchanger Group' was born in 1998 with the acquisition of Marston in the UK. It's important to mention these historic brands as the longevity of Chart equipment is such that there are still plenty of BAHXs in the field bearing those nameplates.

Who Should Read This

Anyone who owns, operates, maintains, or is responsible for overseeing the operation and/or maintenance of a Chart BAHX.



What This Bulletin Covers

This bulletin addresses recommended operation, inspection, maintenance, and assessment philosophies that will promote optimal and extended operation of Chart BAHXs. These recommendations are based on Chart's 60+ years of experience in designing, manufacturing, troubleshooting, and repairing our heat exchangers.

This bulletin is intended to supplement the Chart Installation, Operation, And Maintenance (IOM) Manual and ALPEMA Standards, which contain further detail and additional topics to those covered here. Other valuable resources on brazed aluminum heat exchangers can be found at the end of this bulletin.

If, for any reason, questions arise that are not addressed in this bulletin, or the IOM, you must contact Chart for further information, interpretation, and guidance. Failure to follow correct instructions, practices, and procedures may result in serious bodily injury or death, property damage, and irreparable damage to the Chart equipment.

OPERATION

Lifespan

The lifespan of a BAHX depends entirely on the care with which it is operated and maintained, especially with respect to thermal gradients. Heat exchangers that have been operated diligently with respect to the operating and maintenance guidelines can have service lives of 40 years or more, while poorly controlled processes can cause a heat exchanger to fail even during initial startup. Chart has found that typical industry expectation is an approximate 20 year service life.

End of Life

BAHXs don't 'wear' like brake pads or tires do during normal operation, where there is a predictable change in a measurable value and a minimum safe value for operation (e.g. brake pad thickness or tire tread depth). Chart's experience has shown that the majority of BAHXs are retired from service due to leaks, and the majority of leaks are caused by some form of thermal stress damage.

In situations where a large percentage of the operational life of a BAHX is consumed by relatively few high stress events, the critical events usually occur when operating conditions are changing rapidly and the operations' group has not established procedures to control them. This makes it extremely difficult to predict end of life when the lifespan is largely determined by events that are unexpected, or for which control procedures are not in place to address.

In situations where gradual accumulation of fatigue damage controls the operational life of a BAHX, predicting remaining service life is still difficult. API 572 (8.2.5) states that:

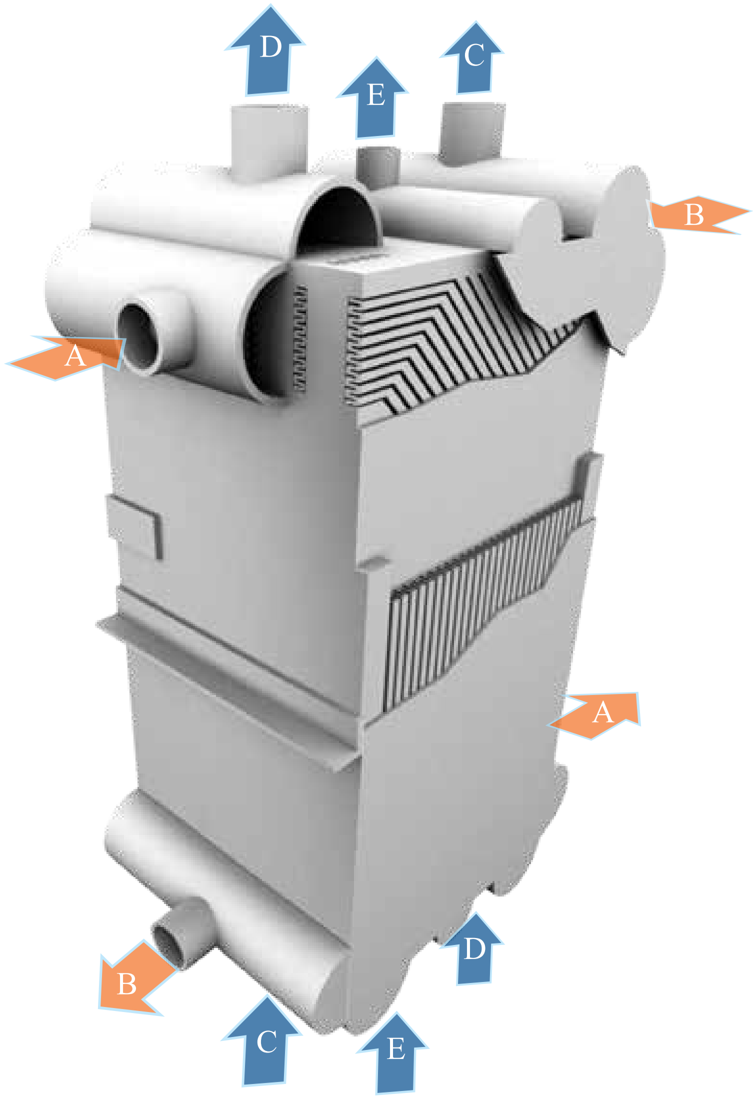
"It is important for the owner-user and the inspector to understand that fatigue cracking is likely to cause vessel failure before detection with any NDE methods. Of the fatigue cycles required to produce failure, the vast majority are required to initiate cracking and relatively few cycles are required to propagate the crack to failure."

Advanced simulations can be used to predict fatigue failure if the historical operating conditions are well-known. Fortunately, the vast majority of BAHXs that experience thermal stress cracking, either from high-cycle fatigue or from low-cycle thermal shock events, will exhibit small leaks that can be detected and repaired in the field.

In the GPA Midstream Technical Bulletin – Brazed Aluminum Heat Exchangers, GPA-TB-001, December 2020 it says:
"Consider replacing a heat exchanger within a reasonable amount of time if analysis of historical operating data shows that thermal fatigue contributed to the leak and especially if the heat exchanger requires a second leak repair due to thermal fatigue."
Chart endorses the GPA recommendation.

Principles of Operation

In a few words, “Keep it clean, keep it dry, and manage thermal gradients.”



Following this advice will protect against the majority of issues that a BAHX faces during operation. “Keep it clean” and “keep it dry” refer mostly to preventing harmful compounds and contaminants from entering the exchanger, while “manage thermal gradients” refers to proper control of the stream temperatures and flow rates to minimize temperature differences and thermal stress within the heat exchanger.

In Chart’s experience, improper management of thermal gradients is responsible for the majority of leaks and damage suffered by BAHXs in the field. Simply put, excessive thermal gradients decrease the life expectancy of a heat exchanger. This can occur, either by slow accumulation of damage due to thermal cycling, or sometimes, even just one thermal shock event.

Virtually all hazards to brazed aluminum heat exchangers can be prevented by keeping them clean, keeping them dry, and managing thermal gradients.

Keep It Clean

A BAHX operates most efficiently when the stream passages are free from obstructions and fouling, and will have the longest life expectancy when corrosive or chemically reactive compounds are prevented from entering the heat exchanger. The best way to keep a BAHX clean is to ensure the incoming streams are appropriately conditioned before they enter the heat exchanger.

PLUGGING

What it is and why it's bad

The passages inside a BAHX can become obstructed when particulate matter entrained in the streams becomes deposited inside the BAHX, when larger debris blocks the inlet port opening inside the headers, or if significant fouling or hydrate accumulation occurs. These conditions can restrict flow and completely plug some passages, which can increase pressure drop, deteriorate thermal performance, and cause flow maldistribution leading to higher thermal stresses. Theoretically, local fin and parting sheet erosion may occur at high velocity areas due to maldistribution, but no confirmed instances of this occurring in the field have come to Chart's attention.

What can cause it

Pipe scale and mole sieve dust can each plug an exchanger, and construction debris such as cardboard, hand tools, and welding dams left in pipes can become lodged inside the inlet headers. These issues can arise during initial commissioning or after maintenance has been performed.

How to detect it

Plugging and obstruction can be detected by measuring abnormally high pressure drop across the heat exchanger while it is in operation. As a general guideline, if the measured pressure drop begins to exceed 2 to 3 times the design pressure drop, Chart would recommend cleaning efforts be undertaken.

How to prevent it

Plugging can be prevented by installing permanent 80 Mesh Tyler Standard filters in all streams. Dual filters are recommended to allow replacement of filters while maintaining operation.

Another plugging avoidance measure is to establish a program or procedure to clean upstream piping and vessels prior to commissioning and after construction, repair, turn arounds, and any other time the system is opened.

If the potential plugging medium is mole sieve dust, prevention is best achieved by proper maintenance of the mole sieve filter system.

How to fix it

If a BAHX has become plugged with particulate matter, the particulate can often be removed by backpuffing. Contact Chart for further guidance.

Larger debris must be identified and located by examining the inside of the inlet headers with a borescope.

FOULING

What it is and why it's bad

Fouling occurs when compounds in the streams solidify inside the BAHX and coat the heat transfer surfaces. The primary detriment of fouling is reduced heat transfer, however severe fouling can lead to obstruction and plugging of the passages. Fouling can increase pressure drop, deteriorate thermal performance, and cause flow maldistribution leading to higher thermal stresses.

What can cause it

Sources of fouling include oils and heavy hydrocarbons, waxes such as paraffin, TEG, and other substances that can coat the fins in a BAHX.

How to detect it

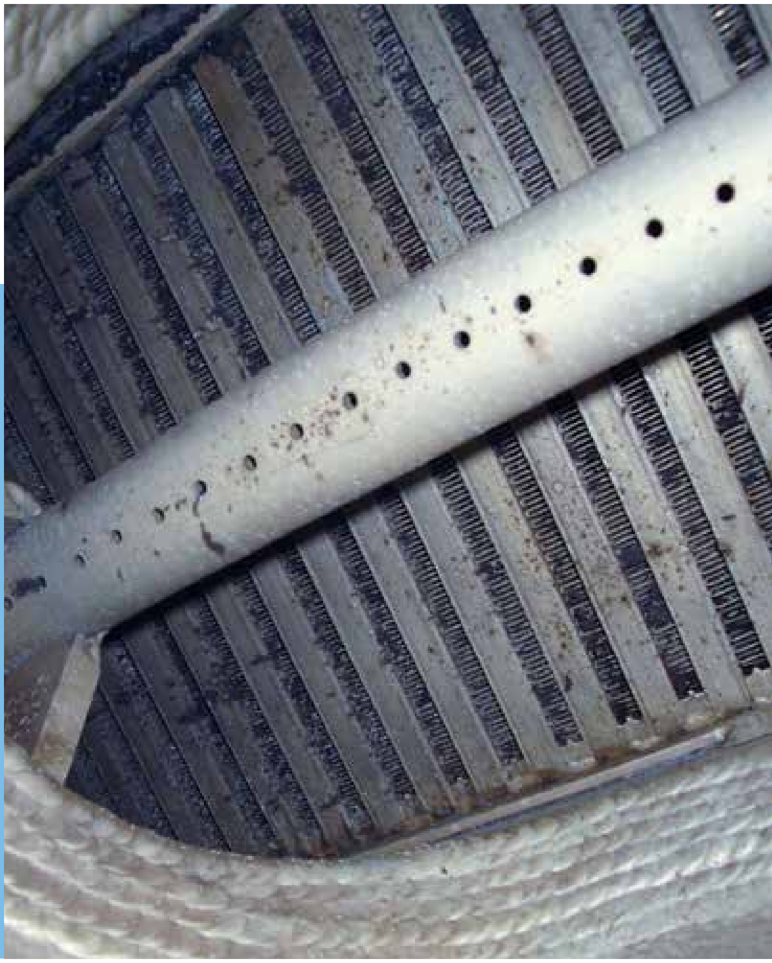
Fouling can be detected by measuring decreased heat transfer in the heat exchanger, or by measuring abnormally high pressure drop. Additionally, some types of fouling can be seen by visually inspecting the inlet or outlet headers and port fins.

How to prevent it

Ensure proper stream compositions before they enter the BAHX. Pretreatment systems must remove all contaminants from incoming streams before they enter the BAHX.

How to fix it

If a BAHX has become fouled, chemical cleaning is often necessary. The cleaning agent should be selected based on the specific fouling compound, and must be safe for use with the BAHX. Specialized cleaning companies having experience cleaning BAHX are preferred. Contact Chart for a list of recommended vendors.



CHEMICAL ATTACK

What it is and why it's bad

Keeping a BAHX clean also entails preventing corrosive or chemically reactive compounds from entering the heat exchanger. Corrosion and chemical attack will thin pressure retaining parts, and can result in catastrophic failure. BAHX's have no allowance for corrosion.

What can cause it

Chemical attack can come from many different sources. Some of the more common sources are:

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

Trace impurities of certain compounds can react with liquid water to form acids, which can attack aluminum. These compounds include:

- H_2S, NH_3, CO_2, SO_2, NO_2, CO, Cl

How to detect it

Monitor the streams to ensure the appropriate pH level and monitor stream composition for harmful compounds.

How to prevent it

Control stream compositions to prevent harmful compounds from entering the exchanger. Maintain the pH of streams between 5 and 7. Ensure the BAHX and upstream piping and equipment are free of water prior to operation.

How to fix it

There is no remedy for accumulated corrosion damage. The stream compositions must be corrected and controlled to prevent further damage. Perform a pressure test to ensure design pressure retaining capability is intact if corrosion is suspected to have occurred.

Keep It Dry

Most BAHXs are operated at cryogenic temperatures, which can cause certain compounds to freeze within the unit. Hydrates, water, benzene, and CO_2 are notable examples of compounds that may freeze inside a heat exchanger. If there is liquid water anywhere in the exchanger, it can turn to ice, which will expand as it freezes and cause layers to rupture. Streams with hydrates or high water content can cause hydrates to accumulate in a core and cause plugging, and streams with high CO_2 concentrations can cause CO_2 ice to form and cause plugging.

Mole sieve beds or glycol dehydration units are commonly used to remove water from incoming streams, and amine units are commonly used to remove excess CO_2.

ICE FORMATION

What it is and why it's bad

If water is present in incoming streams, it can create a thin layer of ice coating the fins. This can increase pressure drop, deteriorate thermal performance, and cause flow maldistribution leading to higher thermal stresses.

If pockets of liquid water are allowed to freeze inside a BAHX, they will expand and rupture the fin layers. A single ice rupture will fail the fins in the originating layer, and damage the fins in multiple layers adjacent to the originating layer.

What can cause it

Ice formation is caused by streams with water content that is high enough to freeze inside the BAHX during operation (streams with high dew point). It is also caused by residual liquid water in the BAHX or in upstream piping and equipment that is fed into the unit and not purged prior to startup.

How to detect it

The first sign of ice formation is increased pressure drop. This can progress to fin rupture if it is not corrected.

Fin rupture occurring in layers near the outside of the BAHX will create visible bulges in the cap sheets. If the fin rupture only occurs internal to the BAHX, then the bulges will be inside the BAHX and not visible from the outside.

How to prevent it

Ice formation can be prevented by continuous dew point monitoring of stream inlets and a properly functioning dehydration system. Ensure dryness of BAHX and upstream piping and equipment before startup by draining low points and purging with dry gas with a dew point below -40° C. During operation, the dew point of a stream should be below the coldest temperature of that stream.

How to fix it

If ice formation is detected before it has ruptured fins, it can be dissolved by alcohol injection or removed by deriming.

Ice formation that has caused fins to rupture typically affects many layers in a BAHX, and requires replacing the unit. Fin failure is not repairable.

HYDRATE ACCUMULATION

What it is and why it's bad

Hydrates are substances containing water that form snow or ice-like crystals at certain temperature and pressure regimes. Hydrate formation is distinctly different from ice formation, and it accumulates inside of BAHXs in a manner similar to particulate fouling. Accumulation can increase pressure drop, deteriorate thermal performance, and cause flow maldistribution leading to higher thermal stresses.

What can cause it

Hydrate accumulation is caused by hydrate formation upstream or inside of BAHXs, typically in natural gas feed streams. Hydrates can form at high pressure and warmer temperature regimes that vary with the stream composition.

How to detect it

Hydrate accumulation can be detected by increased pressure drop and decreased thermal performance.

How to prevent it

Prevent hydrate accumulation by predicting the hydrate formation pressure and temperature regimes for the specific stream composition and ensuring they don't overlap with the operating conditions.

How to fix it

If hydrate accumulation has occurred, methanol injection can be used to dissolve the hydrates. This can be done on an as-needed basis, or continuously. If the hydrate accumulation is severe, then deriming may be required.

CO_2 ICE FORMATION

What it is and why it's bad

CO_2 can freeze inside a BAHX similar to water, except that it won't expand and rupture fins. It can increase pressure drop, deteriorate thermal performance, and cause flow maldistribution leading to higher thermal stresses.

What can cause it

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.

How to detect it

CO_2 ice formation can be detected by high pressure drop.

How to prevent it

Ensure the concentration of CO_2 is low enough to prevent ice formation. This is usually accomplished by installing a CO_2 removal system such as an amine unit upstream.

How to fix it

CO_2 ice can be removed by deriming the BAHX.

EXCESSIVE THERMAL GRADIENTS

What they are and why they're bad

Thermal gradients are temperature differences within the heat exchanger metal that cause thermal stress. For many BAHX designs, the allowable thermal stress at the steady state design conditions is twice as high as the allowable stress from the stream pressures. Excessive thermal stress is one of the most prevalent causes of leaks in brazed aluminum heat exchangers, and it is also one of the least understood by operators.

Thermal shock is the term for thermal gradients that are likely to cause heat exchanger failure after relatively few occurences. Thermal fatigue is the slow accumulation of damage due to repetitive temperature cycling events. The stress level from each cycle might be very low, but the cumulative effect can eventually lead to failure.

What can cause them

Excessive thermal gradients are most often caused by transient events, where process conditions such as stream temperatures or flow rates are changing. A typical design will allow for a maximum temperature difference of 28° C between adjacent parting sheets. Localized temperature differences within parting sheets can also lead to high thermal stress.

How to detect them

Thermal shock in a heat exchanger will manifest as one or more leaks. These leaks can be between parting sheets and cause fluids from a high pressure stream to flow into adjacent low pressure streams, or the leaks can allow a stream to leak to outside the heat exchanger.

Thermal fatigue will eventually result in leaks if it is allowed to continue to failure. There is no reliable way to directly measure fatigue damage before it results in a leak.

Inspection of past operating data can identify events that are likely to have caused thermal shock or thermal fatigue. This can allow operations to be changed to avoid these potentially harmful events in the future.

EXCESSIVE THERMAL GRADIENTS

How to prevent them

Prevention of harmful thermal gradients is primarily achieved through control of stream inlet and outlet temperatures and flowrates.

1. Limit the temperature difference between the streams at any point along the exchanger length to 50 °F (28 °C).
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/hr (60 °C/hr) with allowance up to 3.8 °F/min (2 °C/min).

How to fix them

Most leaks can be repaired in the field by qualified personnel. However, there is no way to reverse damage accumulation due to thermal fatigue.

OTHER HAZARDS TO BAHX

Brazed aluminum heat exchangers face hazards that aren't covered by the topics discussed above, but they are much less prevalent and are typically specific to certain applications. These hazards include liquid mercury attack, acetylene generation / decomposition, and NOx gums / salts, among others. For these special hazards, refer to literature specific to the industries and applications that are affected. Refer to other resources listed at the end of this bulletin, or contact Chart for further information.

INSPECTING OPERATING DATA

The most valuable thing an owner of a BAHX can do to promote the longevity of their unit is to examine their operating data on a regular basis. Operating data includes stream flow rates, inlet and outlet temperatures, and inlet and outlet pressures for all streams in a BAHX, often recorded at one minute intervals by a distributed control system (DCS). This data contains information about how the unit has been controlled, events that may have caused high thermal gradients, and how well it is performing. If there are any issues or problems with a BAHX, including plugging, fouling, or high thermal stress, there will most likely be indications of the issues in the operating data. Additionally, the operating data may indicate whether general operation or specific procedures can be improved in order to minimize thermal stress and extend the service life of the BAHX.

Periodic inspection of operating data is the easiest way to assess the history of a BAHX, and can be a valuable tool in improving current operations and procedures. In examining operating data, be on the lookout for the following conditions:

1. Pressures above nameplate max pressure specific for that stream.
2. Temperatures above nameplate max temperature.
3. High rates of change of stream or metal temperatures. This can indicate thermal shock in extreme cases, or thermal fatigue for regularly occurring temperature cycles.
4. High local stream-to-stream temperature differences. Indicates thermal shock, or higher susceptibility to thermal fatigue.
5. Rapidly or cyclically changing flow rates. This can cause thermal cycling, leading to thermal fatigue.
6. High pressure drop. This can indicate plugging, hydrate or ice formation, or fouling.

For a well-controlled process, review the operating data at least on a monthly basis.

For new operations, review the operating data continuously until the operations are understood or until known process control issues are under control.

BAHX ASSESSMENT

The current status of a BAHX can be assessed in part by performing various inspections. Some inspections can be performed while the unit is in operation, while others require the unit to be out of service.

The owners and operators should establish an inspection schedule based on service, operating conditions, code requirements, and manufacturers recommendations.

The inspections should also be performed if damage is suspected, or if there is concern about the current status of the BAHX, or lack of knowledge of the operating history of the BAHX.

WHILE OUT OF SERVICE

Visual Inspection

External

Visually examine the exterior of the exchanger for bulges in the cap sheets or other anomalies such as cracks. Bulges in the cap sheets indicate ice formation has occurred. Cracks likely indicate thermal fatigue or thermal shock damage.

Perform dye penetrant test on all external welds. Cracks most likely indicate thermal fatigue or thermal shock damage. Do not dye penetrant test the brazed surfaces, as the results will not be meaningful.

Internal

Insert a borescope into the header bodies and inspect the port fins. Debris or particulate indicates plugging, discoloration or residue may indicate corrosion or fouling, cracks may indicate thermal fatigue or thermal shock damage.

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 chemical attack or corrosion is suspected
- If thermal shock or thermal fatigue is suspected

DURING OPERATION

Visual Inspection

While the unit is operating, inspect the exterior of the unit or insulation covering for anomalies such as frost spots, dripping fluids, and vapor clouds. These indicate external leaking is occurring. Perform this inspection every shift.

Fluid Composition Testing

Measure the fluid composition of the streams, both upstream and downstream of the unit. Changes in purity from upstream to downstream of the BAHX indicate internal cross pass leaking is occurring. 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.

Monitor Operating Data

The operator of a BAHX should continuously monitor the real-time temperature, pressure, and flowrate operating data. Watch for indications of:

- High local stream temperature differences
- High rate of change of stream or metal temperature
- High pressure drop

IN CONCLUSION

This document provides an outline of recommended best practice for the optimum performance and maximum longevity of Chart BAHXs. Its contents are drawn from our extensive experience and, together with the APEX series of informational webinars, provides unparalleled access to our technical experts. However, both are intended as supplements to, rather than replacements for, the latest editions of Chart's Installation, Operation, And Maintenance manual and the ALPEMA standards; details for both, together with other useful references, can be found below.

Other BAHX Resources

The APEX webinar series is the place to learn from Chart. Each topic is selected from customer feedback and delivered by a subject expert. The number of participants for each webinar is capped for maximum effectiveness and interaction.

Chart Energy & Chemicals Installation, Operation, and Maintenance Manual

The Standards of the Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association ("ALPEMA")

ANSI NBIC Part 2: Inspection

API 510: Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration

API 572: Inspection of Pressure Vessels

API 579: Fitness for Service

API 668: Brazed Aluminum Plate-Fin Heat Exchangers

GPA technical bulletin GPA-TB-001

EIGA Doc 145: Safe Use of Brazed Aluminium Heat Exchangers for Producing Pressurized Oxygen

UOP Technical Library – whitepapers on many topics including mercury guard beds, LNG feed pretreatment, molecular sieves, and more.

www.petrowiki.org

CONTACT US

Founded in 2016, Chart Lifecycle, Inc., was established to provide plant stakeholders, from process and mechanical engineers through to operation and maintenance personnel, with best practice for the maintenance and management of Chart proprietary equipment for optimized performance and lifespan. Chart Lifecycle, Inc., is also your 24/7 single point of contact for spares, repairs, warranties, technical expertise, project development, field services, and training. Other services include:

- Annual service agreements
- Extended warranties
- Customized operating solutions and best practices

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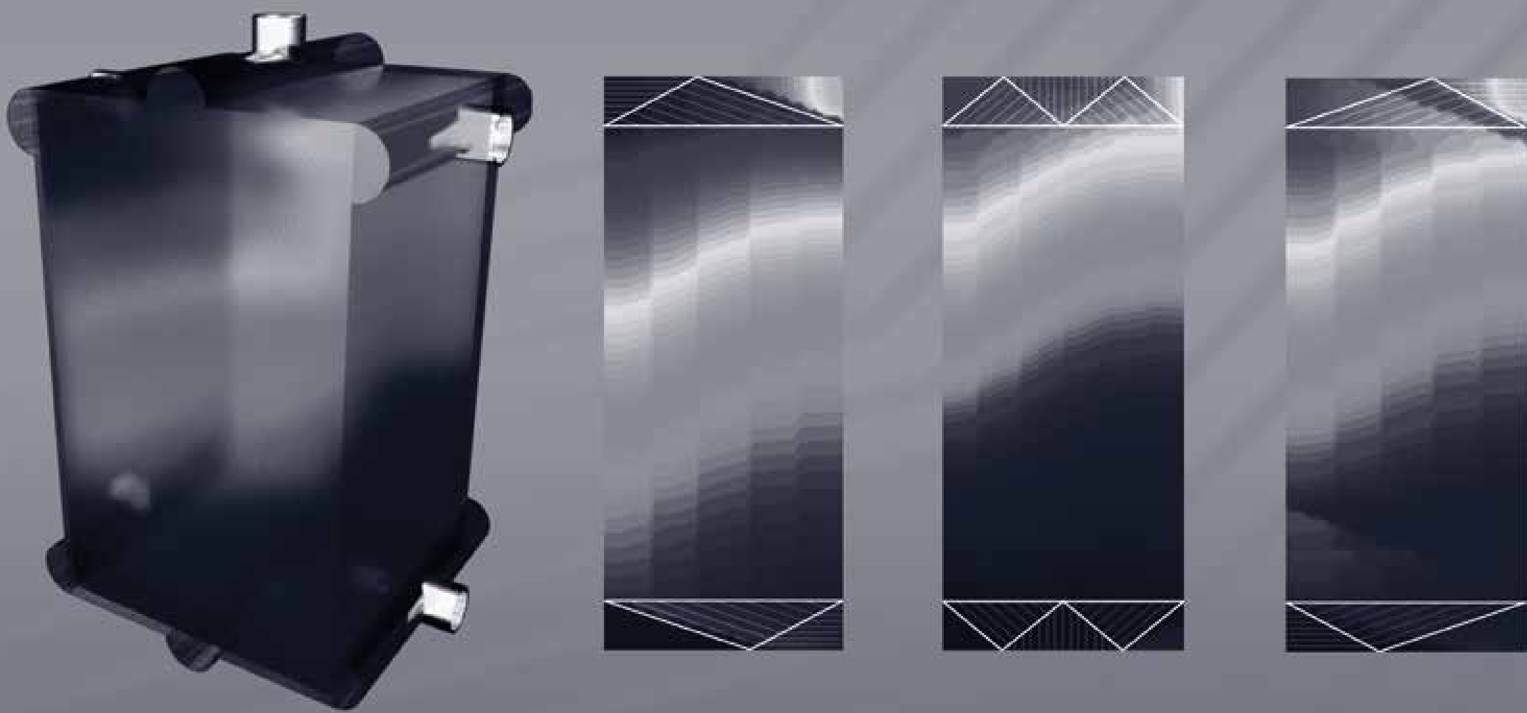

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