HEAT EXCHANGE ENGINEERING

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Developments in Gasket Sealing Technology for Girth Flanges on Shell and Tube Heat Exchangers

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Abstract

Achieving and maintaining a successful seal in shell and tube heat exchanger girth flanges can present significant challenges, esp. in critical service applications involving high temperatures and pressures. Conventional gasket technology based on metal jacketed, kammprofile and spiral wound gasket designs have been used with varying degrees of success for many years. Each possessing different mechanical characteristics that give rise to areas of both strengths and weaknesses with respect to long term seal performance. Sealing in cyclic service can be particularly problematic, inherent fluctuations in axial load and radial shear stresses can lead to premature seal failure, particularly across commonly bolted tube sheet connections. In addition, economic pressures continue to push refinery and petrochemical operators to increase efficiencies, often resulting in extended production cycle times between planned maintenance events. Recent development work has led to the introduction of a novel gasket, herewith referred to as the dynamic recovery gasket, incorporating design features of both spiral wound and kammprofile sealing technology. The dynamic recovery gasket has been shown to offer significant improvement in long term sealing performance under cyclic operating conditions when compared to conventional gasket styles in both laboratory and field service environments. This paper reviews the most commonly used gasket styles in heat exchanger girth flange connections and discusses the development and benchmark testing of the dynamic recovery gasket design. Field service performance is discussed with particular emphasis on a refinery process known as vis-breaking where variability in the quality of crude feedstock and seasonal changes in product demand pose particular challenges in maintaining long term seal integrity.

Introduction

Historically flange design calculations found in shell and tube heat exchanger design codes such as BS EN 13445 section 11, ASME VIII Division 1 & 2 mandatory appendix II, PD 5500 Section 3.8 and TEMA standards approach the question of non-standard flange design using the Taylor Forge method. The Taylor Forge method has been around since the 1930's and entails the use of a simplified version of classical plate and shell stress theory. By applying known boundary conditions it is possible to calculate moments and stresses in various parts of the flange and ensure they are kept within defined limits. With regard to mechanical integrity this approach has proved successful as is afforded by its worldwide acceptance. The approach requires that the two conditions are considered; assembly and operation. Basic gasket data is required in the form of 'Y' and 'm' factors. The gasket 'Y' factor defines the minimum seating stress of the gasket at what is effectively zero internal pressure while the 'm' factor defines the relationship between the gasket stress and working pressure. The gasket factors, as of which to-date have no standard test procedure for their derivation, are used to calculate the amount of bolting required for the assembly and design condition and also to confirm mechanical compliance. They offer no guidance with respect to long term seal integrity, nor do they offer any specific guidance with regard to what might be the most appropriate gasket to select. For example no guidance is given as to what the maximum permissible assembly and/or working gasket stress might be; or how different gasket styles give improved levels of sealing performance under conditions of fluctuating stress that may occur during start-up, shut downs, normal operational conditions or during un-planned process trips or excursions.

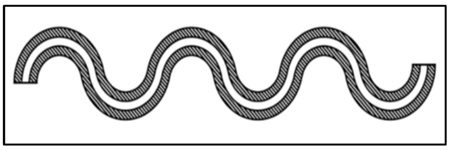
Although alternative non-mandatory design approaches can now be found as informative appendices in some pressure vessel standards non-standard flange design found in codes such as ASME VIII, EN13445 and PD5500 they are not intended to predict connection leakage behaviour, their primary purpose is to ensure the mechanical integrity of the vessel.

In the refining sector increasingly stringent emissions legislation, requirements for increased process flexibility, the ability to handle varying qualities of feed stock (crude oil) and increased operating cycle times between scheduled maintenance outages all place increasing demands on the exchanger girth seal. Various gasket styles are used in these typically spigot to recess (TEMA type) connections. For the purpose of this paper we will limit the gasket review to those used in more demanding applications, typically at temperatures in excess of 200^{o}C and pressures above 10 barg.

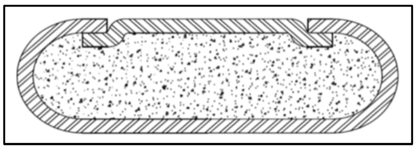
Gasket Styles

The most common gasket styles used in shell and tube body connections are one of four types:

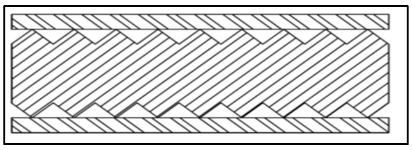
Corrugated metal gasket (CMG), see section detail. This is a relatively low cost gasket fabricated from a concentrically corrugated thin piece of metal usually austenitic stainless steel with a defined corrugation pitch and height. This is then faced with a thin layer of sealing material – typically graphite. This style of gasket seats at a relatively low stress, however it offers little resilience in cyclic service and is not suitable where seating land width may be restricted. Sheet metal size restrictions can limit single piece gasket size. Welding and dressing is difficult and if not carried out correctly can give rise to radial leak paths



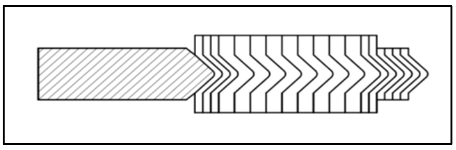
Double jacket gasket (DJ), see section detail. Despite its inherent limitations this gasket is commonly found in heat exchanger applications. It is fabricated from a thin metal jacket comprised of a box and lid. The jacket encapsulates a non-metallic filler such as millboard or graphite. This type of gasket effects a metal to metal seal requiring relatively high localised stresses and good, smooth mating surfaces. Stress raising nubbins are sometimes used to ensure sufficient gasket stresses are generated. It offers little resilience in cyclic service. Size is limited as welding and dressing to a good finish suitable for metal to metal sealing is required.



Kammprofile gasket (Kamm), see section detail, is comprised of a solid metal ring typically 3 mm thick with precision machined serrated contact surfaces that are faced with a soft sealing material. Materials of construction can vary but austenitic stainless steel with soft graphite are typical in the refining sector. Gasket seating stresses are very low and the solid metal core confers high load bearing capability. Larger gaskets using ring rolling and fusion welding techniques are possible without compromising seal integrity. Resilience is limited, however the relatively high stiffness and creep resistance of the resulting connection can generate useful bolt strain that ca be beneficial in cyclic service conditions.



Spiral wound gasket (SWG), see section detail, is manufactured by winding two strips of material, one metal one non-metal around a circular mandrel. The strips are formed into a chevron style profile immediately prior to winding. Resistance spot welds around the periphery of the gasket at the start and end of the winding operation lock or fix the resulting structure. Modifications to the gasket to suit TEMA type flanges include an inner ring compression stop and locating nose. Typical material combinations are austenitic steel and graphite. Compression stop requirements can give rise to sizing issues in narrow land width connections. Larger gaskets can be difficult to handle and install. Performance in cyclic service can be improved by

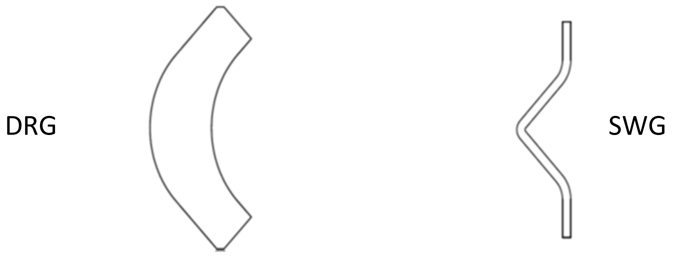


modifying construction parameters, however when constructed to ASME specification resilience in cyclic service can be compromised

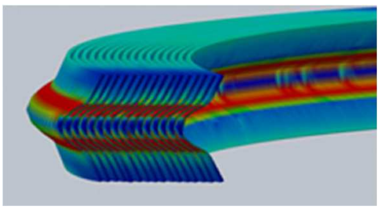
Dynamic Recovery Gasket (DRG)

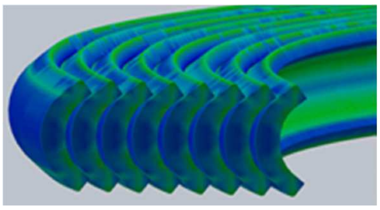
A lengthy and rigorous development programme resulted in a unique gasket style based on a combination of both spiral wound and kammprofile functionality. The gasket is wound, like the SWG however the metal winding strip differs fundamentally in its geometry. The unique shape is formed in a separate manufacturing process. A comparison of the wire sections highlights the fundamental differences

Wire profiles



The dynamic recovery wire profile is curved and not uniform in thickness across its section such that when wound results in a structure which, when placed under a range of axial stresses typical of those in service, dissipates the stress in even manner compared to the traditional SWG. The SWG profile can be particularly prone to high areas of stress being generated around the nose area of the wound gasket giving rise to permanent or plastic deformation under cyclic loading conditions. The following simulation where high stresses are shown in red visually illustrates this effect;

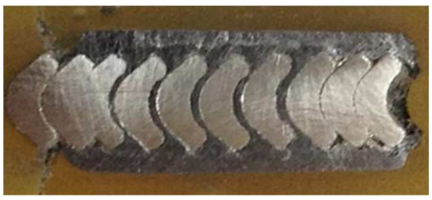




SWG under load

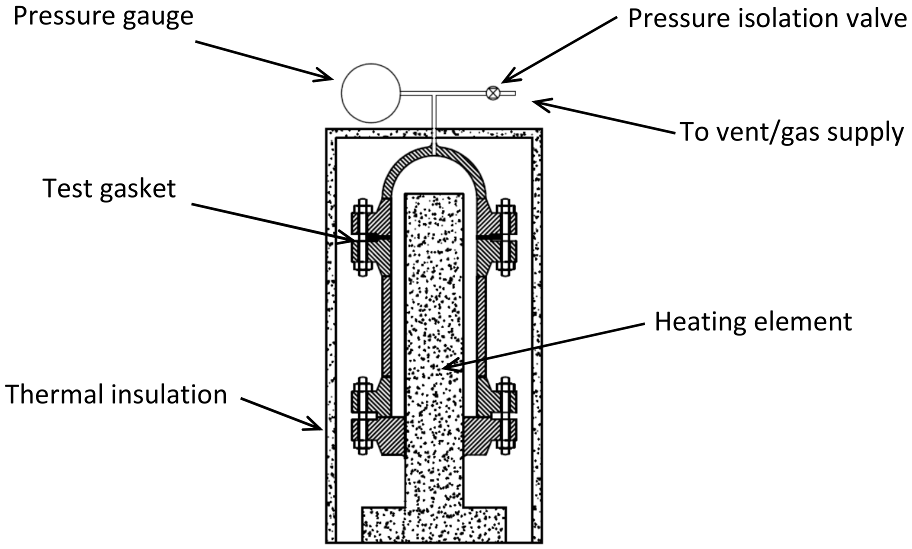
Dynamic recovery gasket under load

In addition to improvements in resilience the unique wire profile, on winding results in a serrated contact face, similar to that observed on kammprofile gaskets. Facing of these surfaces with a soft sealing material, such as graphite has the beneficial effect of reducing the seating stress of the gasket, improving tightness and improving the gaskets ability to effect a seal on damaged flange sealing faces. The sectioned photograph clearly illustrates resulting serrated sealing faces of the dynamic recovery gasket.



Benchmark Testing

Benchmark testing of the dynamic recovery gasket was carried out using a modified version of the industry recognized 'Shell Thermal Cycle Test'. The test is part of Shell's type approval test programme for gasket qualification. The test is carried out in two parts; an ambient leakage test phase, followed by a set number of leakage tests carried out under elevated temperature conditions. The test rig is cooled to room temperature and depressurized between each high temperature leakage test exposing the connection to a thermal cycle. A schematic of the test rig is given below:

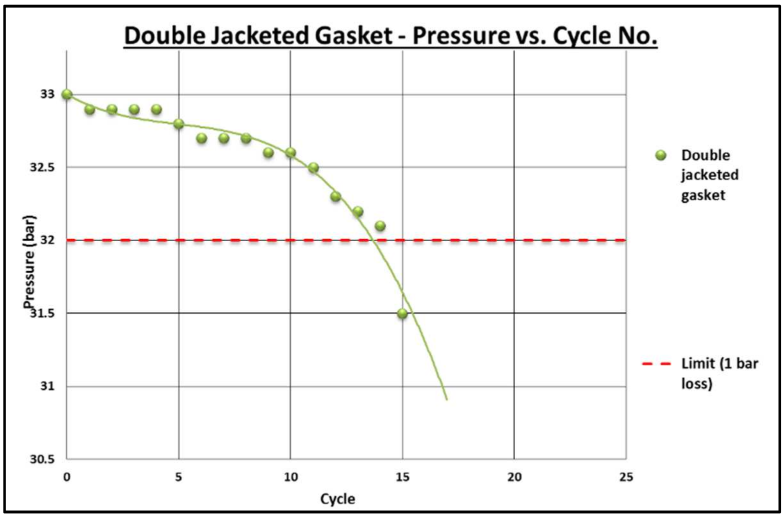


The test gasket is installed between a pair of ASME B16.5 RF WN flanges fitted with ASTM A193 B16 stud bolts. The bolts are tensioned to induce an assembly stress of 290 N\mm^2 (42 ksi). The test rig is then pressurized to 51 barg (N_2) and allowed to stabilize. This is followed by an ambient temperature pressure decay test over a 1 hour period, during this test the pressure should not fall by more than 1 barg. Successful compliance of the ambient pressure test is followed by elevated temperature testing. The rest rig is depressurized and heated to a defined temperature, 320^{o}C, at a rate of 2^{o}C/min. When at temperature the test rig is pressurized to 33 barg and allowed to stabilize this followed by an elevated temperature pressure decay test over 1 hour, the maximum allowable pressure drop is 1 barg. The rig is then depressurized and cooled to room temperature and the procedure repeated. At no time can the bolts be re-tensioned.

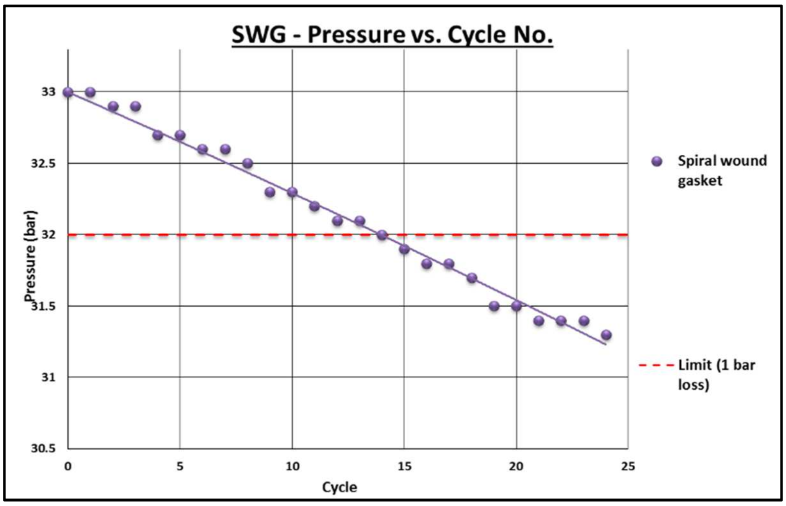
The number of thermal cycles in the standard test is 3, however for the purpose of benchmark testing the number of thermal cycles was increased to 24. This number of cycles was selected following consultation with the refining industry, as being more representative of field service conditions. For comparative purposes the test was carried out using all of the previously discussed, commonly used gasket styles.

Graphical results of Internal Pressure v Thermal Cycle No. are given below. The intersection between the horizontal red dotted line and data line indicate the number of cycles achieved before test failure i.e. pressure drop greater than 1 barg.

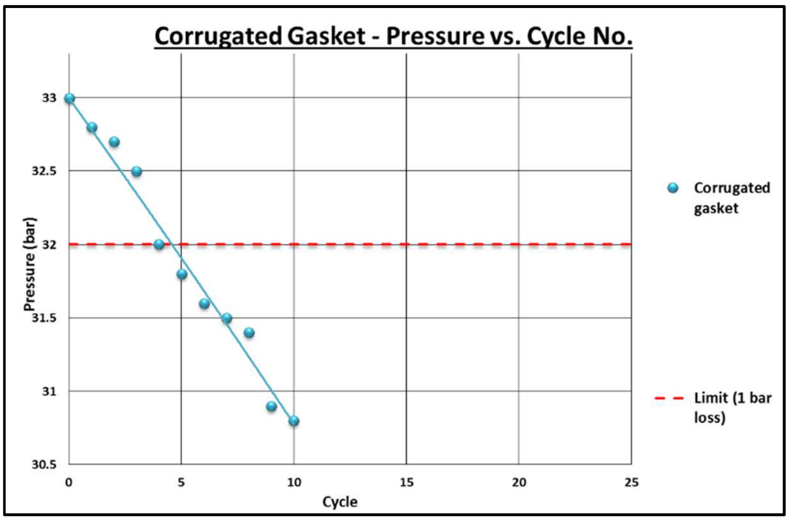
Double jacketed (DJ) gasket 13 cycles before failure. Test terminated after 15 cycles – Gross pressure loss.



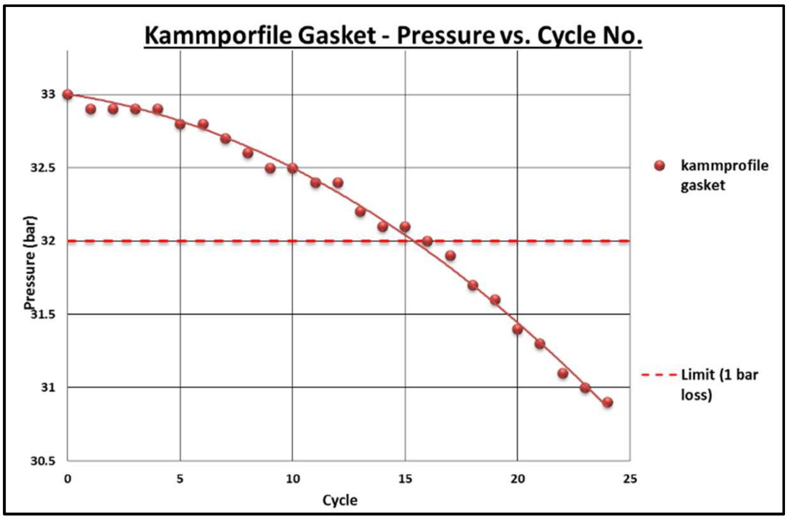
Spiral wound gasket (SWG) 14 cycles before failure. Pressure loss after 24 cycles 1.75 barg



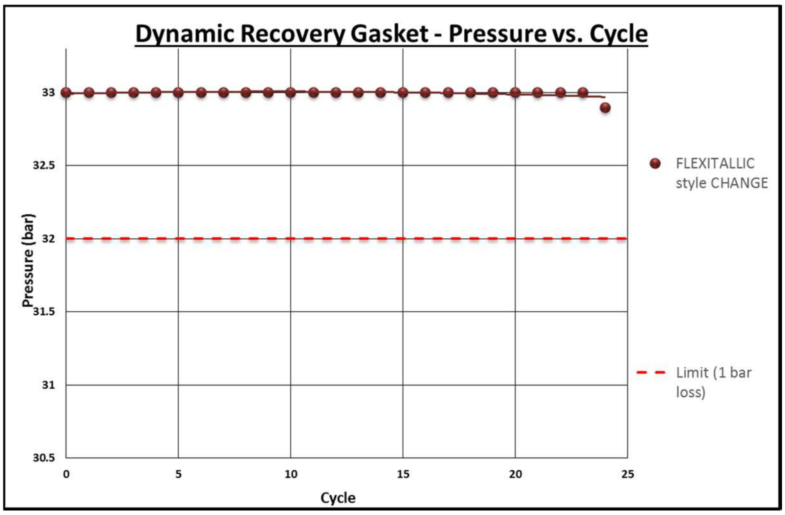
Corrugated metal gasket (CMG) 4 cycles before failure. Test terminated after 10 cycles – Gross pressure loss.



Kammprofile (kamm) gasket 16 cycles before failure. Pressure loss after 24 cycles 2.1 barg



Dynamic recovery gasket 24 cycles, no failure. Pressure loss after 24 cycles <0.1 barg.



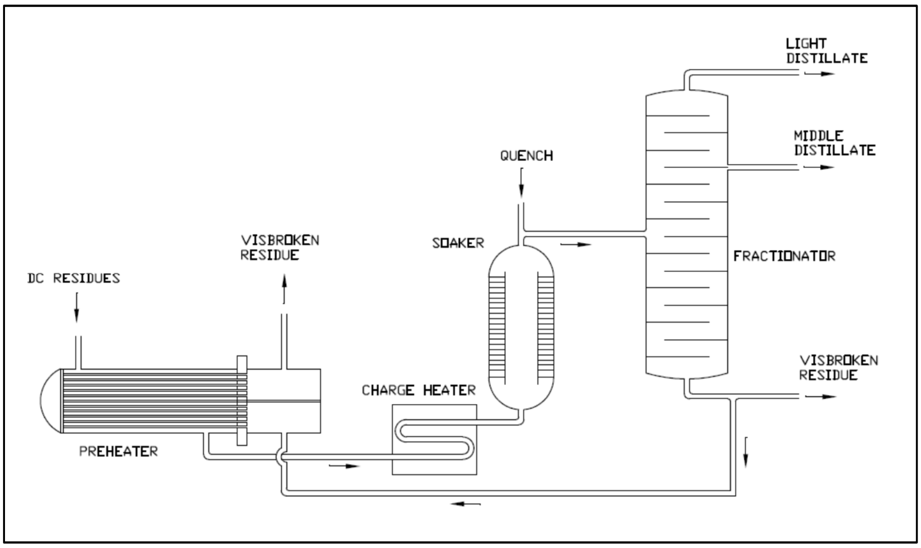
The benefits of the novel dynamic recovery gasket can be clearly seen when benchmark tested in a modified, cycle extended, test regime designed to simulate field service test conditions.

Refinery Based Case Study

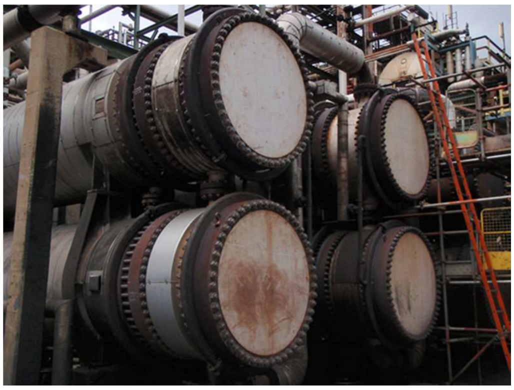
Location: Total LOR Refinery (UK)
Process: Vis-breaker (soaker technology) pre-heating
Exchangers: TEMA R (AES). Design Code ASME VIII Div 1. Approx 35 years old.
Media: Crude vacuum distillation (CVD) heavies (tube side) and vis-breaker residues (shell side)
Design pressure: 38 barg (shell), 36 barg (tube)
Design temperature: 370°C (shell), 390°C (tube)

The vis-breaking is a mild thermal cracking process designed to reduce the viscosity of crude distillation heavy fractions while having minimum impact on the boiling point range, the cracked fractions can then be used for blending with lighter fuel oils. Small amounts of lighter and some middle distillates can also be produced depending on demand. Over cracking is controlled via quenching with cooler gas oil, before flashing over to a fractionation column. Cracked residue that deposits in the bottom of the fractionation column is vacuum flashed in a stripper and the distillate recycled.

Vis-breaking – Simplified schematic;

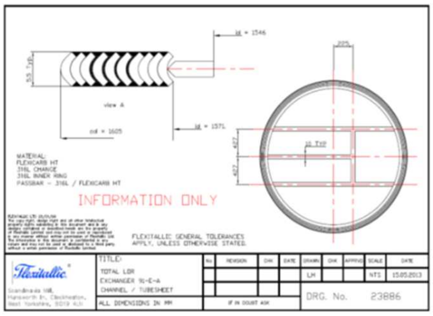


Two horizontal banks of 2 x 2 shell and tube heat exchangers are used to pre-heat CVD heavies prior to vis-breaking. One bank is in operation allowing maintenance of one bank while the other is in service. Exchangers on both banks have been subject to body flange leaks for many years. Leaks are particularly prevalent at the tube-sheet connections where, as is general practice, both the shell and channel side gaskets are loaded using common bolting. Various approaches have been adopted in an attempt to mitigate leakage including using different gasket styles, assembly stresses and live loading. All previous attempts have failed to successfully resolve the issue. Processing VD heavies gives rise to fouling (coking) of the tubes necessitating de-coking to be carried out on a regular basis. The source and condition of the crude can have a significant impact on extent and frequency of fouling and the processing of heavier and dirtier crudes has become more common place over recent years. The de-coking operation requires taking the unit off line followed by removal of the channel cover and reverse jet high pressure water cleaning. Tube-sheet gaskets, stressed using common bolting, at both the shell and channel locations remain in place during this operation i.e. the tube bundle remains in place. The channel cover is then replaced, including a new gasket and the unit made ready for operation some time, typically 6 to 8 weeks later. Under this operational regime it can be seen that the tube sheet gaskets will be exposed to approximately 7 to 8 thermal cycles in a year.



The situation is further exacerbated by the fact that changes in demand patterns for certain refinery products occur on a seasonal basis. During the summer months the demand for bitumen, a key raw material required for the manufacture of asphalt used in the building and repair of roads generally increases. CVD heavies are an important constituent of bitumen making them a commercially important product in their own right. As a consequence the requirement for vis-broken product can suddenly fall. At such times for reasons of economy, the pre-heaters full of heavy crude distillate are placed into bypass mode, the temperature of the pre-heater, shell and tube side is reduced by around 100°C. The number of times this can occur will depend on the demand pattern. Analysis of data would suggest that during the summer months the pre-heaters are typically in bypass mode 12 days per month i.e. some 40% of the time. Operating the unit in this way gives rise to additional process related thermal transients that have the potential to subject exchanger body connections to stress fluctuations.

A gasket design review for the two banks of exchangers (91-E1 A thru F and 91-E C thru H) was undertaken in quarter 1 2013. Dynamic recovery gaskets where designed for all tube sheet connections, a total of 16 gaskets. Channel side gasket where fitted with partition bars to reflect internal baffle arrangements. Materials of construction were selected in accordance with application conditions (SS316L, high purity flexible graphite). The gaskets here installed during routine maintenance outages during May 2013 for the first bank and October 2013 for the second bank. Since installation, approximately 4 years ago, no leakage from the previously problematic tube-sheet body connections has been reported.



Conclusions

Benchmark seal integrity testing under repeatable laboratory test conditions, designed to simulate gasket load transients caused by changes in process temperatures and pressures, has shown that the dynamic recovery gasket out performs all gasket styles commonly used in flanged heat exchanger girth connections.

The dynamic recovery gasket design has demonstrated that, under refinery field service conditions in a historically problematic sealing application subject to significant cyclic operating conditions, sealing performance was significantly improved resulting in leak free operation for the first time in many years. In addition to the cited case study the dynamic recovery gasket has been successfully used in many problematic sealing applications involving shell and tube heat exchangers.

The unique wire profile and resulting construction of the dynamic recovery gasket gives rise to a innovative gasket with the optimum balance of resilience and tightness, especially in applications where the gasket may be subject to load fluctuations caused by changes in planned and/or unplanned thermal and/or pressure transients.

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Acknowledgements

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