THE SUITABILITY OF VARIOUS GASKET TYPES FOR HEAT EXCHANGER SERVICE

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ABSTRACT

This paper describes two important factors that must be considered during the selection of heat exchanger gaskets for petroleum refinery service. These factors are the assessment of the expected level of gasket stress relaxation and the ability of the gasket to resist the radial shear mode of gasket failure. The latest techniques for obtaining the necessary data to evaluate the gasket being considered are detailed. A summary of some generic results of recent tests, for some of the most commonly employed gasket types, is also presented.

ABBREVIATIONS

RA.S.T Test = RAdial Shear Tightness Test

FOREWORD

The results contained in this paper are in a generic format that does not allow the identification of the individual gaskets. The full RA.S.T test report, which does provide gasket details, may be obtained from any one of the participating gasket companies listed in the acknowledgement section of this paper. This is done for two reasons:

a) To encourage end-users to request gasket test data from gasket manufacturers.
b) To allow the gasket manufacturers to monitor the level of interest in this type of testing. In essence, to allow them to gauge the return they can expect from their investment in such leading-edge gasket testing programs.

It is only by end users formally requesting such test data that the gasket manufacturers will be encouraged to invest in the development and continuation of worthwhile testing programs.

INTRODUCTION

In past years there have been several excellent guides published for the general selection of gaskets for pressure vessel bolted flanged joints. Two of the best of these are Winter [1] and Bickford [2]. It is not the intent of this paper to address all issues involved in the selection of gasket materials, as this is an extensive topic. Rather, this paper is written from the perspective of ensuring that the gasket type selected for heat exchanger joint operation is suitable in terms of two important operational factors:

1) The amount of gasket stress relaxation that will occur during operation.
2) The ability of the gasket to withstand radial shear loading.

Whilst these two factors are mentioned in existing gasket selection procedures, there has been little reported effort to actually quantify, (using realistic test methods) their effect on joint operation. In many cases, if these two factors are not considered during gasket selection then it will be impossible to achieve leak free joint operation.

The amount of gasket stress relaxation that will occur in a heat exchanger joint is primarily a function of the gasket type, joint geometry and operational stresses and temperatures. However, other factors, such as differential radial movement between the flange faces and fluctuating bolt load, may have a very large influence on the rate and overall magnitude of the gasket stress relaxation.

It is important, therefore, that the data used to determine a gasket's suitability for a given service be obtained from as realistic as possible test procedure. For exchanger services (and many other services) the relaxation test would therefore need to include differential radial movement between the mating flange faces and also thermally driven bolt load fluctuations. In addition, the test fixture should have component mechanical rigidities similar to common heat exchanger joint configurations.

The second factor that must be considered, radial shear loading, is one of the most common causes of heat exchanger leakage today. This loading occurs when the two mating flanges (or flange and mating tubesheet or cover) operate at different temperatures or are constructed from materials with different coefficients of expansion. This causes differential radial expansion between the flange faces. Since the gasket is the most flexible joint component in this direction, the gasket is placed in radial shear loading, as detailed in Fig. 1. This loading regime is more fully explained in Brown et. al. [3].

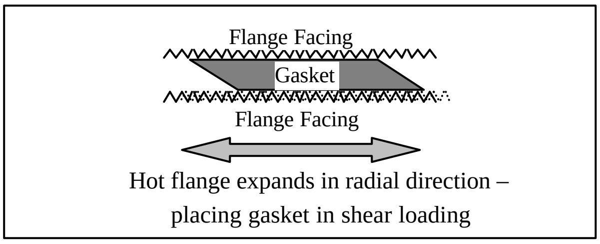

Figure 1 – Gasket Radial Shear Loading

The remainder of this paper outlines recent testing aimed at determining the effect of these two factors, for standard heat exchanger gasket types. The test procedure is detailed and a selection of generic results from the testing of several different gasket types are presented, along with some limited commentary on these test results.

RA.S.T TEST PROCEDURE

In order to satisfy the previously stated requirements for a realistic test procedure, it was necessary to construct a new, specially designed test rig (ref. Fig. 2). This test rig is based on a 24 inch diameter, 24 bolt, heat exchanger type flange with internal electric heating. The bolt loads are monitored using specially designed, water cooled, bolt extensometers (ref. Fig. 3). The flange deflections are monitored by two ceramic rod mounted LVDT systems (Fig. 4).

Figure 2 – RA.S.T Test Rig

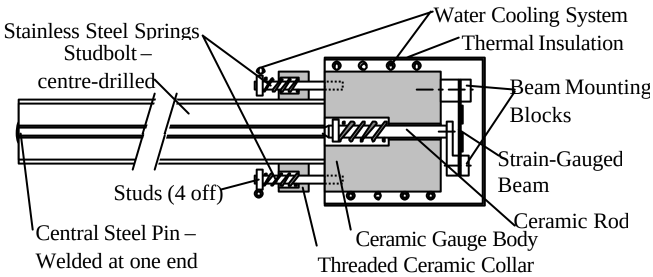

Figure 3 – High Temperature Bolt Extensometer

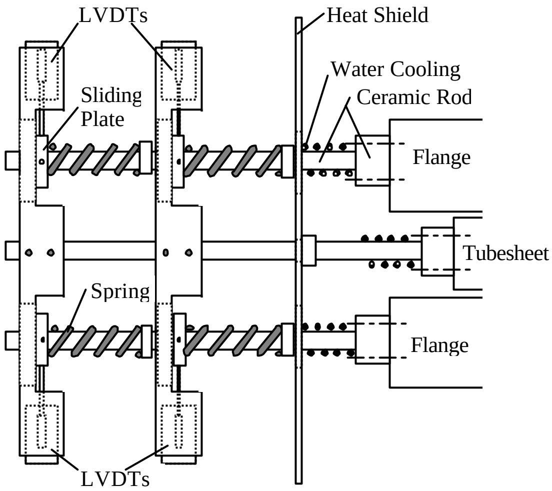

Figure 4 – Flange Deflection Measurement System

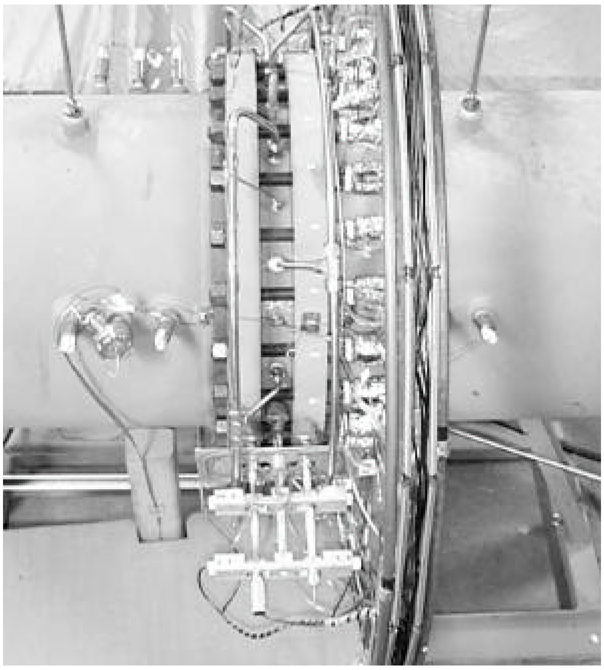

Figure 5 – Tubesheet and Cooling System

The test rig is equipped with a mock tubesheet (ref. Fig. 5), which can be water cooled to induce differential radial movement between the tubesheet and the flanges. The tubesheet also has a secondary seal fitted, between the gasket outer diameter and bolt holes, which allows the monitoring of leakage past the gasket during testing. The rigidity of this secondary seal is several orders smaller than the gasket being tested, and so therefore has a negligible effect on the overall relaxation being measured. A cross sectional detail of this secondary arrangement seal appears in Fig. 6.

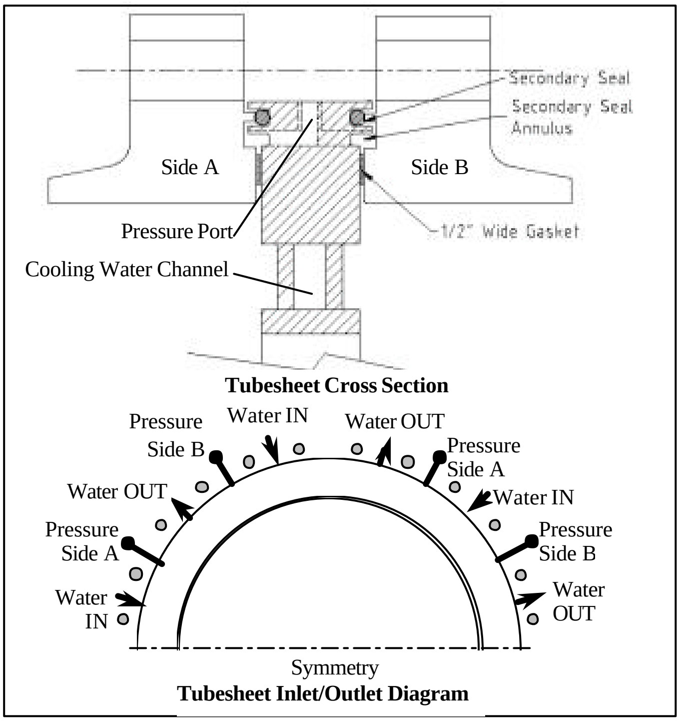

Figure 6 – Tubesheet Details

Leakage of the internal fluid (helium) past the gasket being tested is detected as a pressure rise in the secondary seal annulus. The secondary seal annuli on both sides of the tubesheet are individually monitored, allowing the testing of two gaskets at the same time, one on either side of the tubesheet.

The basic gasket test procedure is as outlined following:

Joint assembly:

1. The gaskets are photographed.
2. The gaskets are held in place on the flange faces with thin (0.01" thick) metal brackets which provide support at three points on the gasket ID, whilst not interfering with the gasket and flange movement.
3. The secondary annulus seals are fitted.
4. The joint is assembled and the bolts are finger-tightened.
5. The LVDT's are fitted and bolt gauge cooling system started.
6. The bolts are tightened to 365MPa (53ksi), which corresponds to a gasket stress of 90MPa (13ksi).
7. The system is filled with helium and pressurised to 0.7MPa (100 psig). This pressure will increase to 1.72MPa (250psig) during the heating cycle and will be held constant at that value (±5%) throughout the testing.
8. The secondary pressure annulus valves are closed.
9. The system is left for 1 hour, to examine gasket relaxation rates prior to heating.

Joint Preliminary Heating Cycle:

10. The joint is heated to 150°C (300°F) on the bolts and this temperature is held for around 1 hour.
11. The bolts are then re-tightened ("hot-torqued") to the original assembly stress.
12. The temperature is then increased to 315°C (600°F) and this temperature is held for a period of 12 hours.

Joint Cyclic Heating:

13. The tubesheet temperature is then cycled between the steady state temperature and a lower temperature value, calculated to give 0.5mm (0.02") movement on radius in the radial direction across the gasket face.
14. This cycling is continued until either 60 hours of cycling is reached, or gross failure of the gasket seal is evident.
15. The system is then cooled and disassembled.
16. The gaskets are examined and any physical defects are noted and photographed.

Further details of the test rig construction and configuration can be obtained from Brown [4].

TEST RESULTS

Gasket Types Tested

The following, commonly used, gasket types were tested. Each type was assigned an abbreviated name, as listed next to each type in Fig. 7.

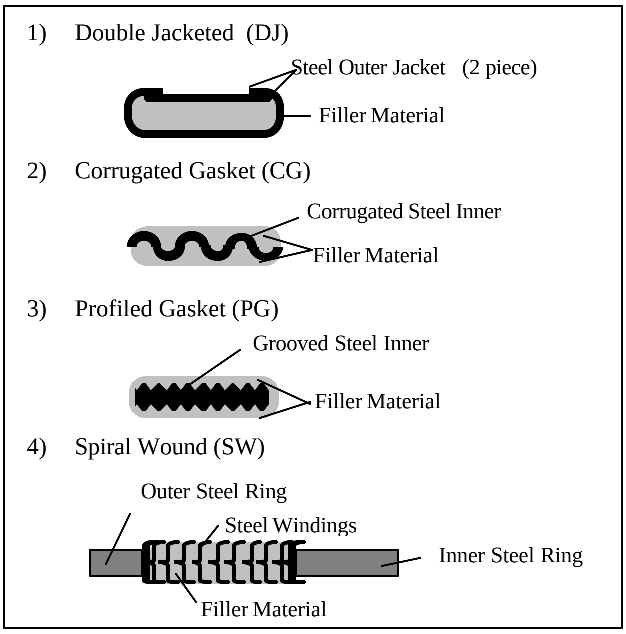

Figure 7 – Tested Gasket Types

Overall Gasket Performance

There was only one gasket type that did not survive the full test duration. The radial shear loading imposed on the gaskets caused destruction of the outer jacket of the DJ gasket type and subsequent gasket load relaxation and gasket leakage. This result confirmed earlier identification of this failure mode for type DJ gaskets from refinery operational experience (Brown et. al [3]). This may be a surprising result to some however, considering that the type DJ gasket is probably still the most widely used gasket in heat exchanger joints.

All other gasket types that were tested survived the test procedure without actual physical destruction. However, there were marked differences between some of the levels of gasket stress relaxation and leakage during the thermal transients. A general graphical overview of the test procedure may be seen in Fig. 8.

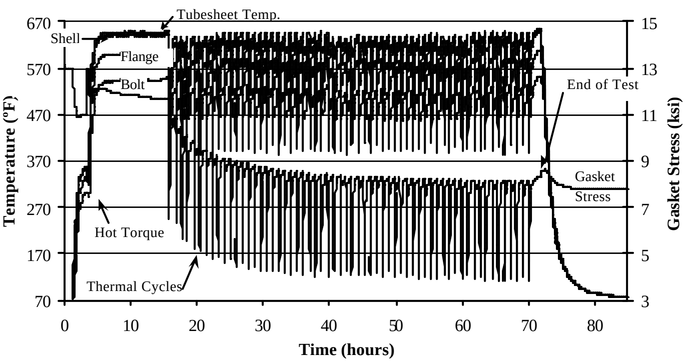

Figure 8 – Sample Test Overview Graph

Measured Gasket Stress Relaxation Levels

Comparison between the various gasket types:

The gasket stress relaxation levels for each of the gasket types tested are detailed in Figs. 9a and 9b. The best and worst of each gasket type are plotted on this graph (only one type PG test was tested). The following points should be noted when reading these graphs:

? The results are for a joint that contains two gaskets, so are slightly less than twice the level that would be expected in a joint containing only one gasket (it should be conservative to assume 75% of this value for joints with only one gasket).

? The results in Fig. 9a include the hot-torque, which eliminates the gasket stress relaxation occurring prior to this step. Fig. 9b is a cumulative record of the relaxation, both prior to and after the hot-torque. If hot-torque was not performed then the expected gasket relaxation level would be approximately the average of these two values.

As is evident from these figures, there is a lot of difference between the relaxation levels measured. The final value varies from 16% to 36% (excluding the failed DJ results). This difference does not, however, fall uniformly into gasket type categories, but appears to be more dependent on the actual individual gasket construction details. Another interesting point from these graphs is the fact that the radial shear appears to accelerate the rate of relaxation occurring, as evidenced by the sharp increase in relaxation immediately following the commencement of the thermal transients. This creates a relatively short-term test, which gives results that are applicable to long-term joint operation.

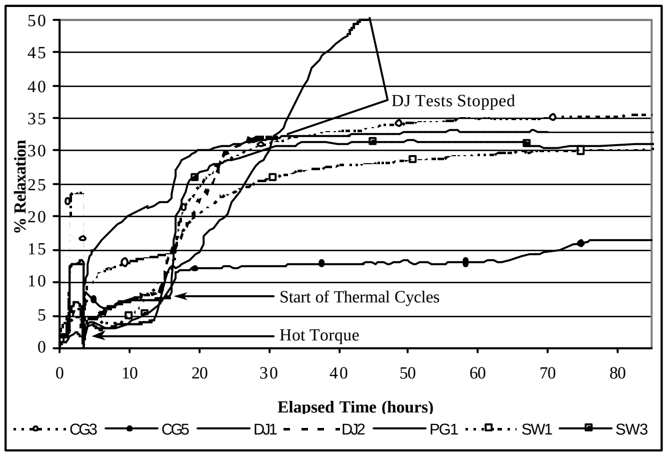

Figure 9a – Relaxation Comparison, Gasket Types

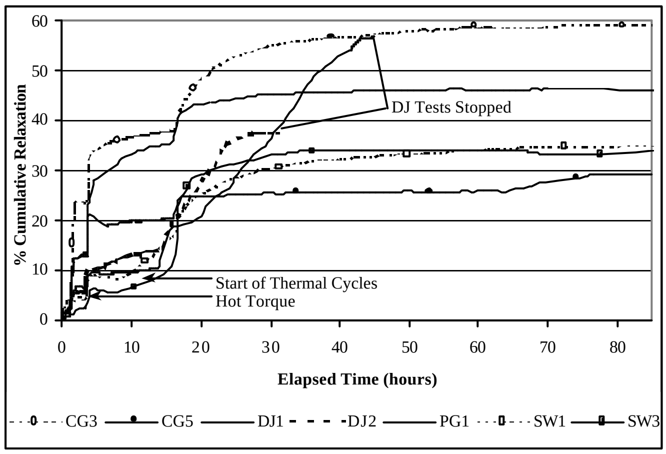

Figure 9b – Cumulative Relaxation Comparison, Gasket Types

Comparison within gasket types:

An interesting comparison may be obtained by looking at the various results between gaskets from different manufacturers within the same gasket type. The results for type CG gaskets are detailed in Figs. 10a and 10b.

Although the type CG gasket is a relatively simple construction, it would appear that small variations in gasket construction, such as filler thickness or the number of corrugations, has a very dramatic impact on the gasket performance. Gaskets CG1, CG4, CG6 and CG7 were all identical. Test CG1 was conducted without hot torque and with the magnitude of radial shear at 1.25 times normal. Test CG6 was conducted with the magnitude of radial shear at 0.8 times normal.

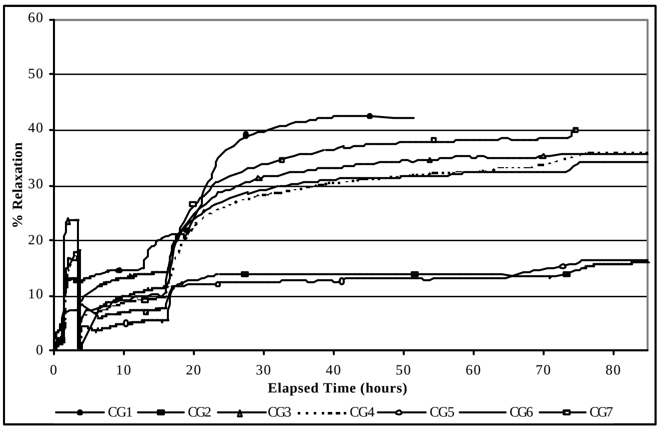

Figure 10a – Relaxation Comparison, Gasket Type CG

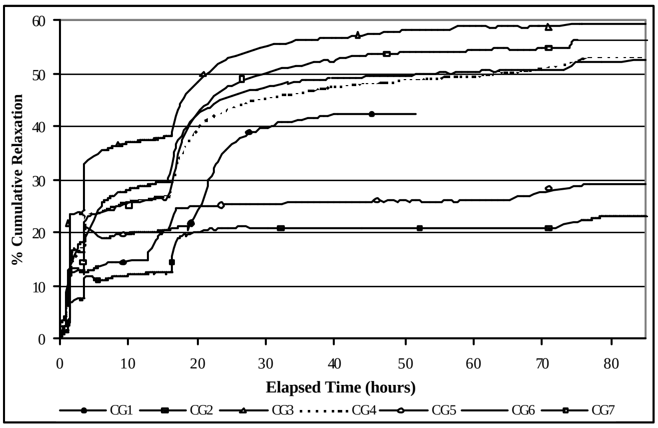

Figure 10b – Cumulative Relaxation Comparison, Gasket Type CG

As can be seen from the graph, it appears that the magnitude of the radial shear (above a certain value) does not appear to have a large effect on the magnitude of relaxation. Additionally, by comparison between the results of test CG1 and the others, it can be seen that tests without hot torque will have relaxation levels equal to the average of the relaxation and cumulative relaxation graphs.

The results for the type SW gasket are graphed in Fig. 11. It can be seen that they are quite similar. However, this is not necessarily in agreement with current industry thinking, as these two gaskets are quite different. The gasket SW1 had metal-metal contact between the flange facing and the inner and outer rings. Gasket SW3 did not have contact. What can be noted, therefore, is that the metal-metal contact evidently made little difference to the amount of relaxation occurring.

The gasket in test SW2 was identical to the one tested in SW3. However, due to a different assembly procedure there was minor buckling (inward cupping) of the SW2 outer ring on one side of one of the gaskets being tested. Even though the ring did not buckle sufficiently to release the windings, it has obviously had a dramatic effect on the amount of relaxation that occurred. This is evidence that for certain gasket types, the assembly procedure is extremely important.

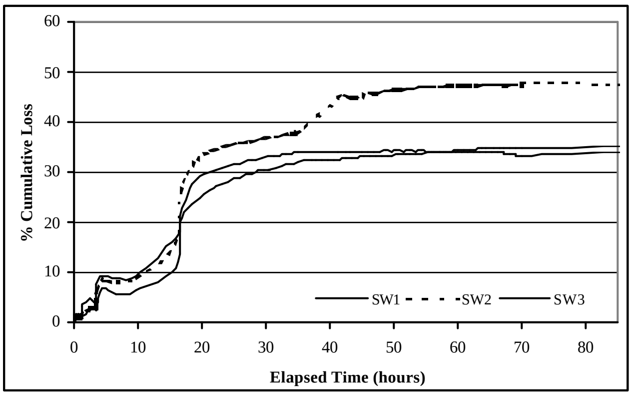

Figure 11 – Relaxation Comparison, Gasket Type SW

Measured Gasket Leakage Levels

For the RA.S.T test rig, the secondary annuli are not perfectly sealed by the secondary seal. This means that the detection of a gasket leak will not be evident as a continually increasing pressure rise in the annuli. An analogy, to assist in explaining what is measured can be seen in Fig. 12. The vessel has a large volume, by comparison to the secondary pressure annulus. The gasket acts as a valve between these two volumes. Ideally the valve would always be shut, and the pressure would remain high in the test vessel and at ambient in the secondary pressure annulus. The fact that the secondary seal does not seal perfectly can be represented as a small outlet hole in the secondary pressure annulus. If the valve (gasket) allows a flow of helium from the test vessel, the pressure will begin to rise in the secondary annulus once the effective flow area through the valve exceeds the outlet area from the secondary seal. The more flow that the gasket allows into the secondary seal annulus, the higher the measured pressure will be. However, if the gasket then re-seals and reduces the flow into the secondary pressure annulus, the measured pressure will decrease. If the gasket then stops the flow all together, the measured pressure will decrease back to ambient.

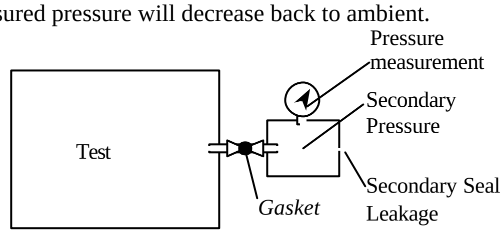

Figure 12 – Leakage Measurement Analogy

In this way, the rate of leakage past the gasket on the RA.S.T test rig can be continually measured and is directly proportional to the pressure increase measured in the secondary annulus. The rate of leakage past the secondary seal is measured during testing and the recorded test pressures are scaled such that a measured pressure rise in the secondary annulus of 10psi corresponds to a leak rate of approximately 0.05L/sec of air at ambient temperature. This rate is approximate only and the adjustment made is fairly rudimentary. However, it is sufficiently accurate to indicate whether or not leakage is occurring past the gasket and to give a rough indication of the magnitude of this leakage.

It is therefore possible to classify two levels of leakage, which may be measured during a RA.S.T test. The first is called initial leakage, which is leakage that causes a pressure spike that exists only during the tubesheet cooling cycle. For initial leakage the secondary annulus pressure returns to zero several minutes after the tubesheet cooling cycle has begun. The second level of leakage is termed gross leakage. This is a leak that is large enough to maintain the secondary annulus pressure above 0.1psi at all times, including between the tubesheet cooling cycles. In general, gross leakage should only occur due to actual physical destruction of the gasket or excessive loss of gasket load.

The spikes in the measured annulus pressure, that may be seen during some of the tubesheet cooling cycles (Figs. 13 and 14), are due to the rapid drop in bolt stress that corresponds to each tubesheet thermal cycle. This reduction in bolt stress allows a small leak of helium past the gasket, which temporarily increases the pressure in the secondary annulus. This does not correspond to a gasket failure, as it is a dynamic behaviour specific to the testing procedure and test medium.

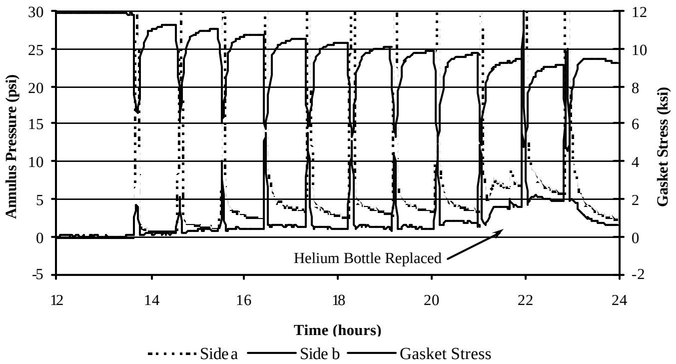

Figure 13 – Sample RA.S.T Leakage Graph (DJ2)

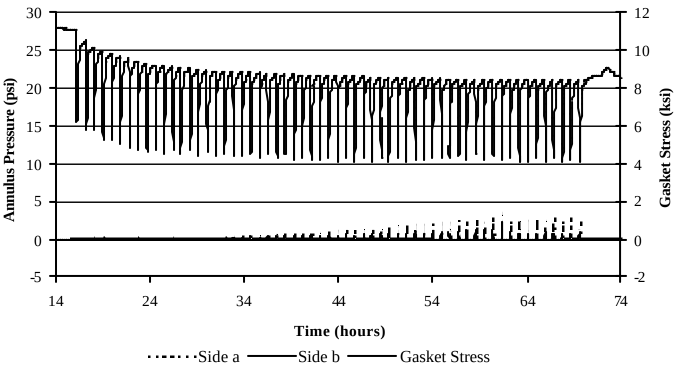

Figure 14 – Sample RA.S.T Leakage Graph (CG3)

As long as the gasket re-seals after each cycle, then the gasket should not be considered to have failed. However, a better gasket will obviously allow the least amount of flow during the cycling and so comparison of the magnitude of this spike between different gaskets does give some indication as to the performance of the gasket. Additionally, there may be certain gas services that are actually similar to the RA.S.T testing, in which case the initial leakage should be considered a failure.

<u>Comparison between the various gasket types</u>:

The comparison results presented following (Fig. 15) are a graph of the maximum value of the transient pressure spike versus time. Only the DJ type gaskets had gross leakage during the test.

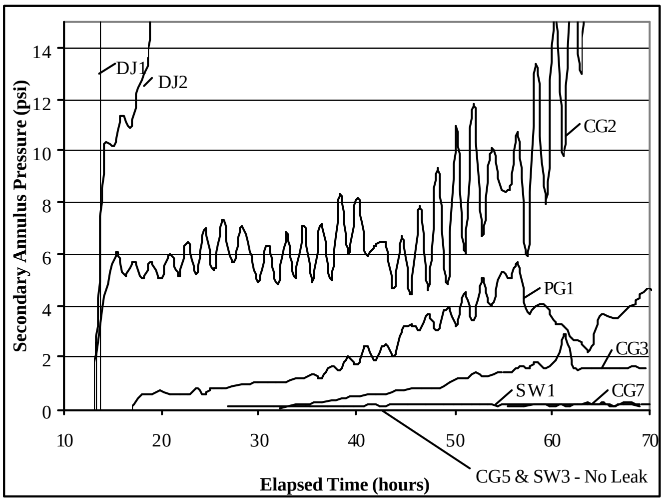

Figure 15 – RA.S.T Leakage Comparison Graph

Once again it can be seen, from the leakage comparison graph, that it is not possible to draw comparisons between gasket performance strictly along gasket type lines. Moreover, it is the individual gasket construction that seems to determine the gasket leakage performance. By examining the individual gasket constructions, with reference to their performance in the RA.S.T testing, it becomes evident which properties (such as filler thickness and density) for each of the types are desirable in optimising gasket performance. Thus the RA.S.T testing should prove a useful tool in developing better gaskets.

A selection of photographs of the post-test gaskets are featured in Figs. 16 to 22 at the end of this paper. These photographs often give indication as to the reason for leakage (in particular Figs. 16 and 17 - type DJ gaskets, show jacket destruction and filler extrusion).

CONCLUSIONS

The major point that this testing has proven is that it is not possible to make generalisations about the performance of gaskets by gasket type. It is essential that the gasket construction that is intended to be used be tested prior to final selection. Incorrect assumptions regarding basic gasket performance (such as the level of relaxation or the ability to handle radial shear) will far outweigh other factors (such as room temperature leakage performance) in obtaining leak free joint operation.

The testing also demonstrated the type of benefit that may be gained from correct gasket selection. From the tests performed it is evident that it is possible to select a gasket with less than 20% relaxation, which also does not exhibit leakage during the thermal cycling. This is far superior when compared to other gaskets, which exhibited twice as much relaxation and also showed leakage during the thermal cycling.

Gasket end-users have two choices, to either request that the gasket manufacturer conduct realistic, controlled laboratory experimentation to ensure that their product is fully suitable for the intended application, or to continue with the “trial-and-error” approach that has been considered the norm in gasket selection to date. It is this trial and error approach that is directly responsible for millions of dollars of lost production and environmental impact due to heat exchanger leakage annually.

ACKNOWLEDGEMENTS

I wish to thank David Reeves of the Chevron El Segundo Refinery for the work he performed during the development of both the test protocol and test rig. More importantly, without his initial groundbreaking work on the radial shear loading effect in the years preceding the development of this project, it is doubtful that it would have been possible to generate the required test funding.

I also wish to thank the following gasket manufacturing companies, for having the foresight and mettle to become involved in one of the most arduous (for the gaskets at least) gasket testing projects ever undertaken:

BF Goodrich - Garlock Sealing Division
Flexitallic Ltd
J M Clipper
Lamons Gasket
Teadit

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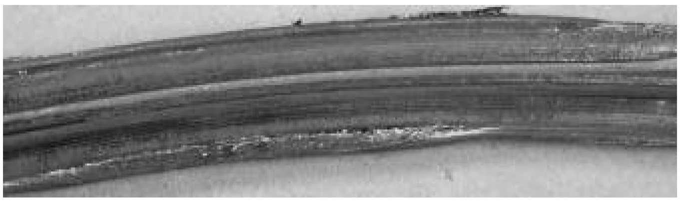

Figure 16 – Type DJ gasket, Post-Test

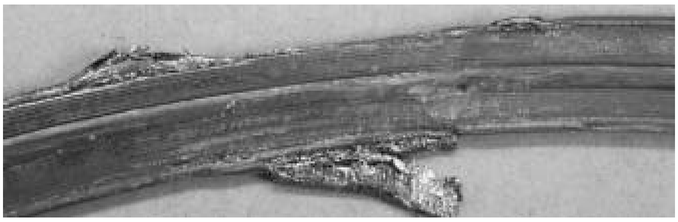

Figure 17 – Type DJ gasket, Post-Test

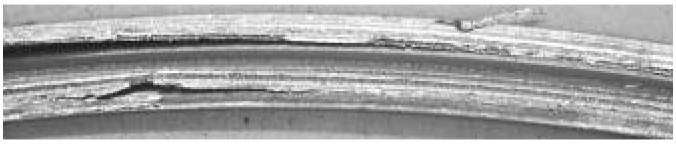

Figure 18 – Type CG gasket, Post-Test

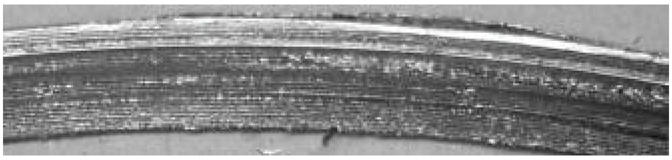

Figure 19 – Type CG gasket, Post-Test

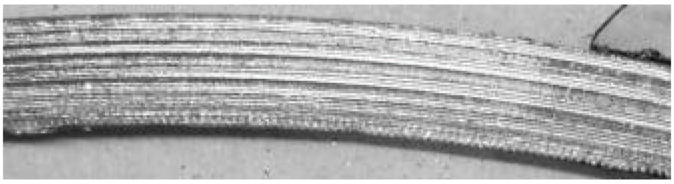

Figure 20 – Type PG gasket, Post-Test

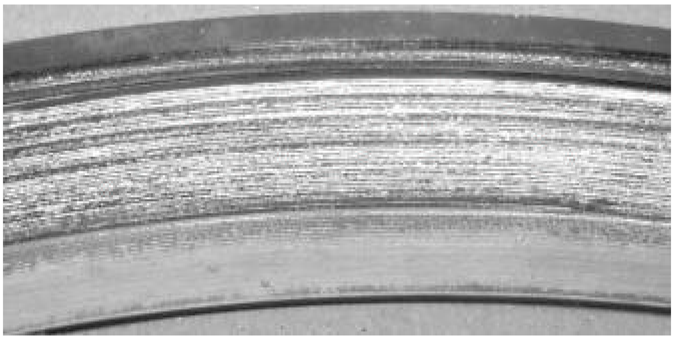

Figure 21 – Type SW gasket, Post-Test

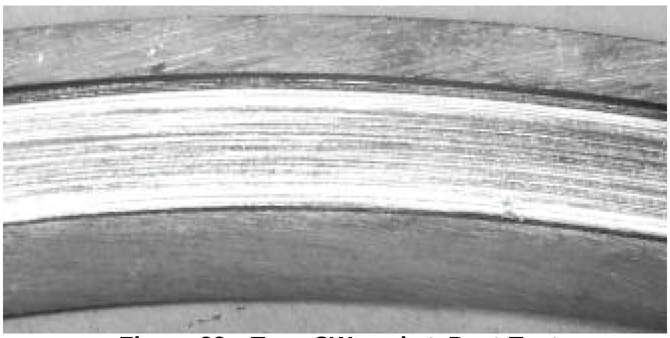

Figure 22 – Type SW gasket, Post-Test