Smart Layer® Saves the Day (Twice!)

Two Case Studies of Smart Layer in Action and a Recent Design Improvement

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Adam McNeilly
Chart Industries
La Crosse, WI, United States

ABSTRACT

Two Brazed Aluminum Heat Exchangers (BAHX) equipped with Chart patented Smart Layer® technology performed flawlessly when Smart Layer indications revealed thermal fatigue damage prior to loss of containment. This case study demonstration of Smart Layer functionality confirms the value this feature brings to operations through enhancing safety, improving predictability, and protecting against loss of profitability. Additionally, an exciting new development in Smart Layer design is shared.

Introduction

Two Brazed Aluminum Heat Exchangers (BAHX) equipped with Chart patented Smart Layer® technology performed flawlessly when Smart Layer indications revealed thermal fatigue damage prior to loss of containment. This case study demonstration of Smart Layer functionality confirms the value this feature brings to operations through enhancing safety, improving predictability, and protecting against loss of profitability. Additionally, an exciting new development in Smart Layer design is shared.

Background

Since Smart Layer was introduced to the industry in 2018, many customers have recognized the benefits of having a passive early warning system to detect thermal fatigue damage integrated into their BAHXs. For the vast majority, the presence of Smart Layer providing a silent protective watch over the units continues to go unnoticed. In cases where thermal fatigue has occurred, heat exchangers equipped with Smart Layer technology have alerted operators at the first sign, allowing for defensive action to prevent a more serious loss of containment and emergency plant shutdowns. This article will share two of these success stories, along with other recent developments in Smart Layer design, that demonstrate the value that Smart Layer provides for plant safety and operational reliability.

Smart Layer® Basics

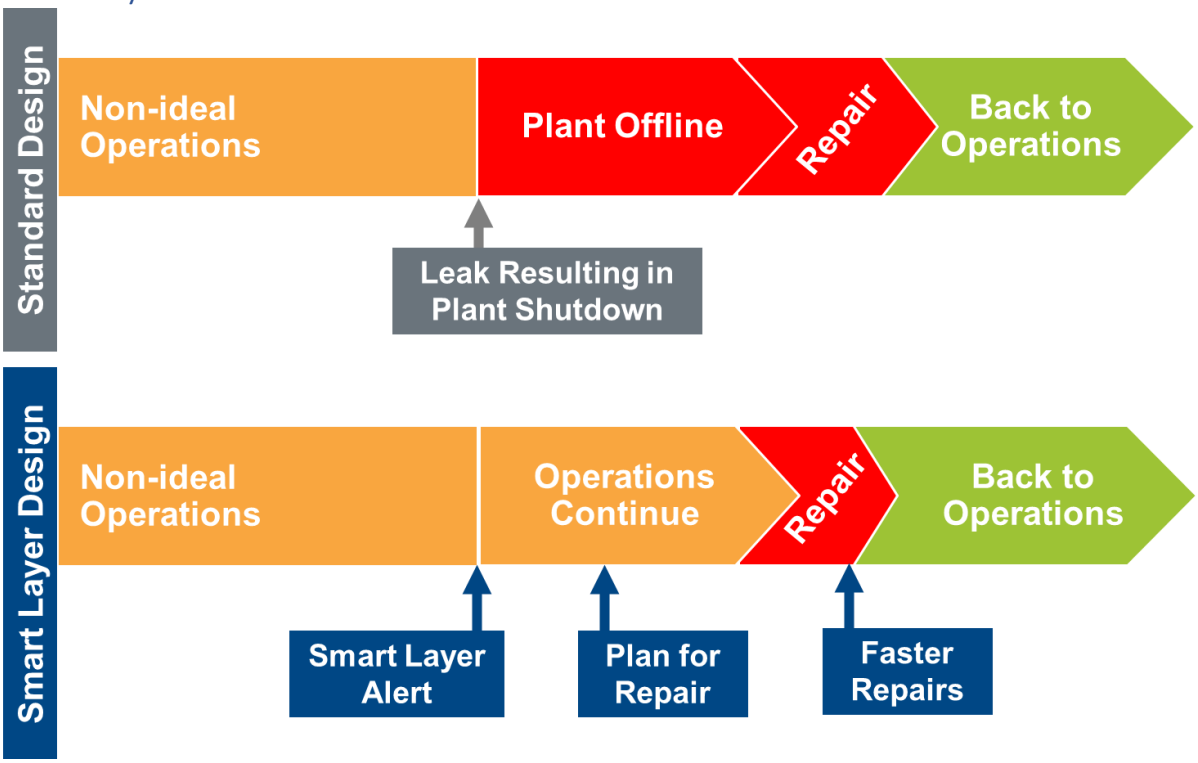

Figure 1: Smart Layer turns emergency repairs into planned repairs

Smart Layer operates on the premise that thermal fatigue typically accumulates fastest in the outside cap sheets and parting sheets. In a typical BAHX, a fatigue crack through a parting sheet would result in cross stream contamination, while a fatigue crack through the cap sheet would result in a loss of containment. A loss of containment incident usually requires an immediate shutdown of the plant, leading to expensive expedited repairs and costing significantly more in lost productivity.

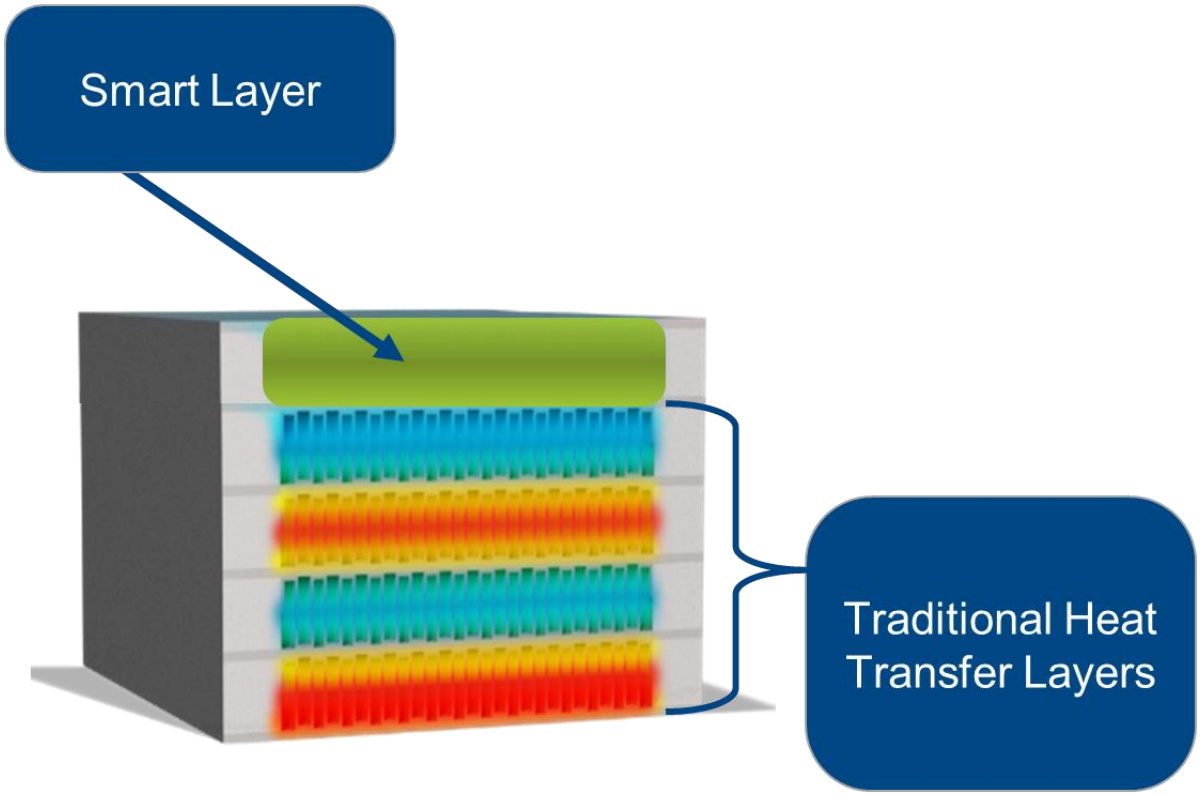

Figure 2: Smart Layer replaces outside dummy layers

Smart Layer is a system of specially designed inactive layers located on the outside of the core block that are charged with nitrogen. By monitoring the charge pressure while the BAHX is in operation, an operator can determine if any cracks have formed in the outside parting sheets or cap sheets. A fatigue crack in the outermost parting sheet would cause the Smart Layer pressure to rise to the pressure of the adjacent active layer, and it would prevent any external leaking of the process fluid by containing it within the Smart Layer. A crack in the cap sheet would be indicated by a drop in Smart Layer pressure. This would only allow the inert Smart Layer nitrogen charge to leak to atmosphere. In either case, Smart Layer alerts the operator that fatigue damage has occurred. Since there is no loss of containment, no emergency shutdown is required. This allows the owner time to plan an orderly repair and assess plant operations to discover the root cause of the fatigue on their preferred schedule.

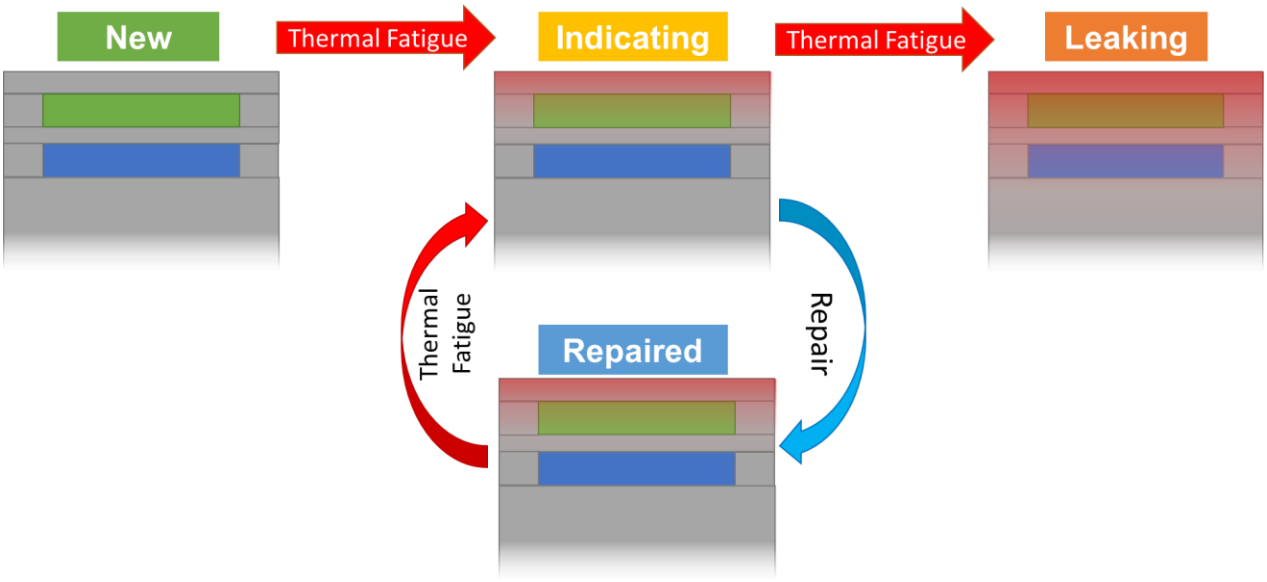

Figure 3: Smart Layer conditions

Thermal fatigue damage can occur under operating conditions that exceed Chart's thermal guidelines, such as during frequent transient events, constant temperature cycling, or unstable flow. This damage occurs preferentially in the outer sheets. When a critical threshold of damage has occurred, a sheet crack will develop, and the Smart Layer condition will advance from New to Indicating. The first crack will result in Smart Layer alerting operators that thermal fatigue damage is occurring, prior to the occurrence of any external leaks. At this point, the owner should review their operating data and schedule a repair, but they may continue to operate.

After repairs, the unit is now in the Repaired condition, there are no external leaks, the Smart Layer functionality is restored, the unit is returned to operation, but it is likely that residual fatigue damage exists in the unit. If no changes to operations were made, the same conditions that caused the initial Smart Layer indication are likely to cause thermal fatigue damage to continue to accumulate until another indication occurs, returning to the Indicating condition. The owner may repair the heat exchanger a second time, although at this point, Chart strongly recommends putting a replacement unit on order. If operations continue in while Smart Layer is Indicating for too long, the damage may progress until an external leak is formed, which is the Leaking condition. At this point, the owner must remove the unit from service until repairs or replacement can be made.

Success Story A

Success story A concerns a demethanizer tower side reboiler designed with Smart Layer technology and commissioned in late 2019. The plant owners indicate that they had previous experience with parting sheets and cap sheets cracking at this plant requiring numerous repairs. The Smart Layer was given an initial charge pressure of ~200 psi. Within a year of commissioning the new reboiler, the first Smart Layer indication occurred.

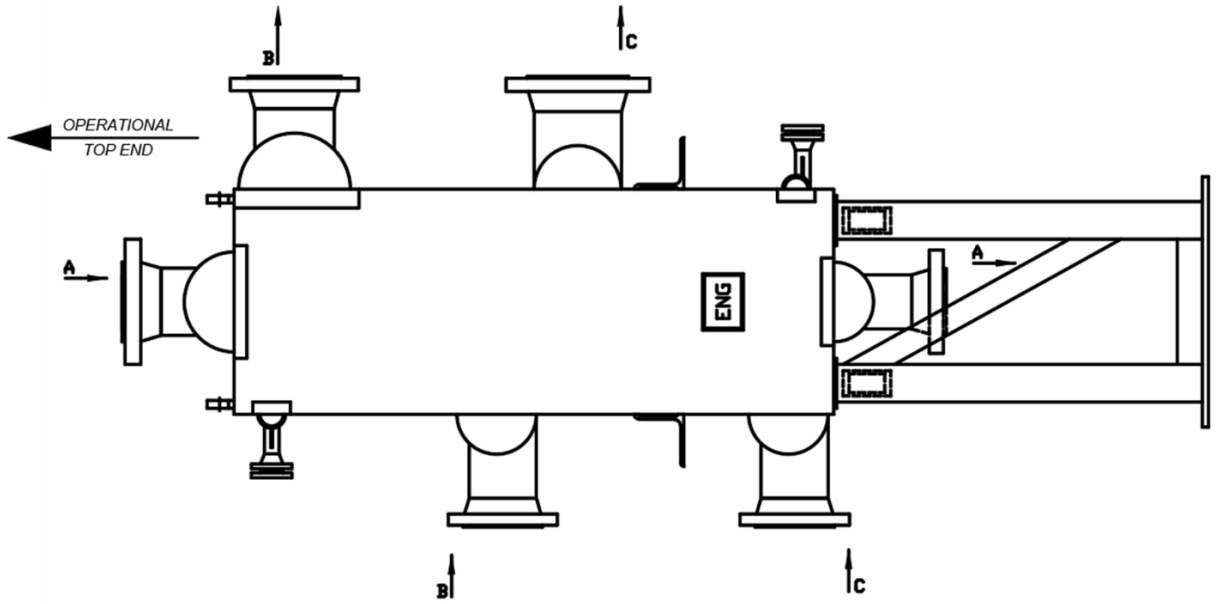

Figure 4: Story A BAHX diagram

First Indication

The first Smart Layer fatigue indication occurred in the middle of 2020 and manifested as a loss of Smart Layer charge pressure. It was discovered that both cap sheets had formed cracks midway up the length of the core, near the inside edge of the bar column. No loss of process fluid containment occurred, and the unit was able to continue to safely operate for several months until repairs were made. The BAHX was repaired by welding the cap sheet cracks closed. The Smart Layer was recharged and the unit was placed back into service with intact Smart Layer functionality in the Repaired condition.

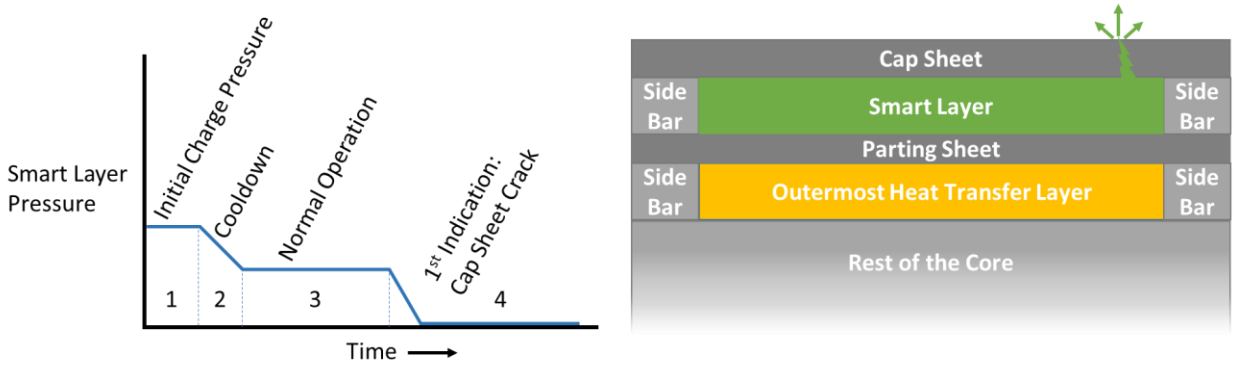

Figure 5: Story A – 1st Indication

Second and Third Indications

After the BAHX was placed back into service, the unit was able to operate normally until the second Smart Layer indication occurred, this time as a rise in Smart Layer pressure. The outside parting sheets between the outermost active stream and the Smart Layer had cracked, allowing

process fluid to leak into the Smart Layer. No loss of process fluid containment occurred, and the unit was again able to continue to safely operate for several months until repairs were conducted.

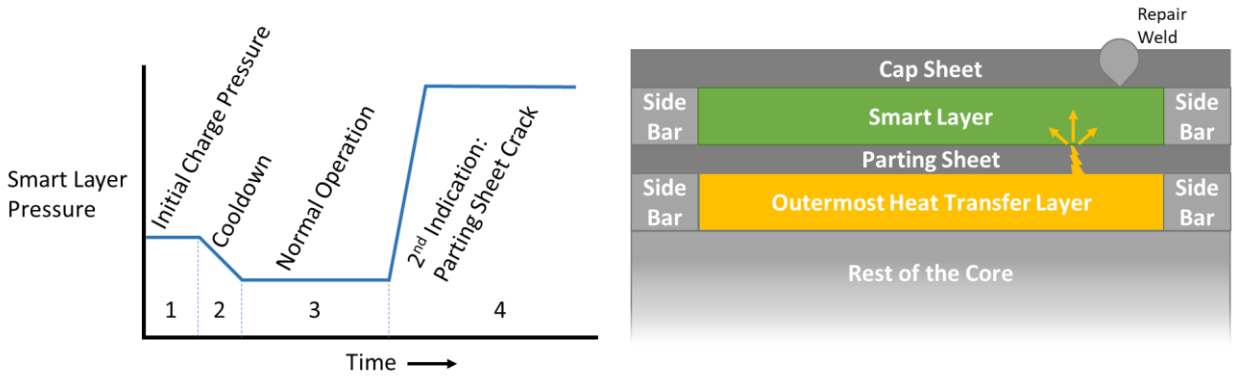

Figure 6: Story A – 2nd Indication

The outermost heat exchange pitches were isolated from their process streams and connected to the Smart Layer, effectively adding them to the Smart Layer inactive layers. This allowed the Smart Layer to again be recharged and continue to operate after the core was returned to service in the Repaired condition.

After another period of normal operation, additional leaks in the cap sheet occurred at the same locations where the original cracks had appeared. This caused the Smart Layer pressure to drop and resulted in the third fatigue indication. Again, no loss of containment happened.

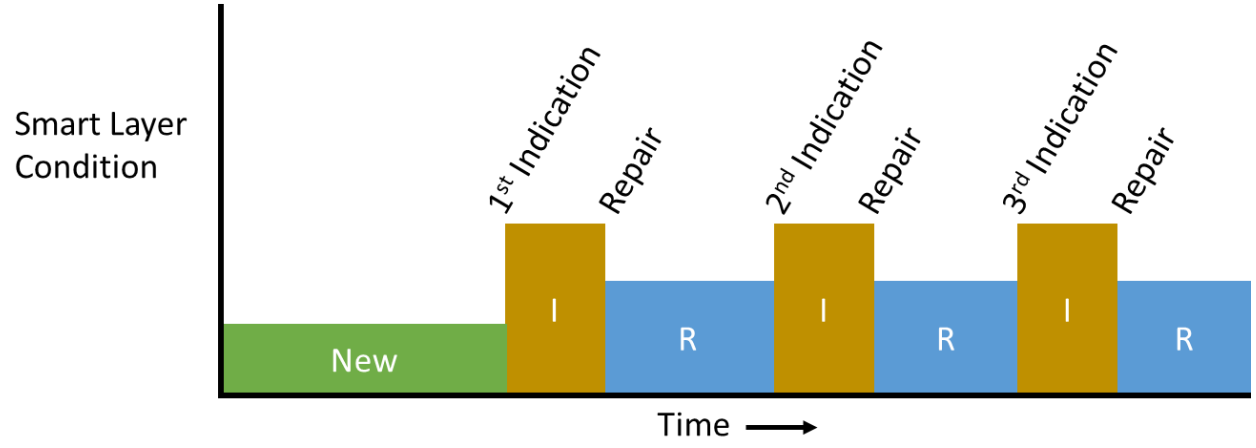

Figure 7: Story A Smart Layer condition progression

Root Cause

Chart performed an analysis of the plant operating data, and although the unit was not fully instrumented, some key insights were identified. Specifically, reboilers are known to be sensitive to outlet pressure variations, and differential pressure measurements can identify when reboilers have entered an unstable flow regime. Although this instrumentation was not installed for this unit, there were indications of unstable flow occurring.

Operators revealed the unit was regularly operated at 50% of design duty. Turndowns have been known to cause unstable boiling and premature failure caused by thermal fatigue in similar reboilers, as identified by the GPA in their technical bulletin GPA-TB-001 and described by Vallee et. al. in their 2019 paper "Best Practices for Design and Operation of Reboilers with Plate-Fin BAHXs."

Success Story B

Success story B involves a replacement side-bottom reboiler designed with Smart Layer that was installed in 2020. The outgoing BAHX was a two-module[1] design that had leaked at the inter-module weld joint.

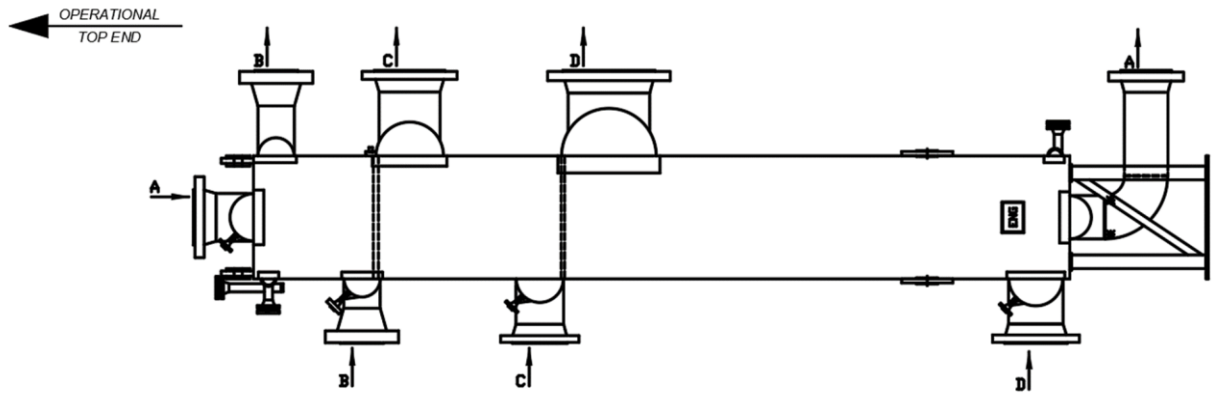

Figure 8: Story B BAHX diagram

First Indication

The first indication occurred in later 2021 when the Smart Layer pressure rose. The plant continued to safely operate until a scheduled shutdown when an inspection revealed a cross-pass leak between the outermost active layer and the Smart Layer. The outermost heat exchange pitches were isolated from their process streams and connected to the Smart Layer. The unit was returned to service in the Repaired condition with Smart Layer functionality intact.

Second and Third Indications

After the repair, the unit operated normally for a year until another Smart Layer indication occurred in late 2022. The inspection report states that a cross-pass leak into the Smart Layer and an external leak from the Smart Layer were found. If found separately, neither of these leaks would cause a loss of containment, but when they are encountered together, they can lead to an external leak of process fluid. Although specific details were not available, it is likely that after the first indication and repair, a second indication occurred and the unit entered the Indicating condition again, and continued operation eventually led to further fatigue damage and the unit progressed to a Leaking condition with an external leak.

[1] A modular core (no longer manufactured by Chart) consists of multiple cores welded together at the cap sheets to form a composite unit. Increases in vacuum furnace sizes now allow many designs that were previously welded module assemblies to be built as single-braze units.

The core was repaired by excavating the cap sheet crack, welding it shut, and sealing outside layers with the cross-pass leaks and venting them to the Smart Layer.

After another period of normal operation, additional leaks occurred in the cap sheet and parting sheets occurred, progressing the unit to a Leaking condition. Repairs were made and the core was returned to service with Smart Layer functionality restored.

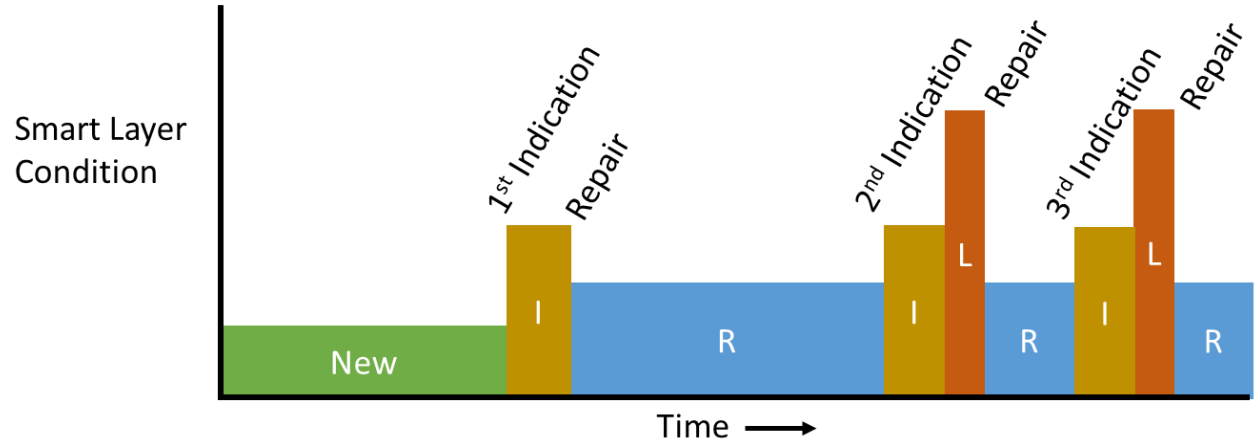

Figure 9: Story B Smart Layer Indication Stage progression

Root Cause

No root cause analysis was performed, but discussions with the customer indicate they were running the reboiler at turndown conditions.

Smart Layer Value Demonstrated

With these two BAHX and their multiple fatigue indications, the Smart Layer system performed as designed:

- Smart Layer functioned correctly for both types of failure modes it was designed to detect: damage to cap sheets and damage to outermost parting sheets.
- It indicated to operators that ongoing fatigue damage was occurring prior to any loss of process fluid containment.
- Each plant was able to safely continue operations after indications occurred.
- BAHXs were returned to service multiple times with the Smart Layer functionality restored.

Other lessons learned:

- Smart Layer technology does not increase or decrease the robustness of the heat exchangers, it simply provides an advanced indication of fatigue damage occurring to the heat exchanger.
- Fatigue is cumulative, and repair of fatigue cracks cannot undo fatigue that has accumulated in other areas of the unit or prevent fatigue from continuing to accumulate in the repaired area.

- If operated in the Indicating condition for too long, the unit can progress to where an external leak occurs.
- Unstable flow is known to cause premature failure to BAHX, especially in reboiler applications. Following GPA and other industry best practices will help get the most life out of the units.
- If no process changes are made, expect the frequency of leaks to increase the more times a BAHX is repaired.
- Per the GPA technical bulletin:

> *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.*

Recent Improvements – Smart Layer 2.0

Smart Layer has recently been improved to offer stronger protection and simplified installation for the consumer. The original configuration of Smart Layer only allowed for the containment of the lowest pressure stream in the BAHX. This limited the protection that Smart Layer offered in terms of stacking arrangements available, leak containment scenarios, and repairability. Additionally, it required a relatively large Pressure Relief Device (PRD) to accommodate for the unlikely scenario where a high-pressure stream communicates with the Smart Layer, which would require continuous venting.

With the recent redesign and introduction of Smart Layer 2.0, it can contain even the highest-pressure streams in the parent BAHX. This removes the limits on stacking arrangements, maximizes the scenarios where potential leaks are contained, and allows for greater flexibility in terms of repairability. It also removes the risk of the unlikely but problematic pressure relief case where a stream with pressure above the MAWP of the Smart Layer leaks into the Smart Layer. This means that the remaining pressure relief scenarios can be protected against with a much smaller PRD.

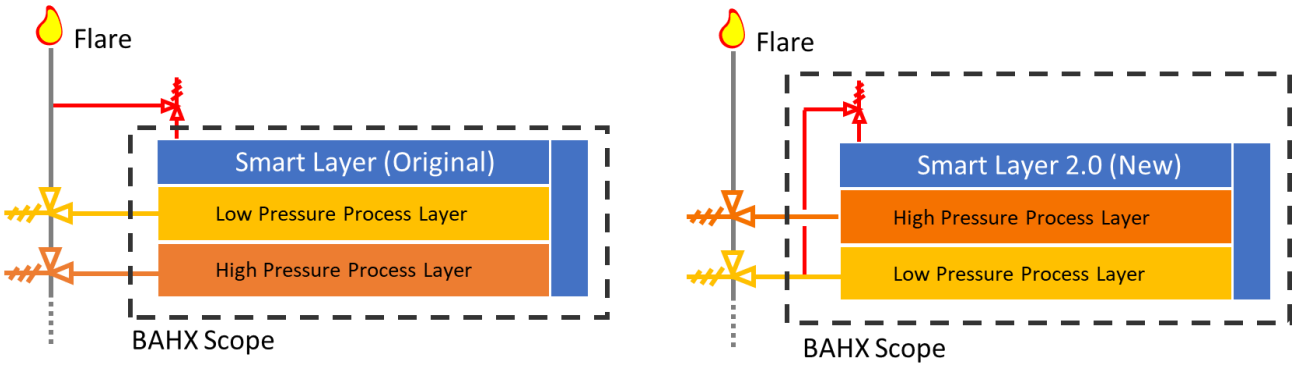

Figure 10: Original Smart Layer configuration vs New Smart Layer 2.0 configuration

With the initial offering of Smart Layer, most owners opted to connect the Smart Layer pressure relief valve to a common flare. This required additional piping design, materials, equipment, and

labor that added significant cost to a Smart Layer installation. The new 2.0 design allows the directs the pressure relief into an active layer stream, where existing plant pressure relief can be utilized. This eliminates the need for Smart Layer specific external venting to flare. Units can ship directly from the Chart factory with the appropriate Smart Layer pressure relief already installed so that the user can pipe up to a Smart Layer equipped BAHX the same as any other unit. Pressure monitoring must still be integrated with the plant DCS system and appropriate alarms configured.

Conclusion

Two examples of how Smart Layer functioned in the field were discussed. In both cases, the system functioned as intended, by:

- Capturing the initial fatigue damage.
- Alerting the operators to the ongoing fatigue damage.
- Containing the initial damage without an external leak.
- Allowing the unit to continue safe operation until repairs could be made.
- Returning to service with Smart Layer functionality intact, ready for the next indication.
- Plant safety was not compromised.

The root causes of the underlaying fatigue damage are suspected to be due to unstable flow caused by prolonged turndown conditions. This is a known cause of BAHX fatigue failure in reboiler applications, as described by GPA and other industry sources.

Additionally, an improvement in Smart Layer design has simplified Smart Layer pressure relief. This redesign allows Smart Layer to use existing plant pressure relief systems to be used instead of requiring a dedicated path to flare.