FAILURE OF HEAT EXCHANGER GASKETS DUE TO DIFFERENTIAL RADIAL EXPANSION OF THE MATING FLANGES

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ABSTRACT

Mating flanges on heat exchanger joints often operate at different temperatures, especially on tubesheet joints. There is therefore a subsequent difference in radial expansion between the mating flange faces. This creates a situation where the gasket is put into a radial shear loading pattern by the flange faces. This form of gasket loading may lead to failure in certain gasket types. It is thus necessary to consider this effect when selecting large diameter heat exchanger gasket types.

This paper presents an explanation of this radial shear mode of gasket failure. It uses actual refinery joint case history to clearly demonstrate the necessity of considering this effect during the selection of heat exchanger gaskets.

ABBREVIATIONS

ASTM = American Society for Testing and Measurement
RFWN = Raised Face, Welding Neck Flange

NOMENCLATURE

Δu = magnitude of differential radial expansion between flange faces
d = gasket outer diameter
a = coefficient of thermal expansion for the flange material
ΔT = temperature difference between the mating flanges

INTRODUCTION

The selection of gaskets and the analysis of the causes of joint failure for high temperature heat exchanger flanged joints are complex subjects. There are several dominating effects, such as bolt assembly loads and gasket relaxation, which must be taken into account when assessing the ability of a bolted joint to seal. However, in specific cases there are also other additional factors which must be assessed during gasket selection to ensure successful sealing of the joint.

Extensive studies at two different refineries found that metal gaskets leak in 30 to 45 percent of heat exchanger applications. The problem is most pronounced in plants that undergo a number of startups and shutdowns and in exchangers where rapid heating or cooling of either the channel or shell side occurs during process changes, or when the exchanger is taken in or out of service.

Historically, one of the most troublesome types of joints to seal has been large diameter heat exchanger tubesheet joints. This type of joint is subjected to a different loading pattern than a normal, symmetrically loaded joint, which makes them more difficult to seal. This difficulty is due to the fact that there is a temperature difference between the two internal fluids. The two flanges and the tubesheet therefore operate at different temperatures. This leads to differential expansion between the joint components in both the axial and radial directions.

This difference in temperature results in changes in gasket and bolt loads. However, one of the more fundamental effects is that the difference in radial growth of the two mating flanges (or the flange and tubesheet) must be accommodated by the gasket. This effect is not commonly included in the gasket selection process and there is no standard test available to determine a gasket's suitability to cope with this effect.

The determination of the effect of temperature on the joint component loading has been covered in articles such as Singh et. al. [4] and Brown et. al. [2]. However these papers do not examine the effect of the radial movement on different gasket types. In the article by Martens et. al. [3] a solution to one case of differential radial expansion, which exceeded 1mm (0.04”) in magnitude, was to weld in place an external metal gasket. In the article by Martens and in others, such as that by Winter [5], the problem is presented and recommendations are made that it be included in the gasket selection process. However there have been no definitive studies into the problem and there are presently no standard testing procedures to guide the designer on the appropriate amount of differential expansion that is acceptable for certain gasket types.

It is therefore the goal of this paper to highlight the magnitude of this problem in the refining industry and to provide guidelines for future gasket testing to quantify this effect. In order to establish these guidelines, temperature data was taken from an operational reboiler tubesheet joint to determine the amplitude and the cyclic nature of the radial expansion. The gasket failure modes due to the differential radial movement of the gasket were also examined and photographic evidence of gasket failure, due to this effect, is presented.

DIFFERENTIAL RADIAL EXPANSION

The tubesheet joint of a shell and tube heat exchanger forms a barrier between two fluids of different operating temperatures. Each flange is exposed to only one fluid temperature and therefore the temperature of the fluid that it is in contact with determines the flange operating temperature. The tubesheet will operate at a temperature between the two flange operating temperatures. Due to this difference in operating temperatures there is a subsequent differential radial expansion between the mating flange and tubesheet faces.

These operational flange temperatures, and subsequent deflections, may be determined using finite element analysis or by the graphical method presented in Brown et. al. [1]. Using these methods it becomes clear that it is possible for many types of flanges, other than tubesheet flanges, to have different flange pair temperatures. This depends on the heat transfer properties of each flange and the surrounding vessel components. For instance, a high temperature incoming nozzle next to a flange will provide an additional source of heat for that flange and thus there will be differential radial expansion between that flange and its mating flange.

It should, however, be noted that there will be contact heat flow between the flanges, via the gasket, and so there is a limit to the maximum magnitude of temperature difference. Estimation of this limit, from field temperature measurement of exchanger tubesheet joint flanges, indicates that the temperature difference will rarely exceed 50°C (90°F). Conversely, however, the problem is often further exacerbated by the use of materials for joint components that have different thermal coefficients of expansion, such as a stainless steel tubesheet for example.

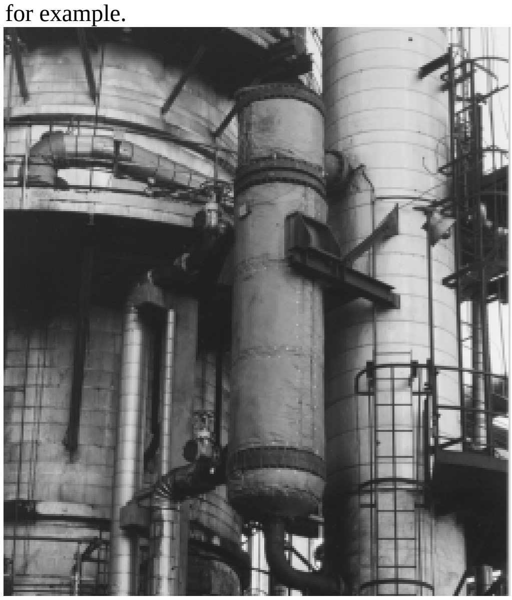


Figure 1 – Reboiler Heat Exchanger

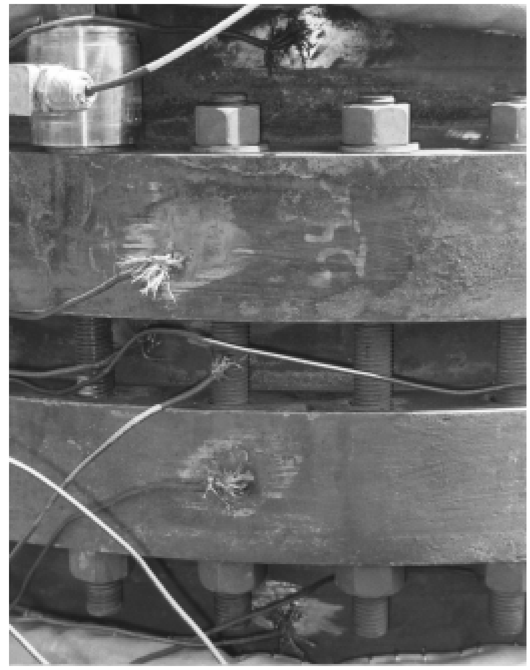


Figure 2 – Thermocouple Placement

MAGNITUDE OF THE DIFFERENTIAL RADIAL EXPANSION

In order to examine the magnitude of differential radial expansion occurring in a typical heat exchanger joint, thermocouples were placed on the tubesheet joint of a reboiler (Figs. 1, 2). The flange is carbon steel (ASTM A105) RFWN construction with a 1090mm (43”) outside diameter. The component temperatures were measured during a period of start-up and during normal operation. A sample of the obtained data is graphed in Fig. 3. It can be seen that during start-up the difference in temperature between mating components exceeds 35°C (63°F). Even during “steady state” operation, the temperatures are constantly varying and the difference in temperature between mating parts oscillates with an amplitude in excess of 15°C (27°F).

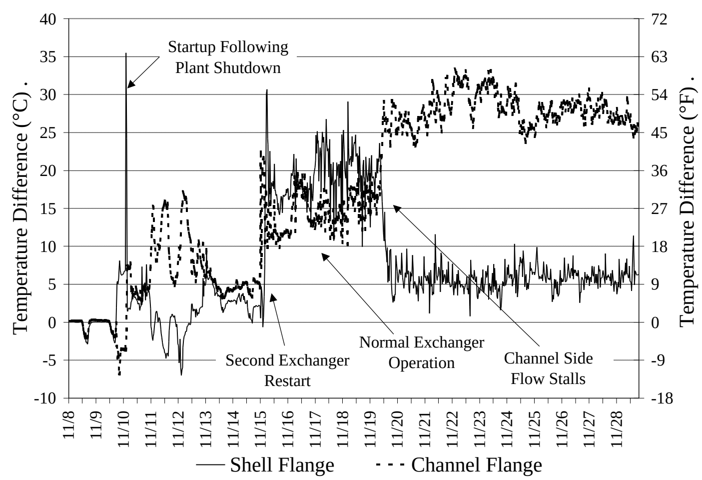


Figure 3 – Difference between tubesheet and flange temperatures for 21 days of operation

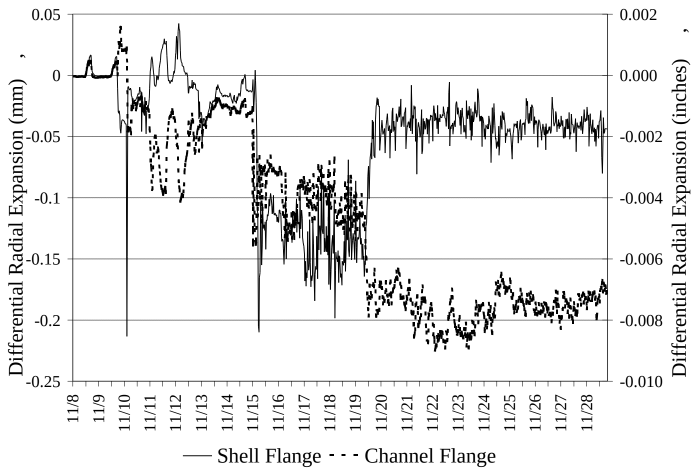


Figure 4 – Differential Radial Expansion (same period)

From the measured temperatures an approximation of the differential expansion was made using the equation:

$$\Delta u = d.a.\,\Delta T \qquad [1]$$

The differential expansion of the two mating surfaces, channel flange to tubesheet and shell flange to tubesheet, were subsequently graphed (Fig. 4). It is evident that during start-up or upset conditions, the differential expansion can exceed 0.2mm (0.008"). Furthermore, during normal operation the gasket is experiencing up to 0.1mm (0.004") of radial movement in a cyclic pattern, which may be sufficiently rapid to induce fatigue in many gasket materials.

GASKET FAILURE MODES

Depending on the type of gasket between the flanges, differential radial expansion may severely damage the gasket structure. With a solid metal type gasket the differential radial expansion may result in radial slippage between the flange and gasket surfaces. Alternatively, if there is no slippage between the contact surfaces, the gasket will be placed in a shear loading pattern which may cause actual physical destruction of the gasket material due to low cycle fatigue.

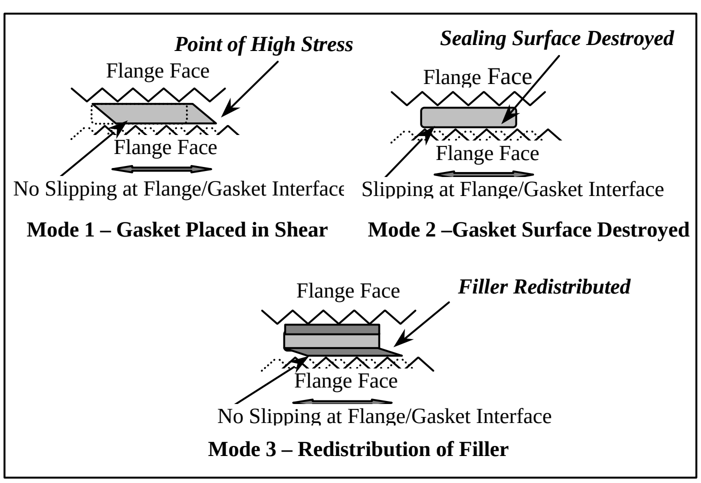


Figure 5 – Gasket Failure Modes due to Radial Movement

For gaskets that have a soft filler material in contact with the flange faces there is a third mode of failure. The radial expansion may be taken by radial shearing of the filler material between the gasket body and the flange face. This continual radial movement may very well result in a redistribution of the filler material to the point where the effective thickness of the gasket is reduced; subsequently reducing the operational gasket stress to a point where leakage occurs.

Double metal jacketed gaskets, with a soft internal filler, are commonly used in heat exchanger joints due to their ability to handle high temperatures. However this gasket falls into the first category and the differential radial expansion must be either taken in shear by the gasket or there must be slippage between the gasket and flange face.

In order to examine these failure scenarios, a number of gasket samples were taken during a crude unit shutdown from heat exchanger tubesheet flanges. The samples were examined under a microscope to see if there were any signs of failure due to the differential radial expansion. The two common types of gasket failure that were observed are illustrated using two of the samples taken (Fig. 6).

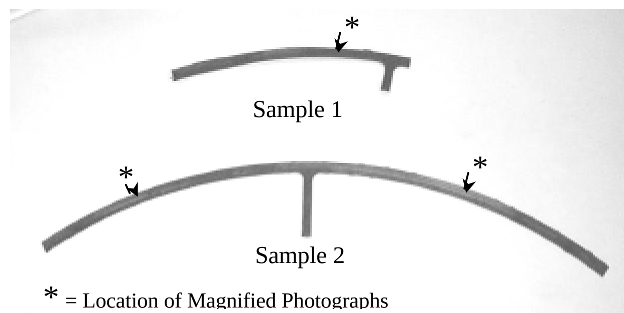


Figure 6 – Double Jacketed Gasket Samples

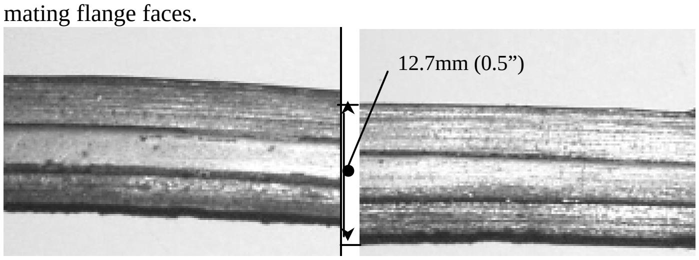
The metal jacket was broken on the inner or outer edge of the gasket at the point where the top jacket is bent over the lower flat jacket in a large proportion of the samples, as was the case with Sample 1 (Fig. 7). This failure can be attributed to a variety of reasons. However, given that we know that differential radial expansion was occurring, a feasible explanation is that in these cases there was no sliding between the gasket and flange faces. This assumption is supported by the fact that there are no radial marks on the gasket surfaces.

Figure 7 – Gasket Sample 1

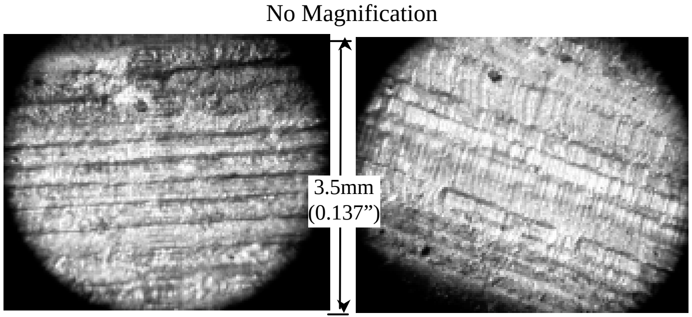
If this is indeed the case, that means that the gasket accommodated the differential radial expansion in shear. Due to the high residual forming stresses in that section of the gasket, it appears that the radial shearing has therefore caused failure of the metal jacket, subsequent release of the internal filler and possible joint leakage.

The second failure mode observed (Sample 2) is when there is slippage between the flange face and the gasket. This may cause leakage of the joint by decreasing the gasket stresses and also by creation of radial leak paths in the gasket. The sample presented illustrates this mode of failure very well, due to the fact that the radial scoring on the gasket occurs on only one sector of the tubesheet joint. This means that the differential expansion only occurred (or rather was of sufficient magnitude) on one pass of the exchanger.

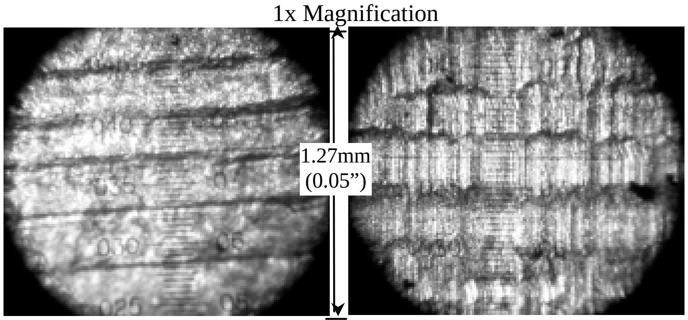
If the photographs (Fig. 8), which were taken under increasing magnification, are examined, it may be seen that on one side of the pass partition there are very clear circumferential grooves from the flange facing, with minimal radial movement. This is presumably the last pass of the exchanger, where the fluid temperature differential is the smallest. However in the next section, presumably the first pass where the temperature difference is at its greatest, there is a very evident pattern of radial scoring caused by differential radial movement of the mating flange faces.



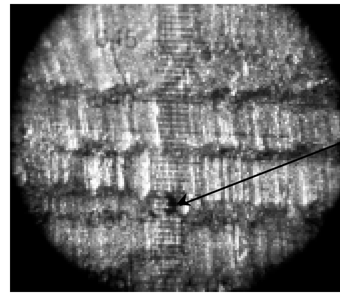
No Magnification



1x Magnification



3x Magnification



3x Magnification (different position)

Figure 8 – Magnified Photographs of Sample 2

The photographs demonstrate that the magnitude of the thermal movement is in the order of 0.127mm to 0.254mm (0.005” to 0.01”). It can be seen that this movement caused scaring of the metal jacket material and therefore a creation of numerous radial leakage paths.

CONCLUSIONS

The evidence presented during the course of this article makes it clear that the differential radial movement of heat exchanger flanges must be taken into account when selecting a gasket. However, at this stage, there is no way of assessing this effect with relation to the performance of different gasket types.

It is therefore proposed that a standard test be devised which will examine the ability of various gasket types to withstand differential radial movement of the mating flanges. This test should be able to induce a differential radial expansion of the mating flanges of at least 0.25mm (0.01”) while the gasket is under temperature and compressive loading. The test rig must have the ability to measure any change in the rate of gasket stress relaxation due to radial shearing and movement of filler material. It should also be capable of detecting a large increase in the joint leakage rate, due to the presence of radial scoring caused by slippage between the flange face and the gasket.

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