SUCCESS
In A High-Pressure Refinery Heat Exchanger Diaphragm Removal/Retrofit

Some creative thinking and willingness to take the initiative helped resolve a significant recurring reliability issue, all during a quick turnaround window.

This article describes the successful removal of a tube side cover plate diaphragm (gasket) from a high-pressure heat exchanger. The diaphragm was replaced with a metal pressure-energized seal ring. While the technology has been utilized in piping and offshore applications for several years, this retrofit was its first known application on a refinery heat exchanger of this magnitude. Modification of the cover plate to accept the pressure-energized seal ring eliminated the need to reinstall the metal diaphragm gasket, thereby saving 75% of the reassembly cost of the exchanger.

Taper-Lok®

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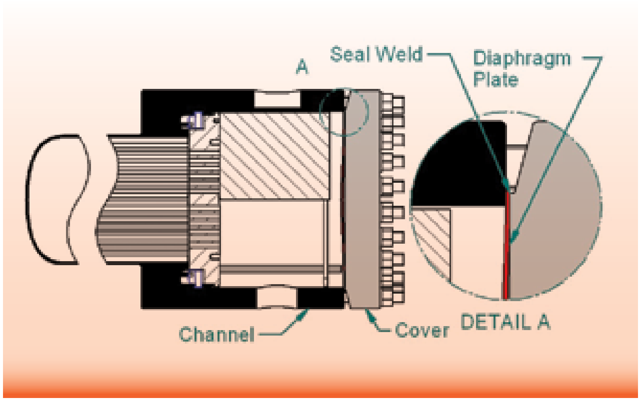

Fig. 1. Schematic of exchanger design with diaphragm

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Utilized in conjunction with mechanical multi-jack bolt tensioners, this innovative retrofit has eliminated a recurring, costly problem (in both maintenance cost and loss of opportunity). This additional reliability coupled with the significant future cost savings from less downtime justified the retrofit—*not including the cost savings foreseen by preventing unplanned outages from the exchanger.*

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The problem

It is not uncommon for diaphragm plates in high-pressure heat exchangers to develop cracks in their seal welds. The diaphragm, which is generally a thin plate of alloy steel, serves as the gasket and corrosion resistant liner for the channel cover (Fig. 1). This arrangement is common for heat exchangers in hydrogen services at operating pressures above 1600 psig in our refinery's Gas Oil Hydrotreater (GOHT) unit. We have had multiple diaphragm leaks over the past several years.

Until recently, the repair process had been the same. It entailed removing the diaphragm, machining the channel face, welding and re-machining a nickel "butter-coat" layer on to the channel face and finally welding on a new diaphragm under controlled heat. This repair would suffice for a time, until some process upset or other anomaly would create another cracking "event."

This procedure had become the standard operation of repair and, in turn, our "insanity clause," as we continued to perform the same repair steps repeatedly, and yet, after returning the exchanger to service, would expect a different result.

Criticality of process [1]

Hydrotreaters process feedstock for fluid catalytic cracking units (FCCU) and hydrocrackers. The economic impact of these conversion units are crucial to a refinery's profit and loss statement as well, maybe even more so than hydrotreaters. Downtime in a hydrotreater forces refinery logistical issues such as throughput curtailments in the FCCU and hydrocracking units. Their close integration to each other (and the bottom line) emphasizes the need for unit availability. Equipment reliability is critical to success.

From a business perspective, hydrotreater units are required to meet the low sulfur fuel specifications that are now in effect. Hydrotreater units are critical to a refinery's balance sheet. The cost associated with taking one out of service can be dwarfed when compared to the potential lost income. Hydrotreaters are often large volume units. The 3-2-1 and 2-1-1 crack spreads have been favorable for refiners in the recent years; even further elevated the last few years following both hurricanes Katrina and Rita.

Hydrotreater units are expensive to build. Their high pressure and elevated temperatures necessitate heavy wall vessels, piping and ancillary equipment. Their severe service often requires exotic metallurgy. The preferred method of fabrication is butt-welding due to material and equipment costs and to prevent possible leak locations. These constraints often minimize block valve installations between equipment and any possibility of isolating or "bypassing" equipment, without taking the complete unit down.

Hydrotreater units also are expensive to start up and shutdown. They are labor- and maintenance-equipment intensive. Large volumes of inert gas are required to cool and protect the multimillion-dollar catalyst beds and equipment. There is always some associated risk involved in starting up or shutting down a hydrotreater unit. Rapid thermal gradients can damage equipment and the repair or replacement time could be several weeks or months.

Why diaphragms crack [2, 3, 4]

Diaphragms are generally fabricated from thin stainless steel (SS) sheets (0.100"-0.125") such as 304 or 304L.

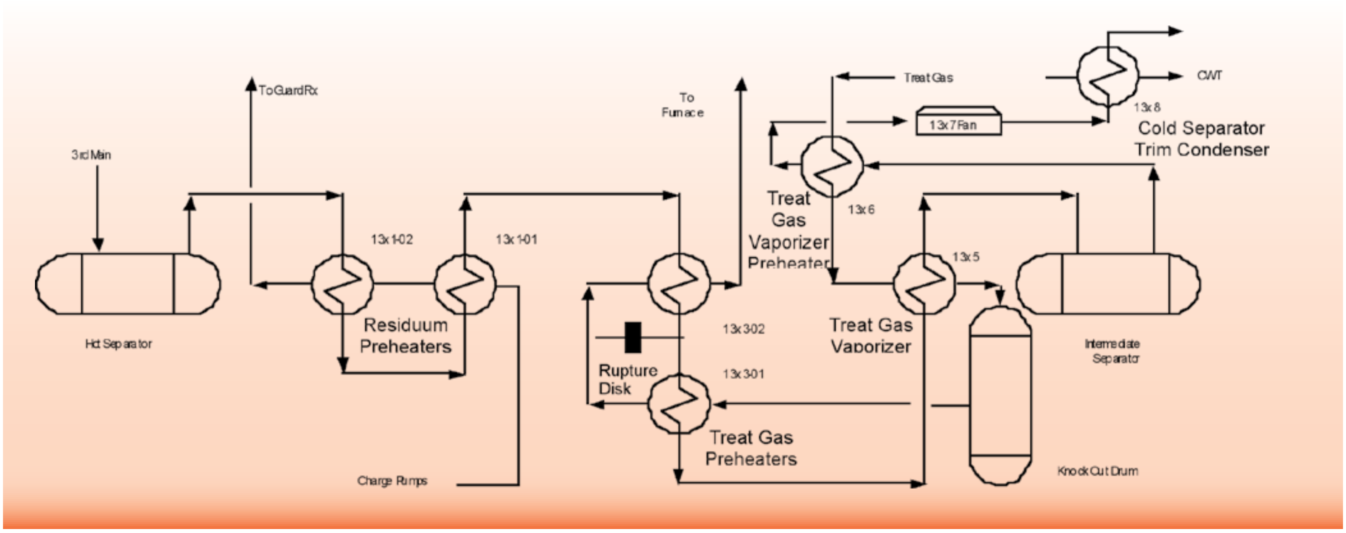

Fig. 2. Process schematic of GOHT single train high-pressure heat exchanger section

Diaphragms are GTAW fillet welded to exchanger channels in a lap-joint configuration along the edge of the diaphragm plate. This joint configuration has limited transverse strength due to the limited size of the effective fillet leg or cross sectional area of the fillet weld reinforcement. Because of the thin diaphragm, there is high welding residual stress adjacent to the weld.

There are several reasons why cracks can develop. They include:

- Tensile overload caused by differences in the thermal expansion of the low alloy steel channel (carbon or Cr-Mo) and the SS diaphragm. Some exchanger channels contain effluent streams up to 730 F and diaphragms can be over 80" in diameter.

- Chloride Stress Corrosion Cracking (SCC) – A salt which drops out in hydrotreater effluent exchangers is ammonium chloride. The diaphragm is susceptible to this failure mode due to its high residual stress. The crevice between the diaphragm and channel contain concentrated chlorides and aggravate the cracking mechanism.

- Polythionic Acid Stress Corrosion Cracking – Hydrotreater effluent systems use austenitic SS for sulfidation resistance. Polythionic acids are formed in the process during shutdown periods when the prevalent metal sulfide scale reacts with oxygen and water condensed during the steam out cleaning process. These acids cause SCC in SS, which is sensitized from welding or from operating temperatures in excess of 750 F.

SCC is the result of combined mechanical stresses with corrosion reactions. The combination of a susceptible alloy, sustained tensile stress and a particular environment lead to the eventual cracking of the alloy. It is difficult to alleviate the environmental conditions that lead to SCC. Chloride levels required to produce stress corrosion are very small, generally below the macroscopic yield stress. The stresses are often externally applied but are quite often residual stresses associated with fabrication, welding or even thermal cycling. Unfortunately, stress relieving heat treatments cannot completely eliminate all the residual stress.

Knowing, and ultimately reducing (or eliminating) the important variables of SCC propagation is the best avenue for success. These variables again are:

- The level of stress,
- The presence of oxygen,
- The concentration of the chloride,
- The elevated temperature and
- The conditions of the heat transfer (often the design).

This failure mode is not uncommon for exchangers of a certain age, design and service. Diaphragm fillet welds encounter high stresses from the combination of high hoop stress and large compressive stresses generated from the cover plate bolting. This cracking is common in the diaphragm welds of high-pressure heat exchangers in hydrotreating units found throughout our nation's refineries and abroad.

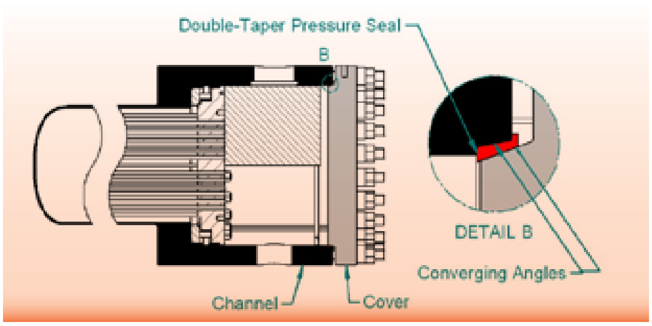

Fig. 3. Schematic of exchanger design with double taper pressure seal [5]

Seeking a solution

Faced with repeated failures of the diaphragm welds in hydrotreater exchangers—*14 exchangers, seven in two separate trains (see Fig. 2)*—and the economic impact of these exchangers to the refinery, developing a solution to this phenomenon became a priority.

The Reliability and Maintenance groups designed or investigated a handful of possible solutions, but none of them received total buy-in. Then, following several months of study, an innovative, alternate solution was identified. It involved eliminating the diaphragm plate entirely and replacing it with the pressure-energized seal ring (Fig. 3). The solution from Taper-Lok® was simple, effective and quite field compatible within the timeframe of a shutdown.

Seal concept…

The Taper-Lok metal pressure-energized seal ring was designed to use on piping applications for topsides of offshore platforms, flow lines, production risers, manifolds, chemical plants, refineries, power generation, supercritical wet oxidation and numerous other practical applications. Most assemblies consist of a male flange, female flange, seal ring, and a set of studs and nuts. The pressure-energized seal ring seats into a pocket in the female flange and is wedged and seated by a male nose located on the male flange.

Utilizing this concept, the exchangers channel cylinder would contain the female pocket, while the channel cover would have the male nose geometry.

In the pre-bolted condition, the Taper-Lok seal ring lip stands off of the face of the channel. The converging seal surfaces are brought together like a wedge during bolt up. This wedging motion forces the seal ring onto the male nose and into the female pocket forcing a compressive hoop stress. Minimal bolt load is required to achieve the required contact stress on the seal surfaces.

The converging angles of the seal ring create a wedge or "doorstop" effect. As the equipment internal pressures increases, the seal seats tighter into this sealing wedge.

Taper-Lok seals are made from the same material as the process equipment (exchanger channel and cover) to ensure that thermal expansions are consistent across all components. The effects of bi-metallic (galvanic) corrosion are eliminated. A baked-on moly coating is applied to the seal to prevent galling.

This promising sealing technology required minor modifications to the heat exchangers. It was simple, reusable, provided a metal-to-metal seal and took very little time to make the modification. This application, however, was unique in that there was no published history utilizing the seal on a refining exchanger of this pressure and severity.

Reliability assessment and risk mitigation

Since this could have been the first use of this type of seal on a fixed equipment cover, a reliability assessment had to be conducted and the risks needed to be identified and subsequently mitigated. All known applications for Taper-Lok pressure-energized seals were researched. These seals, it was discovered, had been used in many different types of connections, including:

- weld neck flanges
- blind flanges
- closures
- clamps
- swivel flanges
- misalignment flanges
- tube sheets

This application was unique in that there was no published history utilizing the seal on a refining exchanger of this pressure and severity.

Fig. 4. Machining pressure seal female pocket with ID mounted tool

Fig. 5. Inserting pressure seal into female pocket

Fig. 6. Hydraulic tensioning and installation of mechanical tensioners

These seals also have performed well in temperatures from cryogenic to 1600 F and at pressures to 40,000 psig. Applications of note included:

- heat exchanger internals
- hydrogen processing
- high temperature measurement equipment
- offshore (both sub-sea and topside)
- high pressure compressor connections

A study conducted by JP Kenny proved to be helpful. It compared the Taper-Lok to standard ANSI bolted connections. While the study did not focus on welded diaphragm connections, it did point out some of the beneficial characteristics of the seal. The results of the study showed that the pressure seal was preferable to ANSI standard gaskets connections.[6]

A design of the seal for one of our heat exchangers was created and calculations according to ASME Section VIII, Division 1 Unfired Pressure Vessels [7] were conducted to ensure code compliance. Because the seal is self-energizing, the gasket factor “m” and the minimum design seating stress “y” are both zero, the required bolt load is reduced and equals the hydrostatic end load of the closure only.

A finite element analysis (FEA) was conducted by an independent third-party engineering firm.[8] Analysis consisted of both 2D and 3D nonlinear models with contact elements. Both models showed a wide contact area with pressures at the sealing surfaces to be in excess of 20ksi. The analysis verified that the seal would be kept in an elastic state and that the stresses in the components would be below code the allowable limits.

Even though all data suggested that the Taper-Lok seal would work in our application, we were still concerned with the possibility of a leak or failure of some sort. Without published history, we needed a fallback plan. It was determined that when we implemented the Taper-Lok sealing system in one of our exchangers, we would build a new channel cover with the male nose geometry as opposed to retrofitting our existing closure. This would then require only the cutting of the female pocket into the exchanger channel. In the event of something unexpected showing up during the retrofit, we could reuse the old closure and weld back a diaphragm plate and seal the opening as we had always done.

Implementation

Description of modification…

The modification centered on the elimination of the welded diaphragm gasket and implementation of the double angled pressure seal.

Simple modification procedure…

1. Remove/replace channel cover plate

A new channel cover plate was fabricated to reduce downtime. Originally, the existing channel cover plate was to be modified via a rapid turnaround machining effort to allow the cover to accept the tapered pressure seal; a minor effort that was not difficult. The original channel cover plate was salvaged for modification and installation on the sister exchanger in the second train. It was also available to reinstall if any unforeseen problem existed with the retrofit.

2. Remove metal diaphragm gasket/seal

The diaphragm seal was removed in a multi-step process that began with drilling a hole through the diaphragm and performing a safety check for any residual hydrocarbon. Once complete, the center of the diaphragm was removed by arc gouging, being careful not to cut close to the inside diameter of the channel. The remaining diaphragm, including the fillet weld that attaches the diaphragm to the channel, were machine cut from the channel. The channel was also faced to insure a true, flat surface.

3. Field machine female pocket into exchanger channel (Fig. 4)

The Taper-Lok pressure-energized seal geometry requires two sealing surfaces. One a female pocket, the other a male nose. The female pocket was machine cut into the exchanger channel while the new, fabricated channel cover plate featured the male nose. During assembly, an additional benefit to the design was observed. This male nose on the channel cover plate configuration acted as a guide.

Following the first retrofit, a second exchanger was retrofit in March 2006. The remaining 12 exchangers are scheduled to be retrofit during the next two scheduled GOHT outages.

4. Insert pressure seal ring into pocket (Fig. 5)

Since the Taper-Lok geometry of the female seal pocket is angled, the seal ring was installed into the female pocket and held in place by fricton, providing a hands free, safe installation of the channel cover plate.

5. Insert channel cover plate on studs and pressure seal

6. Pre-tension studs (Fig. 6)

To ensure that the channel cover plate was assembled square and free from misalignment and to reduce bolt interactions, hydraulic tensioning equipment was utilized. Four tensioners were used at 90 degrees and the tensioners were kept under load while all nuts were installed and hand tightened.

A second deviation from the exchanger's original design was applied at this time. In lieu of the traditional heavy hex nuts, mechanical multi-jack bolt tensioners were utilized. This also proved quite fruitful as torque wrenches were then used to apply the proper torque required to seat the pressure-energized seal ring. The traditional impact (and accompanying crane used to hold it in place) was rendered obsolete.

Hot torquing was not necessary after the installation, even after the unit had gone through a few cycles. This is attributed to the spring effect that the seal and component geometry create during and after seal seating. This spring effect refrains the bolts from relaxing.

Conclusion

Several benefits were realized from this retrofit using the Taper-Lok® sealing technology. One of the most important benefits was the elimination of the diaphragm cracking, which, in turn, increased equipment reliability and unit availability. Since the Taper-Lok seal is fabricated from the same material as the pressure parts (channel and cover), bi-metallic or galvanic corrosion cannot occur. All thermal expansion observed during operation is constant. The new seal or "gasket" remains in compression and in an elastic state. The seal is self-energized, creating a tighter seal with any increase in pressure. Elements that promote the cracking are eliminated.

Following the first retrofit, a second exchanger was retrofit in March 2006. The remaining 12 exchangers are scheduled to be retrofit during the next two scheduled GOHT outages.

Additional benefits—*some initially unforeseen*—were the reduced costs or downtime from several items, including:

- the reduction in the exchanger turnaround time from six shifts to three shifts
- the utilization of one crane in lieu of two (one for cover plate and one for impact)
- the elimination of any hydrogen bake out from weld contamination and weld dilution on alloy exchangers with a stainless steel corrosion overlay

- the elimination of machining of weld buildup (Nickel butter coat)
- the elimination of seal weld and metal diaphragm seal
- the elimination of NDE to search for cracking throughout the entire process

Downtime has decreased since the root cause of the process leaks (cracking of diaphragm welds) at the cover have been eliminated. The retrofit was deemed a success. No downside opportunities have been observed or foreseen.❖

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6. OTC 15276 "Large Diameter Flanged Connection Make-Up With Zero Reworks," John W. Aaron III and Waverly L. Johnson, Taper-Lok® Corp.

7. 2004 ASME Boiler and Pressure Vessel Code Section IIII, Division I, Unfired Pressure Vessels, Mandatory Appendix 2, Table 2-5.1, Gasket Material and Contact Facings

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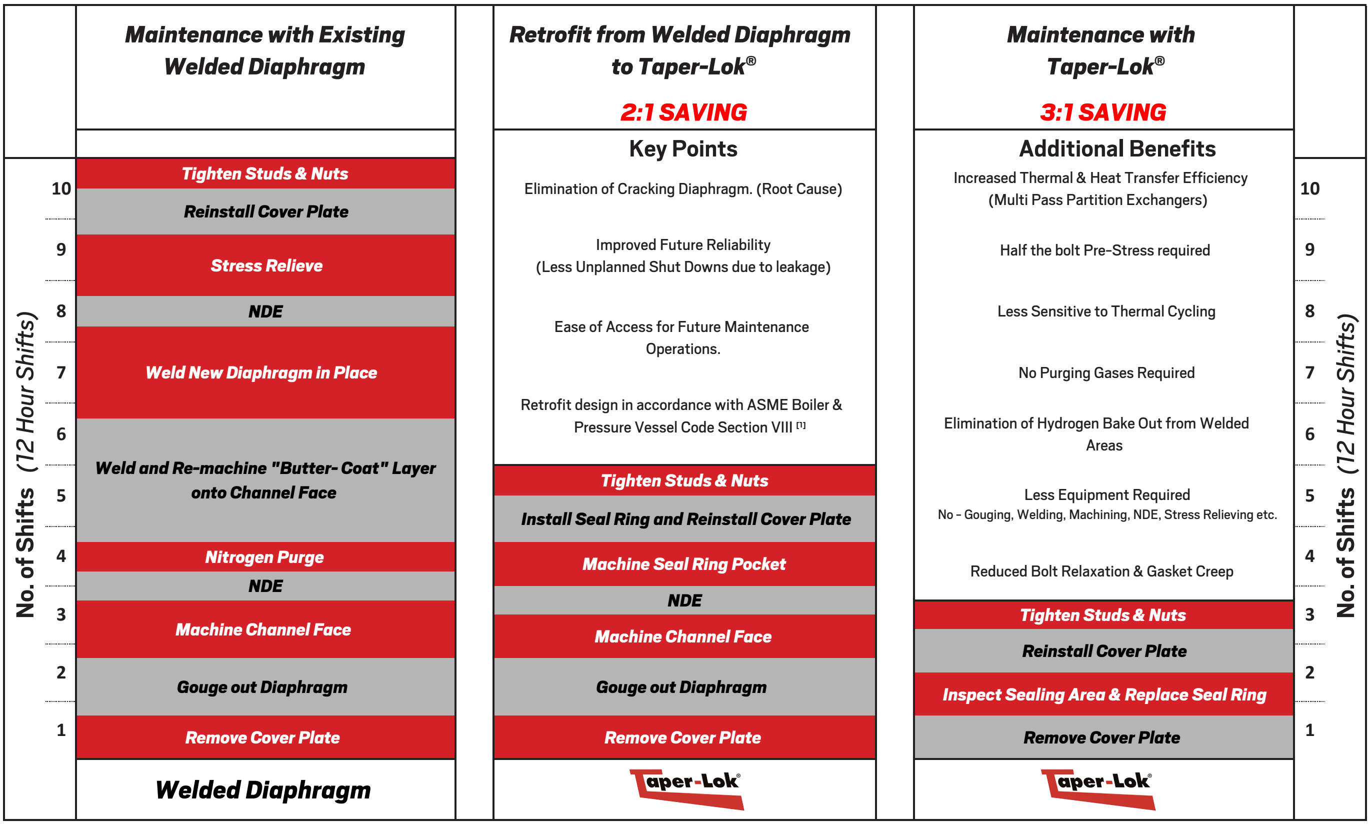

ROOT CAUSES OF WELDED DIAPHRAGM FAILURE THAT ARE ADDRESSED BY THE TAPER-LOK SEALING METHOD

- ☒ *Tensile Overload caused by difference in thermal expansion between Low Alloy Channel & Stainless Steel Diaphragm.*
- ☒ *Chloride Stress Corrosion Cracking (SCC) - Aggravated by concentration of Chlorides in the crevice between Channel & Diaphragm.*
- ☒ *Polythionic Acid Stress Corrosion Cracking due to Stainless Steel becoming sensitized by welding operations.*
- ☒ *Galvanic Corrosion between dissimilar metals.*

[1] *Independent 3rd Party analysis of methodology & interpretation of the ASME code has been undertaken by a PE and is available upon request.*

Taper-Lok Service Commitment

Our clients deserve a service commitment that does not end with installation.

AFGlobal not only provides complete product training, installation and field repair instructions, but also project management support, product design and design calculations... all while providing leak-free service for the life of your connector. Taper-Lok's® oldest connectors have been in operation more than 40 years with combined leak-free service of over 200 million hours without failure.

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