Proceedings of the ASME 2009 Pressure Vessels and Piping Division Conference
PVP2009
July 26-30, 2009, Prague, Czech Republic

PVP2009-77466

SUPERHEATED STEAM TEST RIG FOR COMPRESSED NON-ASBESTOS GASKETS EVALUATION

José C. Veiga
Carlos F. Cipolatti
Ana M. Furtado
Teadit Industria e Comercio Ltda.
8939 Av Martin Luther King
Rio de Janeiro, RJ
21530-012 Brazil

ABSTRACT

This paper presents a Superheated Steam Test Rig and a Test Procedure for Compressed Non-Asbestos (CNA) Gaskets qualification. The Test Rig is a versatile assembly that can use different flange sizes and heating systems. It simulates a Superheated Steam Boiler with a water feed pump, pressurized water tank, pressure relief valve, condenser and the flange pair acting as the Steam generation unit. Heating can be provided by an oven or heating element bands. The Test Protocol enables the evaluation of the gasket performance in Superheated Steam in severe operational conditions like high pressure and temperature with thermal cycling. Different types of non-asbestos compressed gaskets were tested monitoring the leak rate and bolt load at each thermal cycle.

1. INTRODUCTION

With the increased concern for safety, environmental and cost issues, the non-metallic gasket producers focus efforts to develop new materials while improving quality and the production process. As there is a vast diversity of gasket materials in the marketplace, it is difficult for users to specify the correct product because most of the properties shown in data sheets are not related to the performance in an actual application. These properties are evaluated following ASTM International (ASTM) procedures which were developed for material comparison or quality control purposes [1, 2, 3, 4].

The authors have published a paper [5] with a procedure to determine the maximum continuous service temperature of CNA gasket sheets. This procedure also does not address actual field conditions.

Steam service is part of almost every major industrial process. The Fluid Sealing Association (FSA) has developed a standard test method for testing non-metallic gaskets in Saturated Steam [6]. This test method has also been adopted by ASTM as a standard procedure [7]. It provides a means of assessing the performance of various non-metallic gaskets; it is particularly useful for non-asbestos gasket materials. This standard procedure is limited to Saturated Steam up to 295°C (563°F). According to Figure 1 [8, 9], it is possible to observe that there are a significant number of applications where Superheated Steam is required. These applications include higher thermal efficiency equipment and/or when water droplets can cause severe erosion in equipment like steam turbines.

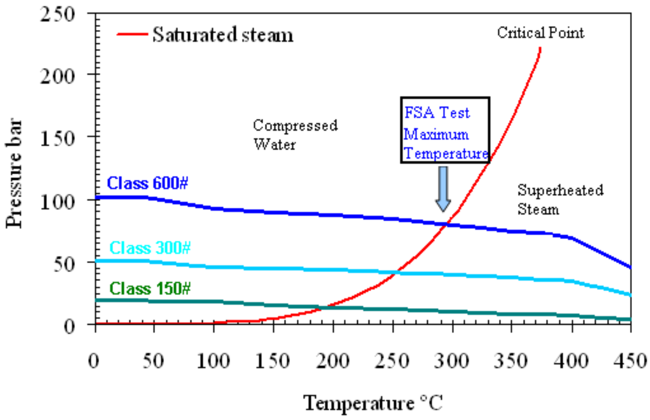

Figure 1 - ASME B16.5 Pressure-Temperature Ratings for ASTM A105 Flanges and the Saturated Steam Curve

Additionally, it is commonly recognized that most industry flanges are 150 and 300 psi rating class designations. Following ASME PCC1 guidelines [10], the seating stresses for 150, 300 and 600 psi bolted flange joint systems were calculated for ASTM SA-193-B7 low-alloy steel bolts, with 50 ksi bolt stress, as shown in Figure 2.

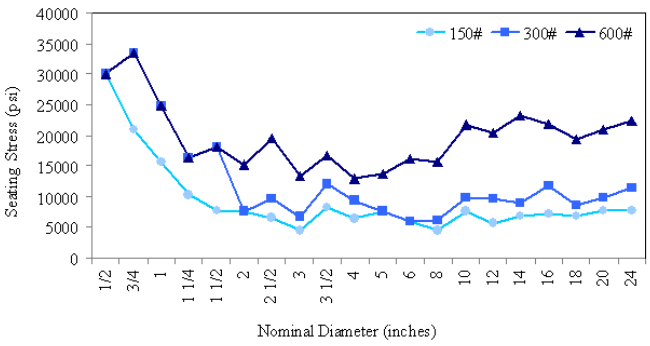

Figure 2 – Gasket Seating Stress for 150, 300 and 600 psi Flanges

The results demonstrate the following:

(a) 600 psi rating class has a higher seating stress than lower classes, and

(b) 150 and 300 psi bolted flanges sizes 2, 3, 6 and 8 inches of nominal diameter have gasket seating stress close to 5,000 psi.

The comparison between the values presented above and the gasket load recommended by FSA/ASTM test procedure (11,000 psi for 2" class 600 flanges) indicates that it may not reproduce the actual field applications where 150 and 300 psi bolted flanges with 2, 3, 6 and 8 inches are used.

An observation carried out within several industries in Brazil showed that most of gasket failures occur with 2, 3, 6 and 8" nominal diameter flanges. These failures occur at the re-start of a line which has experienced thermal cycles.

In many industrial processes, it is necessary to shut-down a steam line frequently. During process re-start, the system is pressurized quickly; however the temperature does not increase at the same rate. Since most of flange connections are not insulated, there is a temperature gradient on it; consequently, during operation the bolts are colder than flanges. When the line cools down the flange thermal contraction is greater than the bolts, reducing the gasket stress. At the re-start of the line the gasket is at its lowest load value.

In order to reproduce the field conditions in the laboratory, a Superheated Steam Test Rig (SSTR) was developed. This device enables to test CNA materials with Superheated Steam. The laboratory results were compared with field performance of the gaskets for validation of the new rig.

To reproduce common field installation practice in Brazil, the following installation conditions were purposely used in this study:

- The use of lubricating grease on the gasket surface;
- No retorque as recommended by the ASME PCC-1;
- Use of 3.2 mm (1/8 in) thick gaskets regardless of flange dimensions or media pressure.

These practices combined with the low gasket stress can lead to a low performance and ultimately a gasket blow-out.

2. TEST RIG DESCRIPTION

Field conditions simulated by the test rig:

- High temperature.
- Successive thermal cycles.
- Superheated Steam media.
- Internal pressure increase before the temperature increase.
- Bolt load consistent with class 150 psi flanges.

To simulate those conditions a test rig was developed with the following characteristics (Figures 3 and 4):

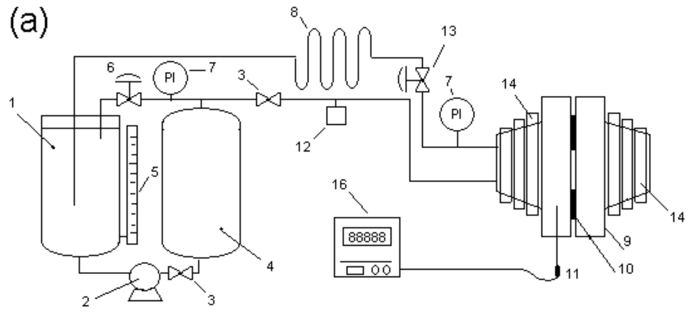

Figure 3 - Schematic of the Superheated Steam Test Rig with heating element tapes.

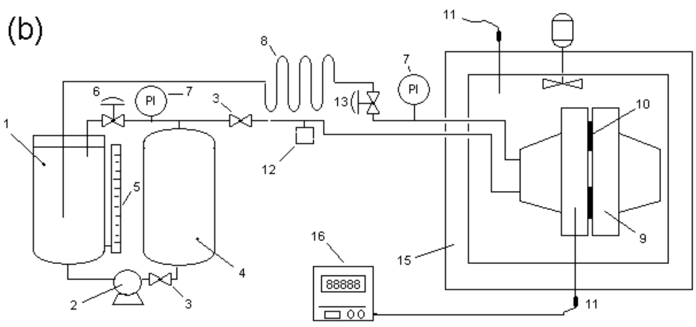

Figure 4 - Schematic of the Superheated Steam Test Rig with oven heating.

Test rig components:

1- Water Vessel.
2- Water Feed Pump.
3- Check Valve.
4- Pressure Vessel.
5- Calibrated Glass Sight Gauge.
6- Pressure Regulator.
7- Pressure Gauge.
8- Condenser.
9- Flange Set.
10- Test Gasket.
11- Temperature Sensor.
12- Pressure Controller
13- Relief Valve.
14- Heating Tapes.
15- Oven
16- Temperature Controller.

- A pair of NPS 6 class 150 cast steel fixture made from two RF weld neck flanges with surface finish of 6.4µm (250 µin). The flange set is the Superheated Steam generator (Figure 5). As shown in Figure 2, it has one of the lowest gasket seating stresses.

Figure 5 - Flange set cast steel 6 in class

- A water supply system with a Feed Pump and Pressure Vessel connected to the flange set like a boiler-water feed system. This system is equipped with a Steam Pressure Regulator to control the water feed keeping the Steam pressure stable. A picture of the water supply system is shown in Figure 6.

Figure 6 - Water supply system with water feed pump, pressure vessel and Steam condenser.

- A condenser to collect the excess Steam generated at the flange set (item 8).

- Two types of heating systems can be used:
  - Heating Tapes on the neck of the flange (Figure 7) that better simulate the heating in field.
  - Oven heating (Figure 8), which is easier to be used than Heating Tapes

- The leak rate is monitored by:
  - High leakage: Determined by the water level in the calibrated glass sight gauge.
  - Low leakage: Determined by the pressure decay method.

Figure 7 - Tape Heating SSTR

Figure 8 - Oven Heating SSTR

3. EXPERIMENTAL

3.1. Test Sequence

The following test sequence was taken on this study:
3.1.1. SSTR Method Test Validation.
3.1.2. Comparison between Oven Heating and Tape Heating.
3.1.3. Comparison between FSA/ASTM and SSTR Test Methods.
3.1.4. Comparison between the SSTR Test Method and the Field Gasket Performance.
3.1.5. Other Evaluations.

3.2. Test Procedure

3.2.1. Center the gasket into the flange face.
3.2.2. Install the calibrated bolts, washers and nuts finger tight.
3.2.3. Record bolt lengths before tightening.
3.2.4. Using a calibrated torque wrench, torque bolts according to the ASME PPC-1 [9] cross pattern. Gasket seating stress: 34 MPa (5000 psi);
3.2.5. Measure and record bolt elongations at room temperature.
3.2.6. Perform a hydrostatic test at room temperature and set pressure;
3.2.7. Start a heating cycle keeping the pressure constant at the set value. The excess pressure is released by the pressure relief valve as the system heats up.
3.2.8. Maintain the set test pressure and temperature for 8 hours.
3.2.9. Record the leak rate after the system has reached the set pressure and temperature and just before a cool down.
3.2.10. Record the leak rate just before starting the cool down phase (after 8 hours of heating).
3.2.11. Perform ten (10) daily cycles repeating steps 3.2.5 though 3.2.11.
3.2.12. The test is completed if one of following condition is reached:
- The gasket fails a hydrostatic test;
- The gasket blows-out;
- The leak rate during the hot phase is higher than the capacity of the water feed pump to replace the lost Superheated Steam;
- Ten cycles are completed successfully.

4. RESULTS AND DISCUSSION

4.1. SSTR Method Test Validation

The purpose of this sequence was to verify if SSTR Test Method was capable of producing different results for three styles of compressed non-asbestos fiber gasket sheets that are available in the market, as shown at Table 1. The test condition used in this evaluation was Superheated Steam at 300°C (572 °F) and 30 bar (435 psi).
The criteria used to select the materials were as follows:
- a product not suitable for the test condition, so a failure was expected;
- a product with application limits close to the test condition;
- a product considered suitable for test condition, so no failure was expected.

Table 1: Samples of Non-Asbestos Fiber Sheet

Material	Composition	Max. Temperature
Style A	Organic Fiber/NBR	220°C (428°F)
Style B	Synthetic Fiber/NBR	280°C (536°F)
Style C	Inorganic Fiber/NBR	400°C (752°F)

The *Style A* test result is shown in Figure 9. The test duration was 6 days. The Superheated Steam leakage in the 5º cycle was already excessive at 5x10^{-2} mg/s.m, when the blow-out occurred (Figure 10) and the test was aborted. The bolt load decreased continuously during each thermal cycle. As expected this product had the lowest performance of the three products selected to validate the test.

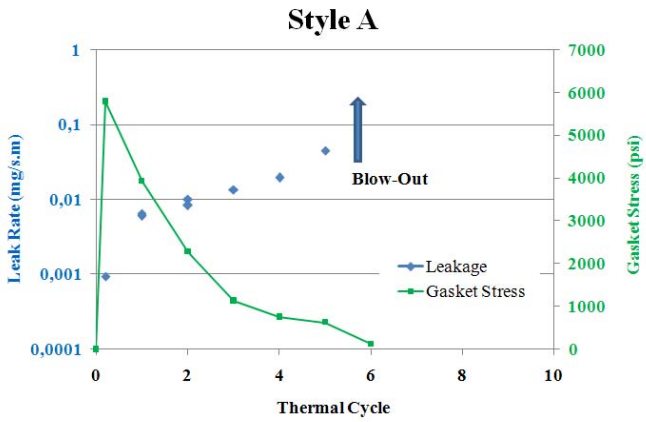

Figure 9 - *Style A* - 300°C (572 °F) & 30 bar (435 psi)

Figure 10 - Blow-out failure of *Style A*

The result for the second product – *Style B* – is shown in Figure 11. The test duration was 8 days, when the gasket failed a hydrostatic test. The leakage of the Superheated Steam had been stable at about 1x10^{-3} mg/s.m**.** The bolt load decreased continuously during each thermal cycle. As expected, the performance of *Style B* was better than *Style A.*

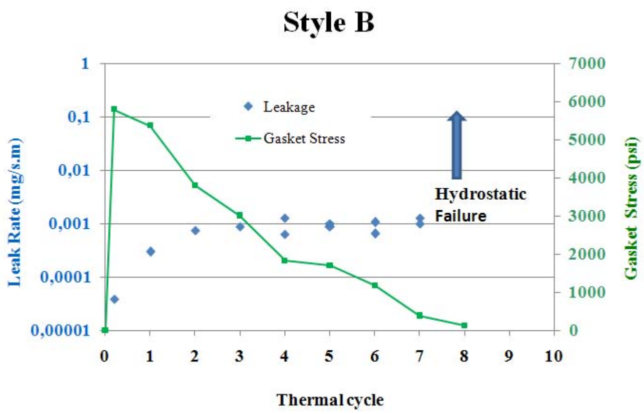

Figure 11 - *Style B* - 300°C (572 °F) & 30 bar (435 psi)

The test result for the third product – *Style C* – is shown in Figure 12. The test duration was 10 days. The leak rate of the Superheated Steam was approximately 2.4 x 10^{-4} mg/s.m. After the 10^{th} cycle an additional hydrostatic test was successfully performed. The bolt load decreased continuously during each thermal cycle, but at a lower rate than the other styles tested. As expected for the product, there was no failure and the leak rate remained stable for the test duration.

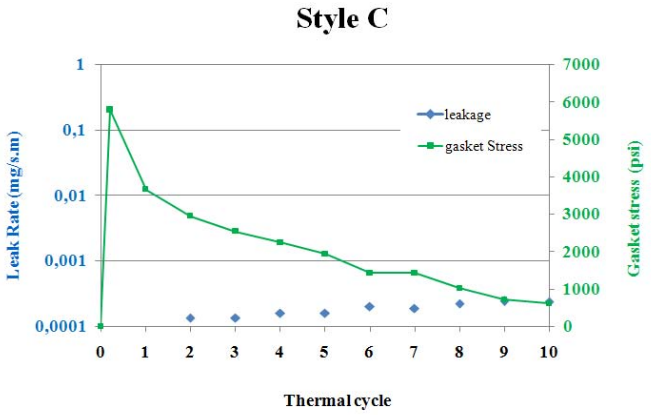

Figure 12 - *Style C* - 300°C (572 °F) & 30 bar (435 psi)

4.2. Comparison between Oven Heating and Tape Heating

The purpose of this test sequence was to verify the influence of the heating in an oven compared to tape heating. The sample used was *Style C* and the test condition was Superheated Steam at 400°C (752°F) & 12 bar (174psi). Ten daily cycles were carried out.

Heating the flange set with tapes wrapped around the flange welding neck is a better simulation of the field conditions where the heat comes from inside, as opposed to oven heating, where it comes from the outside. In order to demonstrate this behavior, temperature measurements were taken as shown in Figure 13. When the flange temperature (T1) in the gasket vicinity was stable at 400°C (752°F) bolt temperature (T2) was 325°C (617°F). This temperature differential causes a linear thermal expansion of the flanges 6.2 x10^{-2} mm (2.4 x 10^{-3} in) larger than the bolts. Consequently the bolts are stretched during the heat–up increasing the gasket stress. This additional bolt stretching does not occur when Oven Heating is used, because there is no temperature differential between bolts and flanges.

The results of Heating Tapes and Oven Heating are shown in Figures 14 and 15, respectively. The following observations were verified:

(a) The leak rate of *Style C* for the both tests was high and increased during each thermal cycle. These results were expected since *Style C* was tested close to its temperature limit.

(b) The bolt load loss was higher with Oven Heating than with Tape Heating. This behavior is in accordance with temperature measurement during the test (Figure 13).

Even though Tape Heating is a better simulation of actual conditions, Oven Heating is more convenient and, being more severe, provides us a “worst case scenario”.

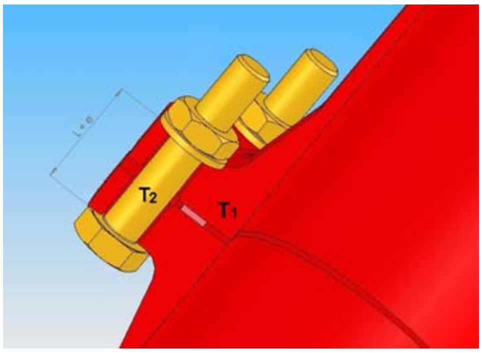

Figure 13 - Temperatures indications.

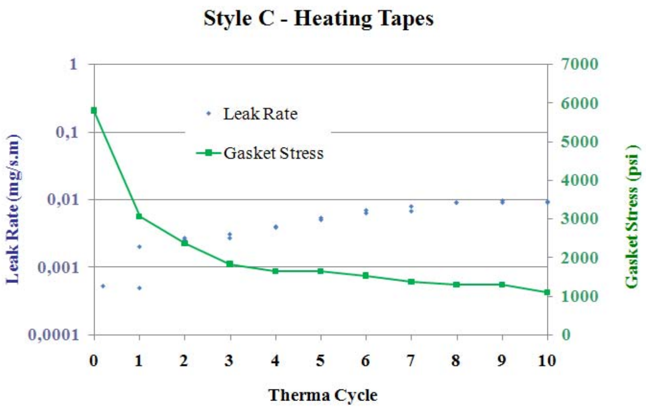

Figure 14 - *Style C* tested using Heating Tapes

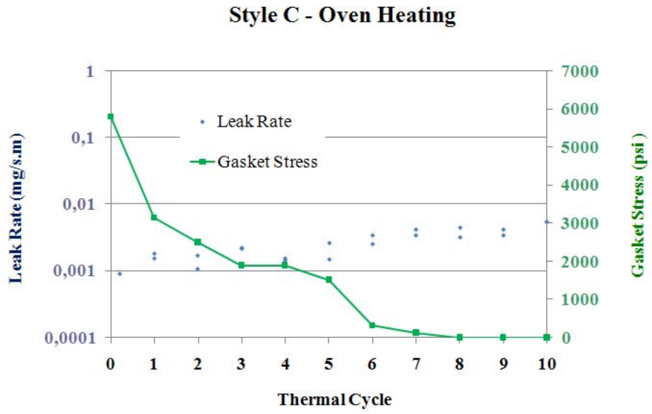

Figure 15 - *Style C* tested in an Oven

4.3. Comparison between FSA/ASTM and SSTR Test Methods.

The objective of this sequence was to compare the current FSA/ASTM Standard Test Method with the SSTR. The CNA sample tested is a product available in the market but not recommended for the test condition, consequently a failure was expected. The Table 2 shows the material composition and its temperature limit.

Table 2: Sample of Non-Asbestos Fiber Sheet

Material	Composition	Max. Temperature
Style D	Organic Fiber/NBR	200°C (392°F)

Since FSA/ASTM standard uses saturated Steam as media, the temperature used was the same for the both tests. However, in order to generate Superheated Steam, the SSTR test was run at a lower pressure. This difference results in two test conditions, as described bellow:

- FSA/ASTM standard method: 10 thermal cycles, Saturated Steam at 250°C (482°F), consequently the pressure is 40bar (580psi).
- SSTR test method: 10 thermal cycles, Superheated Steam at 250°C (482°F) and 30bar (435psi).

The leakage rates for both tests are shown in Figure 16 with the following results:

- The 12 grams water loss result of the FSA/ASTM indicates that *Style D* is adequate for Steam at 250°C (482°F).
- The *Style D* in SSTR with a 10 bar (145 psi) lower test pressure than the FSA/ASTM failed the hydrostatic test at the 5° cycle.

Although *Style D* had failed, the SSTR test was continued for research purposes. It was observed a continuously increase of leakage rate confirming that *Style D* is not suitable for application with Steam at 250°C (482°F).

The main differences between the SSTR and the FSA/ASTM procedures are the SSTR uses lower gasket seating stress and the hydrostatic test at the beginning of each thermal cycle. The SSTR gasket seating stress is 34 MPa (5000 psi) as opposed to 76 MPa (11000 psi) for the FSA/ASTM test. As described in the Introduction of this paper 76 MPa (11000 psi) is not realistic to most class 150 psi flanges, leading to a wrong application compatibility conclusion.

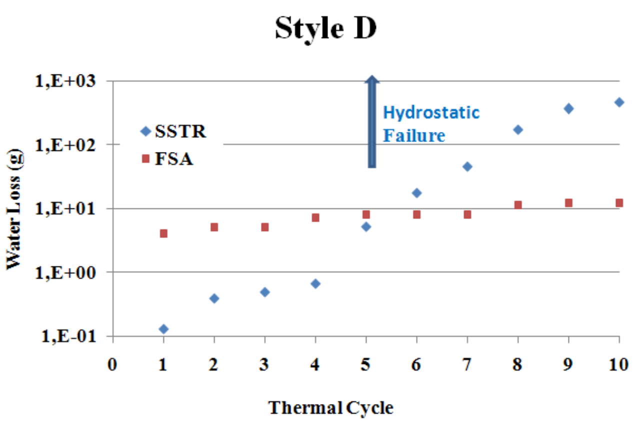

Figure 16 - Comparison between FSA/ASTM Test Procedures

4.4. Comparison between SSTR Test Method and Field Gasket Performance.

As shown in Figure 12, the compressed non-asbestos *Style C* SSTR test result indicates that it can be used in Superheated Steam at 300°C (572°F) up to 30 bar (435 psi). In order to validate the laboratory results, field performance evaluations were carried out in the five major Biofuel Plants located in Brazil.

The renewable energy sources remains high on the agenda of environmentally sustainable developments, these new Plants in addition of Biofuel productions, have also streamlined their process using the combustion of the waste process biomass for electrical energy generation.

These Biofuel Plants are an evolution of old sugar mills and, until just recently, used asbestos gaskets. There are no installations procedures like ASME - PCC-1 here and flanges are not always built in accordance with ASME or EN standards. The surface finishes are not regular and most of them are not thermally insulated. In order to assure that the tested material would meet these conditions, the gaskets were installed following common plant practices such as:

- Grease used on gasket surface to make it easy for its removal;
- No torque wrench used;
- No retorque was applied.

As no torque wrench is used, there is no assurance of correct gasket seating stress which can contribute to an excessive leak or gasket blow-out.

The criteria used to select the field application were:

- Test *Style C* in application with pressure and temperature as close as possible to a previous SSTR test, so a correlation could be established.
- Locations where *Style B* had failed. For these applications a spiral wound gasket (SWG) was being used. However, the Plant Management would like to have the flexibility offered with a CNA gasket sheet.

The Table 3 shows the Field Test conditions where *Style C* was tested. Each plant installed their gaskets using their procedures. “Torque Control” and “Re-tightening” were not applied.

Table 3: Superheated Steam Field Test Conditions

Plant	Number of Gaskets	Temperature	Pressure (psi)
A	6	300 °C (572°F)	21bar (305psi)
B	13	300 °C (572°F)	21bar (305psi)
C	6	330 °C (626°F)	22bar (319psi)
D	16	320 °C (608°F)	21bar (305psi)
	2	310 °C (590°F)	10bar (145psi)
E	4	280 °C (536°F)	21bar (305psi)

All gaskets were installed in March, 2008. At the time that this paper was prepared (February, 2009), they were still in operation without failures. The field test results showed satisfactory correlation between actual application and the SSTR laboratory simulations.

4.5- Other Evaluations

Different from the FSA/ASTM procedure, the proposed SSTR does not use saturated Steam which is limited to the water critical point (374°C or 705 °F). Tests at higher temperatures and pressure are possible and limited only by the mechanical and temperature limits of the flange set and the heating system.

Once the rig was developed, a series of tests were carried out for research purposes and to evaluate the rig capability. Sealability is the most important property of the gasket, because it determines its ability to seal. For this purpose, two styles of compressed non-asbestos fiber gaskets sheet of 3,2mm ($^1/_8$ in) from distinct manufacturers were used. Table 4 shows the composition and temperature limits for each style.

Table 4: Sample of Non-Asbestos Fiber Sheet

Manufacturer	Material	Composition	Maximum Temperature
A	*Style E*	Inorganic Fiber/NBR	400°C 752°F
B	*Style F*	Inorganic Fiber/NBR Wire reinforced	400°C 752°F

The first SSTR experiment was carried out with Superheated Steam at 400°C (752°F) and 12bar (174psi), with 10 daily thermal cycles. According to results, shown in Figure 17, it is possible to verify that:

- The performance of *Style E* was satisfactory since its leakage rate remained at low level and no leaks were observed during hydrostatic test.
- Different behavior was observed for *Style F* as its leak rate increased during each thermal cycle and it failed the hydrostatic test at the 8th cycle.

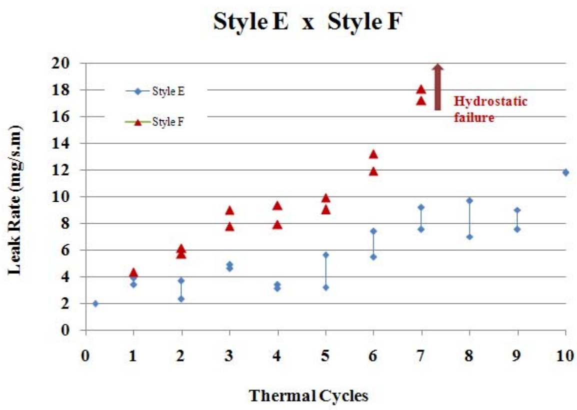

Figure 17 - 400°C (752°F) &12 bar (174psi)

The Second SSTR experiment was with Superheated Steam at 400°C (752°F) but the pressure was increased to 35bar (507psi) without daily thermal cycles.

The leak rates for each style are shown in Figure 18. The test results indicate that both styles failed at this test level. *Style E* had a blow-out on the 6th day (Figure 19) and the sealing performance of *Style F* was substantially reduced as its leakage increased sharply during the 4th day, consequently the test had to be aborted because the leakage rate was higher than the capacity of the water feed pump.

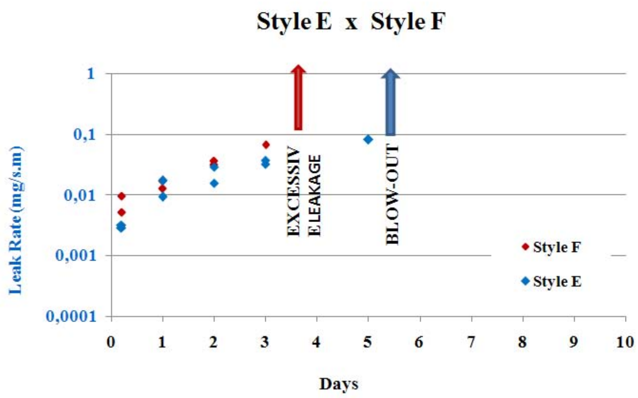

Figure 18 - Comparison at 400°C (752°F) & 35 bar (507psi)

Figure 19 - Blowout of *Style E*

5. CONCLUSIONS

The Superheated Steam Test Rig (SSTR) was developed to meet the need to have a Steam Service Test Method which reproduces the field gasket conditions. The experimental tests showed that:

- The SSTR was successfully developed and a good correlation with field application results was also established.
- It was possible to reproduce in the laboratory Superheated Steam service conditions enabling an economical way to test, compare and develop new products for this application.

- Using Superheated Steam as test media, the SSTR is not restricted by the Saturated Steam pressure x temperature values. Temperatures above the Water Critical Point can be simulated.

- Specific operating conditions of P and T can be easily simulated by just changing the temperature and pressure settings of the rig. The P x T values or charts usually informed by product manufactures can be developed. Other conditions such as thermal cycles or continuous service are also easy to be reproduced.

- The SSTR can also be used to study the temperature influence on non-asbestos gasket degradation and/or service lifetime prediction. However, these studies were not the purpose of this paper.

- Since SSTR uses commercially available flanges, actual field conditions like flange rotation and low bolt load are reproduced. In addition, using a set of standard flanges makes it easy and inexpensive to test other flange configurations, like tongue and groove, male-female or other sealing surface finishes.

REFERENCES

1. ASTM F104-03 - Standard Classification System for Nonmetallic Gasket Materials
2. ASTM F152 - 95(2002) Standard Test Methods for Tension Testing of Nonmetallic Gasket Materials
3. ASTM F146-98e1 Standard Test Methods for Fluid Resistance of Gasket Materials
4. ASTM F36 - 99(2003) Standard Test Method for Compressibility and Recovery of Gasket Materials
5. Cipolatti, C.F. A.; Sousa, A. M.F.; Veiga, J. C. C., “Determination of Critical Temperature of Compressed Non-Asbestos Fiber Sheet Gaskets”, PVP-Vol. 478, Analysis of Bolted Joints, July 25-29, 2004
6. FSA-NMG-204-02) Standard Test Method for Performance of Non-Asbestos Gaskets in High Pressure, Saturated Steam
7. ASTM WK3784 - New Standard Test Method for Performance of Nonmetallic Flat Gaskets in High Pressure Saturated Steam
8. Pipe Flanges and Flanged Fittings - ASME B16.5-2003 – Pressure-temperature Ratings for group 1.1Materials.
9. Perry, R; Green, D., “Thermodynamic Properties”, Perry’s Chemical Engineers’ Handbook, Sixth Edition, McGraw-Hill International Editions
10. ASME PCC1-2000, Guidelines for Pressure Boundary Bolted Flange Joint Assembly