

ALTERNATIVES TO BRAZED ALUMINUM HEAT EXCHANGERS IN CRYOGENIC GAS PLANTS

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ABSTRACT

It has been widely accepted by industry that Brazed Aluminum Heat Exchangers (BAHX) are the most economic heat transfer technology for cryogenic NGL recovery facilities. However, their construction makes the equipment more susceptible to mechanical failure and internal / external leaks than other heat exchanger designs. In the case of the bottom and side reboilers of demethanizers, fatigue failures related to cyclic temperature fluctuations, large differences between stream temperatures or unstable flow regimes are not uncommon.

This paper considers the greenfield or brownfield installation of shell-and-tube or printed circuit heat exchangers in place of BAHX for the bottom and side reboilers of demethanizers. Comparative weights, plot space and relative costs are provided. Case studies for brownfield replacements will be presented.

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Introduction

Phillips 66 operates many Brazed Aluminum Heat Exchangers (BAHX) at its cryogenic NGL recovery facilities. This technology allows for high heat transfer rates in a compact design, thus reducing cost. However, its construction also makes a BAHX more susceptible to mechanical failure and internal/external leaks than other heat exchanger designs. Several failures of these units (resulting in small leaks internally and externally) have been observed in recent years at P66 Midstream facilities. Fortunately, failures at P66 have all been relatively low severity, with small leaks detected by operations during rounds or by reduced performance.

Cyclic temperature fluctuations in BAHX as well as large differences between the temperatures of adjacent streams are known to lead to fatigue failures¹. The thermal stresses are known to be worse for two phase streams, and therefore failures tend to be more common in the bottom and side reboilers of demethanizers.

It has been widely accepted by industry that BAHX are the most economic heat transfer technology for cryogenic NGL recovery facilities. However, in the case of the bottom and side reboilers of demethanizers, it is not immediately obvious that the up-front capital cost savings outweigh:

- Repair costs
- Any downtime associated with leak repairs
- Premature heat exchanger replacement
- Reduced NGL recovery to minimize excursions
- Additional risk incurred by their use

Regarding risk, there is not enough data in industry to positively predict the likelihood of a BAHX failure. What can be said is that the severity of each successive failure in a BAHX is often increased, and it is generally not recommended to repair a unit more than twice. The likelihood of catastrophic failures that pose serious safety risks is remote, however, catastrophic failures of BAHX have occurred in industry². One manufacturer has suggested that catastrophic failures are more likely to be the result of mercury in the feed gas, or ice / hydrate formation than from thermal fatigue.

This paper considers the brownfield replacement of BAHX with shell and tube (S&T) exchangers or printed circuit heat exchangers (PCHE) for the bottom and side reboilers applications. The option of splitting the bottom and side reboilers into separate BAHX cores is also considered. Two brownfield case studies are presented.

¹ GPA Midstream Technical Bulletin – Brazed Aluminum Heat Exchangers, GPA-TB-001, December 2020

² Multiple cases are discussed in the Chemical Safety Board (CSB) report, Enterprise Pascagoula Gas Plant Explosion and Fire, (2016) <https://www.csb.gov/enterprise-pascagoula-gas-plant-explosion-and-fire/> 2019

This paper also discusses technology selection for the bottom and side reboilers applications in new (greenfield) plants.

Heat Exchanger Types Considered

Brazed Aluminum Heat Exchangers (BAHX)

BAHX, also sometimes referred to as plate fin exchangers, have generally been regarded as the most economic heat transfer technology for cryogenic NGL recovery facilities. Aluminum is light weight compared to other common materials of construction and has a high heat transfer coefficient, making it possible to achieve very tight approach temperatures (2-4°F). This combined with their construction yields a very economical and compact heat exchanger design.

BAHX are manufactured by stacking layers of corrugated aluminum plates with different fluid passes separated by parting sheets. The ends are sealed with side bars and cap sheets, and distributors are included to guide fluid flow. This “core” is then brazed together in a furnace. Headers and nozzles are welded to the core.

Figure 1 shows a small-scale model of a BAHX in demethanizer side / bottom reboiler service. Note that the side bars and cap sheets are the same width as in a full-scale exchanger, so they look relatively much thicker than in an industrial size BAHX.

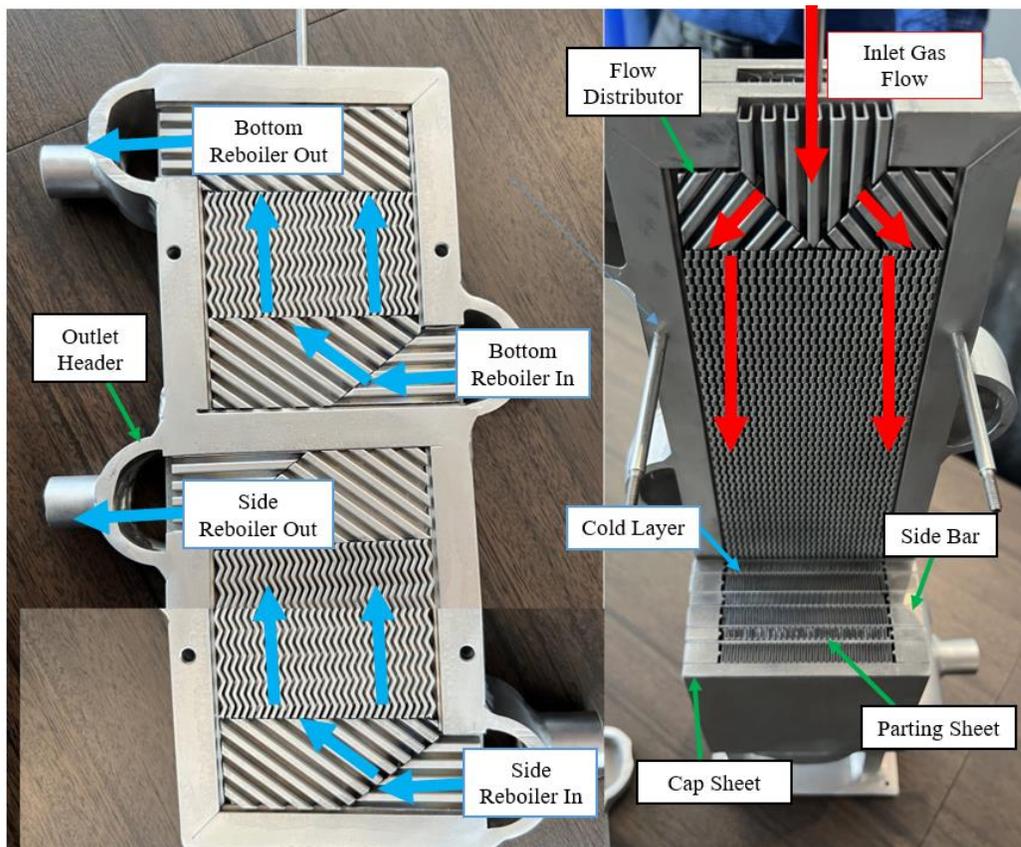
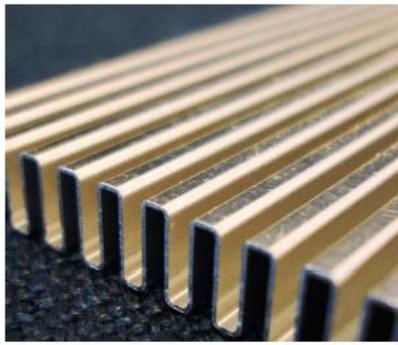
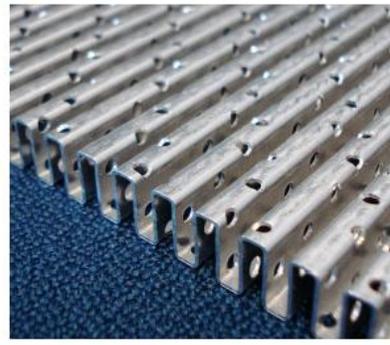


Figure 1: Picture of small-scale model of BAHX

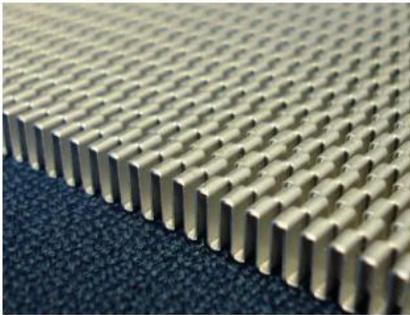
Figure 2 shows a graphic of different corrugated plate configurations.



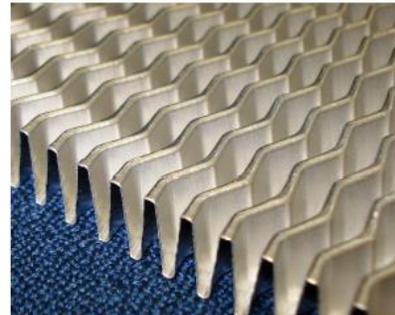
Plain fins



Plain-perforated fins



Serrated fins



Herringbone or wavy fins

Figure 2: Picture of BAHX Corrugated Plate Configurations
Images of fins are from the ALPEMA 4th Edition (copyright)

These units are prone to thermal stresses which can lead to leaks / failure. Some of these thermal stresses are related to the difference in thickness of the various components which causes them to expand / contract at different rates. Thermal fatigue is a well-known phenomenon in BAHX and the Braze Aluminium Plate-Fin Heat Exchanger Manufacturer's Association (ALPEMA) has published guidance to minimize the risk of failure^{3,4}. A summary is given below:

- 90°F max difference between adjacent single-phase streams
- 36-54°F max difference between adjacent two-phase streams or cyclic streams
- +/- 1.8°F/min max rate of change during steady state operation
- +/- 9°F/min max rate of change during transient operation and not to exceed 108°F/hr
 - Transient operation: startup, shutdown, switching modes (rejection / recovery), warmup / cooldown activities

These limits can often be respected with careful operation, but plant upsets such as residue compressor trips and liquid slugs overwhelming the inlet system will invariably result in exceedances that will eventually weaken the exchanger. Off design operation, which is often outside of the owner / operator's control, can also lead to thermal excursions.

³ The Standards of the Braze Aluminium Plate-Fin Heat Exchanger Manufacturers' Association, 4th edition, 2024, www.alpema.org

⁴ Integrity Operating Windows for Braze Aluminium Plate-Fin Heat Exchangers, June 2025, ALPEMA, www.alpema.org

Aluminum exchangers have a maximum design temperature of 150°F, since the yield strength of the material rapidly decreases at higher temperatures. This can sometimes limit the operation of upstream mole sieve dehydration units, specifically how fast they can come out of a cooling step in the regeneration cycle. (Note that even if the plant exits the cooling step below 150°F, BAHX are also more sensitive to any temperature swings resulting from mole sieve switching.)

BAHX have very small flow passages that are prone to plugging, such as from mole sieve dust. These units require upstream strainers to mitigate the risk of plugging, but even then plugging occurs at times. If the strainers are not able to be replaced online, recovery and / or throughput can be negatively impacted. The small passages also make BAHX more prone to damage from ice / hydrates than S&T exchangers. Plugging can lead to direct damage or to flow maldistribution that results in excessive temperature gradients.

Another disadvantage of BAHX is that there are limited suppliers, and only one with a large presence in the US. This can lead to excessive delivery times.

Lastly, aluminum is susceptible to mercury attack. Even very low levels of mercury can lead to catastrophic failure of the BAHX. ALPEMA recommends an upstream mercury guard bed if the inlet gas mercury concentration is 12.2 pptv (100 ng/Nm³) or higher.

Shell and Tube (S&T) Heat Exchangers

Shell and Tube exchangers are commonly used throughout gas plants and other facilities and therefore will not be discussed in detail here. They do not have the same vulnerability to thermal stresses that BAHX do (with the appropriate design provisions), can have higher design temperatures, and are not as prone to plugging. Since they do not have small passages, they are also less prone to damage from ice / hydrates.

While S&T heat exchangers can be designed with very tight approach temperatures, this would result in an unreasonably large exchanger and/or multiple shells. Typically, economical designs are limited to approach temperatures in the range of 15-30°F (application dependent). In a cryogenic gas plant, larger approach temperatures can translate to higher refrigeration loads for the same recovery, or reduced recovery. S&T exchangers also take up significantly more plot space than BAHX and therefore necessitate longer piping runs in reboiler applications.

Printed Circuit Heat Exchangers (PCHE)

Like BAHX, PCHE offer the benefit of a very compact design. However, their construction material (typically stainless steel) and manufacturing process are different than a BAHX, resulting in higher resistance to thermal stress and higher design temperatures. PCHE are also manufactured by stacking plates. However, in this case, the flow pattern on the plates is created by chemical etching (as done with circuit boards, hence the name), and the plates are fused together “using a specialised solid-state joining process known as ‘diffusion-bonding’. This creates a core with no joints, welds or other potential points of failure.”⁵

⁵ <https://ph.parker.com/us/en/product-list/heatric-printed-circuit-heat-exchanger>

Figure 3 shows a close-up image of a plate along with possible flow patterns.

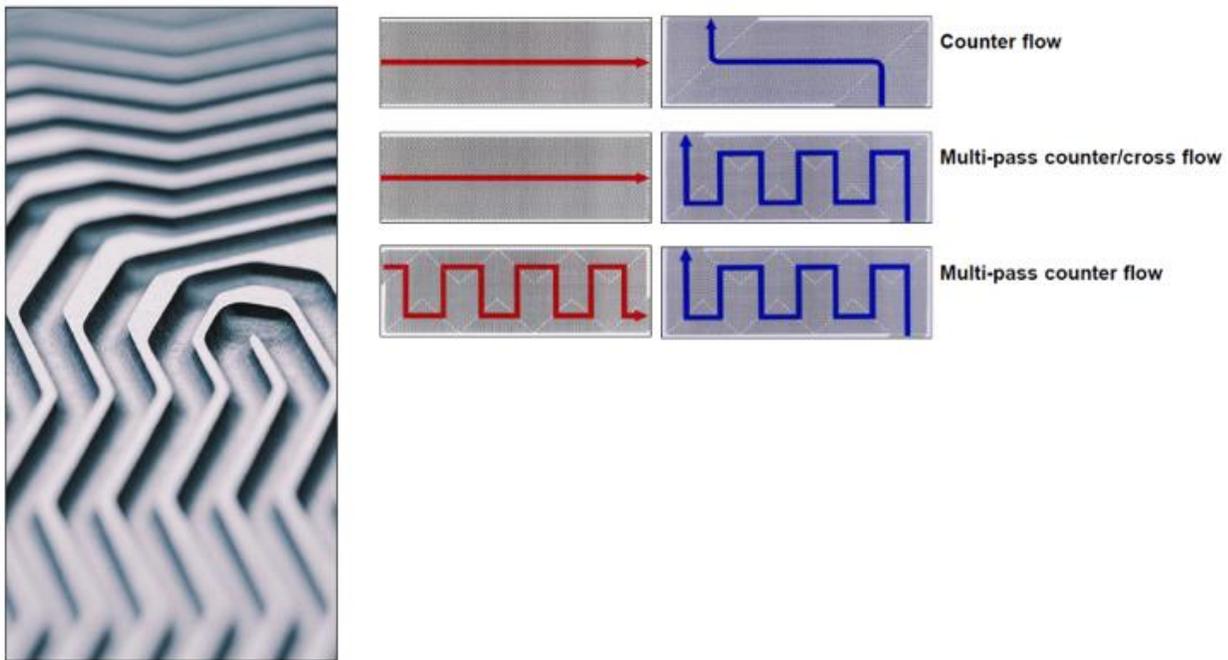


Figure 3: PCHE Plate and Flow Patterns
Images courtesy of Heatric (Parker Hannifin)

Figure 4 helps to illustrate that after diffusion bonding, there is metal grain growth between the plates, such that it becomes like a single piece of metal.

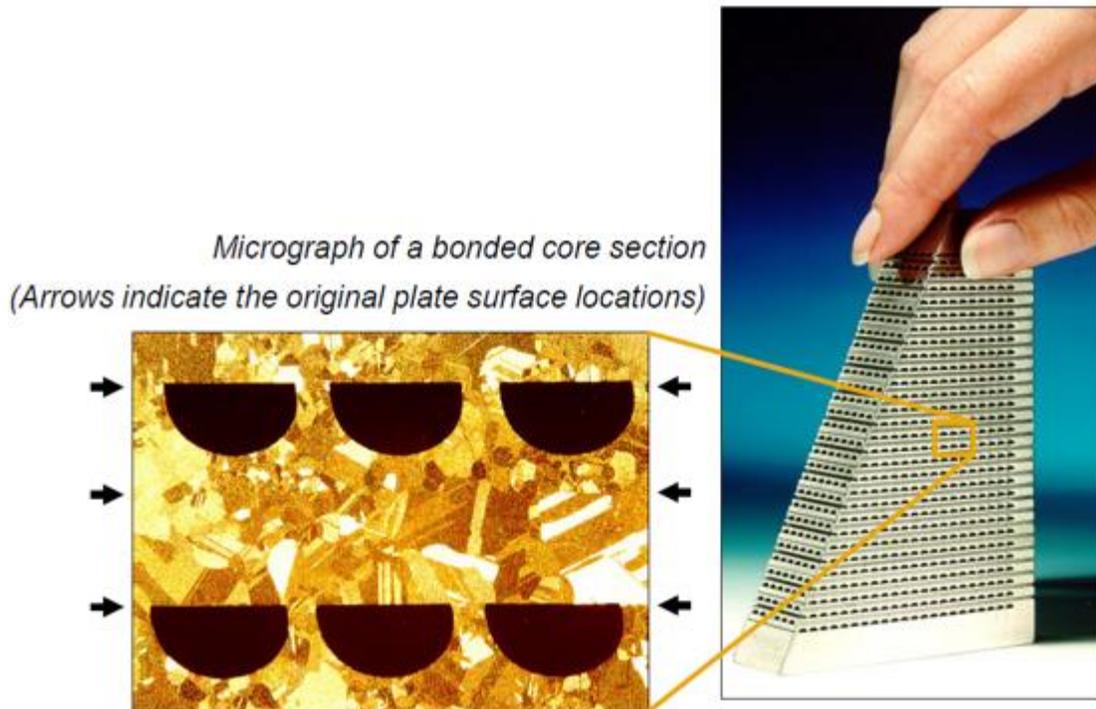


Figure 4: Image of Diffusion Bonded Plates in PCHE
Images courtesy of Heatric (Parker Hannifin)

While fatigue failures in PCHE have occurred, the risk is considered to be lower than with BAHX and leaks are typically internal to the process rather than to the atmosphere. There are no recommended rate of change / differential temperature limitations provided by PCHE vendors that the authors are aware of such as those recommended by ALPEMA for BAHX.

For a demethanizer reboiler application, the PCHE would be constructed of stainless steel. Stainless steel has a lower thermal conductivity than aluminum (BAHX), so a PCHE cannot achieve the tight approach temperatures of a BAHX, but still significantly better than S&T exchangers as PCHE have a better approach to countercurrent flow than S&T. Their application could have negligible impact on refrigeration load and / or recoveries when applied in place of a BAHX.

One manufacturing constraint that many PCHE have is the limited size of the oven used to bond the plates together, which impacts the maximum height of the exchanger (i.e. maximum length of the flow passage). In order to achieve tight approaches, additional plates have to be stacked in parallel, rather than extending flow length that may be needed to achieve the tightest of temperature approaches, and or the ability to manufacture a multi-stream exchanger (3+ streams in a single exchanger) in the sizes used in a typical gas processing plant demethanizer.

Like BAHX, PCHE have small heat transfer passages, so plugging is a risk. However, the straining requirements are no more stringent than for a BAHX.

There are limited manufacturers of PCHE at typical industry gas plant scale, which impacts delivery times.

PCHE are not commonly used in gas plants so there is limited experience in the midstream industry; however, they are commonly used in offshore applications due to their compact design and their ability to withstand higher temperatures than BAHX. Similar to a BAHX, a PCHE can be used inside a cold box or locally insulated at site.



Figure 5: Picture of PCHE designed for Demethanizer Side / Bottom Reboiler Service
Image courtesy of Heatric (Parker Hannifin)

Brownfield Replacement of BAHX

Phillips 66 currently operates over 30 cryogenic gas plants across our midstream footprint. Historically, approximately 30% of our plants with BAHX have experienced leaks at some point, primarily in two-phase services. Note, some plants that had leaks are now out of service. Also, most plants have several BAHX, so this should not be interpreted to mean that 30% of our BAHX have had failures; the percentage of individual exchanger failures is much lower.

Phillips 66 performed evaluations to replace specific existing BAHX with S&T and PCHE exchangers. These evaluations are presented in the following case studies.

Brownfield Case Study #1: 200 MMSCFD Cryogenic NGL Recovery Plant

Phillips 66 operates several nearly identical cryogenic NGL recovery plants, all with a nominal capacity of 200 MMSCFD inlet rate.

In this design, the demethanizer reboilers (bottom and side) are contained in a single BAHX. Both reboilers operate as thermosiphons on the cold liquid side, using hot inlet gas to provide the heat required. This BAHX is the same configuration shown in Figure 1, just at full scale.

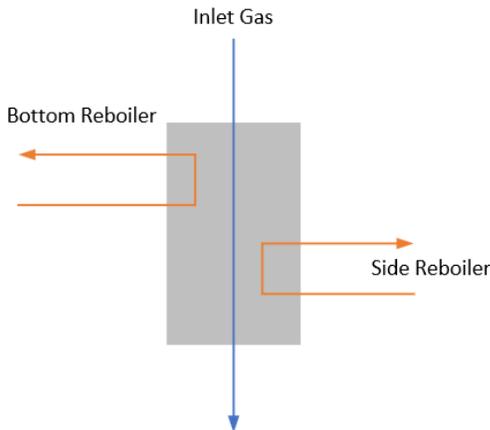


Figure 6: Flow Path of Case Study #1 Subject BAHX

In one P66 plant utilizing this design, this exchanger experienced two failures (leaks) within an 18 month period. A timeline of events and impacts is summarized in the following bulleted list, noting events leading to unplanned costs.

- Plant start up several years prior
- ~June 2020: 1st recorded time pushing >90% ethane recovery
- November 2020: BAHX failure and repair (**cost incurred** for repair and downtime)
- January 2021: Inlet gas composition became significantly leaner
- January 2021 – April 2022: operation at ~100 MMSCFD (half of design rates) and up to 95% ethane recovery
- April 2022: BAHX failure and repair, spare exchanger ordered. Decision made to limit ethane recovery to 45-55% to minimize temperature excursions and thereby the likelihood of further BAHX damage. (**cost incurred** for repair, downtime, reduced liquids production and replacement BAHX)
- September 2023: BAHX replaced (**cost incurred** for downtime)
- October 2023: Decision made to allow operation up to 85% ethane recovery (to keep thermal excursions in acceptable range), still below 95% recovery capability. (**cost incurred** due to reduced liquids production)

The following trends show the plant inlet flow (top) and ethane recovery (bottom) over a seven year period. Although the details of the graphic are difficult to make out, the different trends leading up to the failures highlighted with the vertical lines are evident.

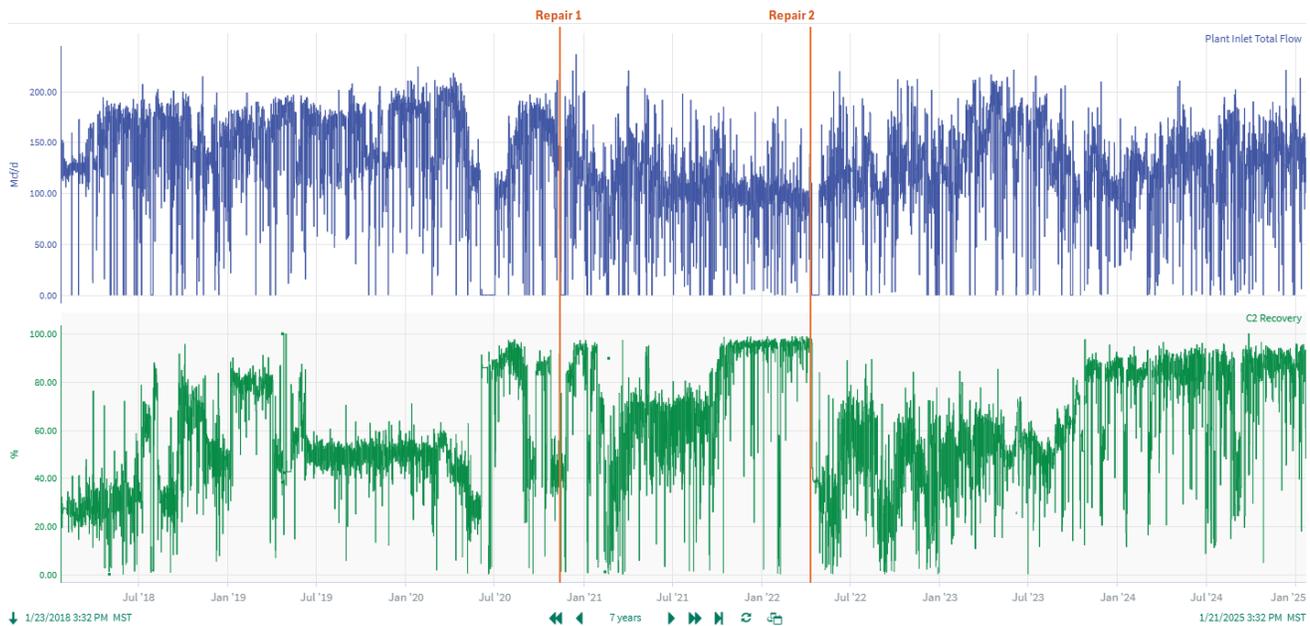


Figure 7: Operating Trends in Case Study #1 Plant

These experiences led us to explore possible alternative exchanger designs for this particular service. One point of thermal stress in this stacked BAHX design is the aluminum sheet separating the bottom and side reboiler sections. Some (but not all) of the thermal stress could be mitigated by separating the services into two independent BAHX. In P66 experience, not all failures occurred near the boundary between the two cold streams, and we have also experienced failures of reboilers that were not in a stacked configuration.

Specifications for the bottom and side reboilers were developed based on the original plant design. Based on these specifications, three budgetary quotes were obtained for comparison against the existing BAHX design:

- 1) Bottom and side reboilers as independent BAHX
- 2) Bottom and side reboilers as separate shell and tube exchangers
- 3) Bottom and side reboilers as stacked printed circuit exchangers. These could also be designed as separate units; the optimum design would be determined with further development.

All designs quoted met the specified approach temperatures. The shell and tube exchangers were quoted as stainless steel to be conservative; it is possible that carbon steel could be considered for the bottom reboiler, though an upset condition where cold liquids drop down the tower would have to be considered. Removable bundles were not specified to be required for the shell and tube designs since it is a clean service.

A comparison of the physical designs is given in Figure 8.



Figure 8: Comparison of Heat Exchanger Options for Brownfield Case Study #1

Ultimately, five cases were considered in the evaluation:

- 1) Maintain existing BAHX design, limit ethane recoveries to 85% to keep thermal excursions in acceptable range, thereby mitigating risk of failure
- 2) Maintain existing BAHX design, maximize ethane recoveries, accepting any costs associated with BAHX failure
- 3) Separate bottom and side reboiler BAHX, maximize ethane recoveries
- 4) Replace BAHX with two S&T, maximize ethane recoveries
- 5) Replace BAHX with single, stacked PCHE, maximize ethane recoveries

The comparison of the possible exchanger alternatives was done based on a 5 year operating period, with the following assumptions:

- Any change in the existing side / bottom reboiler design will require piping and plot modifications. For the S&T option, the installation and piping costs were factored from the exchanger capital cost based on a ratio determined using Aspen's Icarus software (considered FEL-0 level). Since the PCHE and separate BAHX options would require less piping and plot space manipulation, the installation and piping costs were assumed to be approximately half of the S&T case.
- It is assumed that the S&T and PCHE would not require any repairs or related downtime in the 5 year period.
- It is assumed that even if the bottom and side reboilers are broken out as separate BAHX, some repairs will still be required. This is considered justified since not all failures in similar designs occur near the boundary between the two cold streams, and we have also experienced failures of reboilers that were not in a stacked configuration. For the purposes of comparison, it is assumed that the units would not require replacement, but would require repairs and downtime at 50% of the cost of the existing unit.
- The quoted exchanger designs did not deviate from the specified approach temperatures taken from the H&MB. Therefore, it is expected that the application of a different exchanger type would have no meaningful impact on plant recoveries.
- Assumed a 2 week outage for installation of any new HX type.

Table 1: Relative Cost Comparison Over 5 Yr Period for Brownfield Case Study #1

	Maintain BAHX Design Reduced C2 Recovery	Maintain BAHX Design Max C2 Recovery	Split BAHX Max C2 Recovery	Shell and Tube Max C2 Recovery	Printed Circuit Max C2 Recovery
Delivery	65 weeks	65 weeks	65 weeks	30-34 weeks	~60 weeks
Relative Weight (HX only)	1	1	0.9x	3.4x	1.4x
Cost					
Initial TIC incl downtime	0	0	1.5	2.5	2.0
Losses / Repairs	7.5	2.1	0.9	0	0
TOTAL	7.5	2.1	2.4	2.5	2.0

Note that the delivery times shown are based on the dates that the units were quoted; delivery times would likely be different if they were quoted today. Also the value of any losses in recovery or downtime were based on commodity pricing at the times that the incidents actually occurred; any changes in pricing would affect the total cost of the BAHX cases.

The results show that the alternative heat exchanger types would be worthy of further consideration. Ultimately, no alternative heat exchanger design is being pursued for the plant that experienced the side / bottom reboiler failures. A spare BAHX was purchased, and Advanced Process Control (APC) has been deployed at the plant, which bounds plant operation by several parameters including BAHX approach temperatures.

Brownfield Case Study #2

In another Phillips 66 gas plant the bottom and side reboilers are combined with the NGL product heater in a single brazed aluminum heat exchanger core. This exchanger has three services combined into a single unit which presents more opportunity for thermal stresses, increasing the risk for failure. Due to the length of the BAHX, the supplier only has one shop that can manufacture a replacement, which increases lead time for a replacement unit.

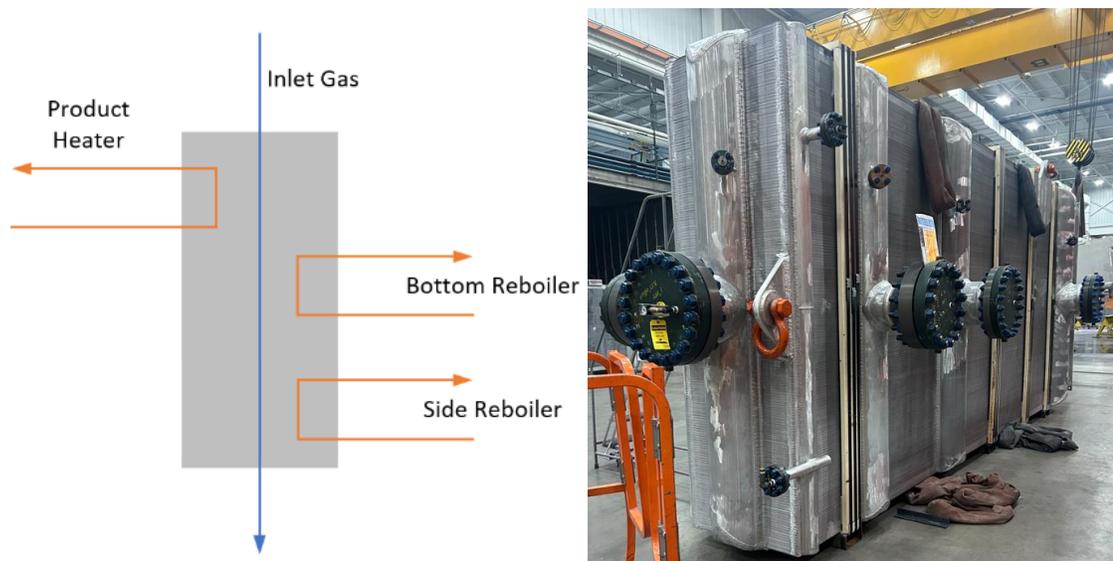


Figure 9: Brownfield Case Study #2 Subject BAHX

The plant has several operating factors working against it. BAHX are most reliable when the process is stable and near the design point. They do not handle turndown well, especially in reboiler service, because it can lead to unstable two-phase flow regimes, which in turn lead to more temperature excursions and thermal stress. This particular plant has been operating far below design rates for years, at 53% since 2017, and at 42% since October 2023. This would be problematic for any BAHX design. This exchanger had significantly longer run times when the plant was operated at/near full design capacity; in the first 5 years of operation, the plant operated at 83% of design and experienced no failures. Aside from the flow, the gas composition has also deviated from design over time which exacerbates the issue.

Another major contributor to thermal cycling / stress is related to pigging operations upstream, which are outside of Phillips 66 control. Any time a pig comes into one of the upstream (non Phillips 66) slug catchers, there is a transient in the plant that leads to thermal excursions in the BAHX.

Multiple failures have occurred in this BAHX. A timeline of events and impacts is summarized in the following bulleted list, noting events leading to unplanned costs.

- August 2020: new BAHX installed
- September 2021: Repair 1 (**cost incurred** for repair and downtime)
- March 2023: Repair 2 (**cost incurred** for repair and downtime)
- July 2023: Ordered replacement BAHX (**cost incurred** for new BAHX)
- September 2023: Repair 3 (**cost incurred** for repair and downtime)
- June 2024: New leak identified, changed to rejection operation (**cost incurred** for lost recovery)
- September / October 2024: Repair 4 (**cost incurred** for repair and downtime)
- December 2024: New leak identified
- July 2025: New BAHX installed

An evaluation was done considering other exchanger types. However, unlike Case Study #1, the specifications for the alternative designs deviated from the original BAHX. First, the NGL product

heater was removed, as it is not utilized in rejection operation and provides marginal value in recovery operation. Also, some heat transfer performance concessions were made for both the S&T and PCHE side and bottom reboiler designs. All quotes were based on the full design inlet rate to allow for future flexibility. However, the approach temperatures were relaxed in both cases.

For the PCHE, thermal performance was limited in part due to construction limitations, but ultimately the most restrictive limitation was ensuring that the new design could utilize the existing BAHX foundation. There was no chance of utilizing the existing foundation for the S&T exchanger alternatives, so iterations settled on approach temperatures in the 8-10°F range to ensure a practical design. Coincidentally, the final PCHE and S&T designs had similar thermal performance in the end, despite the different limitations.

Simulations were performed to determine the effect of different exchanger types on maximum achievable NGL recovery. Up to 80% of design feed rate, there is no impact, because there is sufficient heat exchanger surface and propane refrigeration available to compensate. Even above 80% of design feed rate, the impact on propane recovery is negligible, and ethane recovery losses are estimated to be only 2-4% because of overdesign in other parts of the plant.

The shell and tube exchangers were quoted as stainless steel to be conservative; it is possible that carbon steel could be considered for the bottom reboiler, though an upset condition where cold liquids drop down the tower would have to be considered. Although multiple S&T designs were quoted, the cost estimate was based on exchangers with U-tubes, which was considered to be the most robust design in terms of thermal stress.

Ultimately, four cases were considered in the evaluation:

- 1) Maintain existing BAHX design
- 2) No NGL Product Exchanger, separate BAHX for side and bottom reboilers
- 3) No NGL Product Exchanger, replace BAHX with two S&T
- 4) No NGL Product Exchanger, replace BAHX with two PCHE

The evaluations were done based on current plant rates, since it is not anticipated that the plant will operate at significantly higher rates in the near future. For this reason, no loss was applied due to reduced recovery with the S&T and PCHE designs.

A comparison of the costs associated with all options is presented in the following table, based on the experiences since the current BAHX was installed in 2020. The following assumptions were made to develop this comparison:

- Any change from the existing BAHX design will require piping and / or plot modifications. FEL-II level costs estimates were done for the S&T and PCHE options. The option with separate BAHX was not as fully developed. A TIC / capital cost factor of 3 was assumed to estimate installation / piping costs for this option.
- It is assumed that a S&T or PCHE exchanger would not require any repairs or related downtime in the time period considered.
- It is assumed that even if the side and bottom reboilers are split into separate BAHX, some repairs will still be required since the plant is running ~50% of design rates and there is currently no mitigation for the upstream pigging issues. For the purposes of comparison, it is assumed that the units would not require replacement, but would require repairs and

downtime at 50% of the cost of the existing unit. Some minor penalty due to reduced recovery was also assumed.

- Assumed a 2 week outage for installation of any new HX type

Table 2: Relative Cost Comparison since 2020 for Brownfield Case Study #2

	In Kind BAHX Replacement	Individual BAHX for Side and Bottom Reboilers	Individual S&T for Side and Bottom Reboilers	Individual PCHE for Side and Bottom Reboilers
Cost Estimate Development Level	N/A	FEL 0	FEL II	FEL II
Delivery	75 weeks	65 weeks	50-58 weeks	52 weeks
Relative Weight (HX only)	1	0.4	2.9	0.6
Cost				
Initial TIC incl downtime	1.2	6.1	13.4	9.7
Losses / Repairs	15.7	6.4	0	0
TOTAL	16.9	12.6	13.4	9.7

The evaluation indicates that there is financial incentive to move to a different exchanger configuration. Based on cost, and the ability to minimize reboiler return line lengths, the plant is moving forward with replacing the side / bottom reboilers with two PCHE.

Technology Selection for New Plants

BAHX have been established as the technology of choice for heat transfer in cryogenic NGL recovery units, and with good reason. They are economical and offer superior heat transfer efficiency in a lightweight and compact design. However, failures are not uncommon and are often difficult to anticipate.

Industry experience suggests that the side and bottom reboiler BAHX are the most subject to leaks / failure. Future gas plant projects may consider alternatives to BAHX for the side / bottom reboiler service. The additional cost will need to be weighed against the project's risk tolerance, understanding that the circumstances leading up to most failures would not have been anticipated at the start of the project.

Factors that might steer the decision away from BAHX:

- If the plant is expected to be a swing plant (alternating between recovery and rejection)
- If the plant is expected to operate below design rates for a significant period of time
- If there are unavoidable upstream operations that will cause the inlet flow transients
- If regular upsets due to the configuration of inlet/outlet compression or the configuration of compression in the field are anticipated
- Want to minimize risk of unplanned cost and outages

If a BAHX is retained as the design for a new plant, consideration should be given to purchasing a spare unit and / or ensuring interchangeability with other available plant exchangers / spares. New plants with BAHX should be designed to ensure good accessibility to the side / bottom reboilers to facilitate quick repairs.

General Technology Comparison

Table 3 provides a general comparison of the heat exchanger technologies considered in this paper.

Table 3: Heat Exchanger Technology Comparison for Cryogenic NGL Recovery Plants

	BAHX	PCHE	S&T
Reasonable Min Approach Temperature, °F	2-4°F	5-9°F	15-30°F
Lead time	65 weeks	~60 weeks	30-42 weeks
RELATIVE COMPARISONS			
Equipment Cost (not including installation)	1	3-3.5x	1.5-2x
Weight	1	1.5x	3.5x
Plot space	1	1.4x	4x
PROS & CONS			
PROS	<ul style="list-style-type: none"> • Compact • Low Cost • Heat transfer efficiency • Lowest weight 	<ul style="list-style-type: none"> • Compact • Much less susceptible to thermal fatigue • Integrity not meaningfully impacted by off design operation • High design temperatures • Better heat transfer efficiency than S&T, only slightly less than BAHX 	<ul style="list-style-type: none"> • Delivery times shorter • More suppliers • Not prone to thermal fatigue • Integrity not meaningfully impacted by off design operation • High design temperatures
CONS	<ul style="list-style-type: none"> • Long Lead Times • Susceptible to thermal fatigue (leaks failures) • Integrity suffers with off design operation • Prone to plugging • Susceptible to mercury attack • More susceptible to damage from ice / hydrates • Limited to 150°F 	<ul style="list-style-type: none"> • Cost • Long Lead Times • Limited Suppliers • Less familiarity • More at risk of plugging than S&T 	<ul style="list-style-type: none"> • Plot space • Lowest heat transfer efficiency, could impact refrigeration load or recoveries

Conclusion

BAHX have been established as the technology of choice for heat transfer in cryogenic NGL recovery units and they continue to be an excellent choice for the application. However, when the risk of a failure is considered high, or when repeated failures have occurred, it is worthwhile to consider alternatives. The higher capital cost of a different heat transfer technology could be offset by reduced downtime, avoided repairs and replacements, and avoided reductions in NGL recovery. Each application needs to be considered independently, since individual evaluations will be impacted by the specific commercial terms and operational requirements of the facility.

References

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