EXPERIMENTAL BEHAVIOR OF BOLTED JOINTS

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ABSTRACT

The work is an attempt to verify whether the new gasket constants theory, developed by the PVRC to help in the design of bolted flanges, can be used to predict the actual field behavior of a bolted joint using a non-metallic gasket in conjunction with standard Class 150 and Class 300 flanges. Leakage measurements were made under various fluid pressures and temperatures. Results are compared with the expected values used to determine the gasket assembly loads according to the new gasket constants concepts. In order to have a direct comparison, the same fluid used to determine the gasket constants (Nitrogen) was also used in the experimental work.

INTRODUCTION

The new gasket constants need appeared with the revision of the ASME code for the design of bolted flanges. They are intended to be used in place of the traditional “m” and “y” factors in the calculation of the assembly and operation gasket stresses, that will lead to bolt and flange design.

As the new theory and calculation procedure do consider the room temperature sealability of the gasket (defined by the Tightness Class) as a function of the internal pressure and gasket load, almost instinctively most of the involved people started to broaden the utilization field of these concepts to attempt to perform bolted joint functional (performance) analysis. The idea was to use these concepts on an existing bolted flange connection to obtain such performance information like, for example, predict the leakage rate of a given application or determine the required torque to obtain a pre-defined leakage level. This would be an important contribution to the effort of controlling fugitive emissions.

In order to compare the leakage obtained in an actual bolted joint with the leakage rate (Tightness Class) used to determine the torque to be applied on the gasket during assembly, using the new gasket constants concept, we run a series of experiments using an NBR non-asbestos compressed sheet gasket in conjunction with standard commercial flanges.

TEST CELLS

The test cell consists of a small pressure vessel using either Class 150 or Class 300 commercial flanges with internal heating, as shown in Fig.1 and Fig.2. Three Class 150 and three Class 300 cells were used (Fig.3).

The temperature control of the cells is made through a thermocouple embedded in the flange, four millimeters below the center of the gasket. This way, the test temperature reflects the actual gasket temperature instead of fluid temperature.

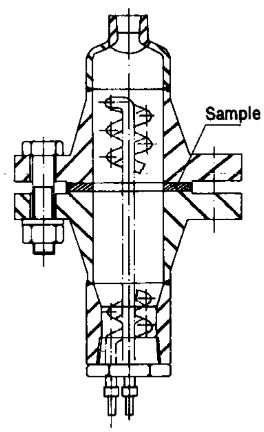


Fig.1: Test cell diagram.

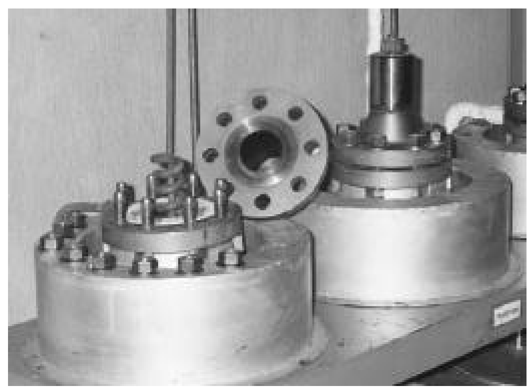


Fig.2: Open and closed test cells.

Fig.3: Class 150 and Class 300 test cells - insulated.

The main characteristics of the cells are described in Table 1.

	Class 150	Class 300
Material	A 181 II	316 L
Flange size, in	2	2
Bolt size, in	5/8	5/8
Number of bolts	4	8
Bolt material	A193 B7	304
Washers	Flat	Flat
Flange surface	Commercial serrated	Commercial serrated
Flange RF OD, mm	91.9	91.9
Max. pressure, psi / bar	285 / 20	720 / 50

Table 1: Test cell characteristics

GASKET

The gaskets used were cut from a commercial NBR bonded aramid fiber compressed sheet material with gasket constants according to Table 2:

The Exact Method constants were determined in accordance with the procedure described in Guizzo's paper "Determination of Design Gasket Assembly Stress With the New Constants - Exact Method" presented at the 6th Technical Symposium of the Fluid Sealing Association, in October 1996.

Constant	Exact Method	PVRC Method
d	0.57	0.50
Gb	13 MPa	11 MPa
a	0.25	0.28
Gs	0.44 MPa	0.30 MPa

Table 2: Gasket constants.

The gasket dimensions are described in Table 3.:

	Class 150	Class 300
Outside diameter, mm	104.65	111.25
Inside diameter, mm	60.45	60.45
Thickness, mm	1.6	1.6

Table 3: Gasket dimensions.

ASSEMBLY

The general assembly procedure considered the following details:

Bolt and nut lubricant:	Molikote P37
Assembly method:	Torque wrench (Assembly efficiency: Ae = 0.85)
Tightness Class:	Tc = 1
Predicted leakage rate:	2 mg/s.m
Torque:	According to the specific test condition, as described below.
Torque steps:	25, 50 and 100% until no further rotation of the nuts
Re-torquing:	No additional re-torquing, at any time

TEST CONDITIONS

A total of fifteen tests were made, with six different gaskets, using Class 150 cells; and a total of 21 tests were made, using nine gasket samples, in the Class 300 cells. All tested samples were cut from the same gasket material, as characterized above.

The tests were run under the general test conditions described in Table 4.
The same gasket was used for the various steps of each run. Each run used a different gasket sample.

	Run 1			**Run 2**		**Run 3**	
Step	**1**	**2**	**3**	**1**	**2**	**1**	**2**
Pressure, bar	16	16	16	16	16	32	32
Temperature, °C	25	100	150	25	150	25	260
Tightness class	T2	T2	T2	T2	T2	T2	T2
Assembly gasket load, MPa	33	33	33	33	33	40	40
Bolt torque, Nm - #150	117	117	117	117	117	-	-
Bolt torque, Nm - #300	58	58	58	58	58	70	70

Table 4: Test conditions.

The assembly gasket load above was determined according to the Exact Method (1) and does not consider the bolting efficiency of 0.85 related to the utilization of a torque wrench for assembly, that was taken into account to determine bolt torque. The actual average calculated gasket load should therefore be corrected by the factor 1/Ae and will change according to the bolting assembly method being used.

More details on the calculation of the above parameters are shown in Annex 1.

In order to be more demanding with the bolted joint, the test cells were totally insulated during the high temperature steps of the various tests. This way the bolts would be at practically the same temperature faced by the gasket and the effect of the gasket creep would be at its maximum, due to the maximum expansion of the bolts.

The test fluid was Nitrogen, the same used to determine the gasket constants for the test material.

The leakage was measured by pressure decay over a period of approximately 100 hours each test step.

RESULTS

Annex 2 shows a typical record of one test run. It shows the results of run 3, test cell T2, class 300, step 1 at ambient temperature and step 2 at 260°C.

The test results are summarized in Table 5.

	Run 1			**Run 2**		**Run 3**	
Step	**1**	**2**	**3**	**1**	**2**	**1**	**2**
Pressure, bar	16	16	16	16	16	32	32
Temperature, °C	25	100	150	25	150	25	260
Predicted leak rate, mg/s.m	2	2	2	2	2	2	2
Class 150:							
Initial leak rate, mg/s.m	0.01	0.004	0.001	0.02	0.007		
100 hours leak rate, mg/s.m	0.003	0.003	0.0003	0.002	0.002		
Initial bolt torque, Nm	117			117			
Final bolt torque, Nm			59		56		
Class 300:							
Initial leak rate, mg/s.m	0.006	0.01	0.001	0.01	0.001	0.008	0.007
100 hours leak rate, mg/s.m	0.006	0.001	0.0006	0.002	0.001	0.002	0.007
Initial bolt torque, Nm	58			58		70	
Final bolt torque, Nm			33		17		38

Table 5: Test results

Figure 4 shows the measured leak rates in comparison with the predicted value of 2 mg/s.m, for Class 150 flanges operating at an internal Nitrogen pressure of 16 bar, at various temperatures, up to 150°C.

Figure 5 shows similar comparison for Class 300 flanges operating at internal pressures of 16 and 32 bar, at various temperature, up to 260°C.

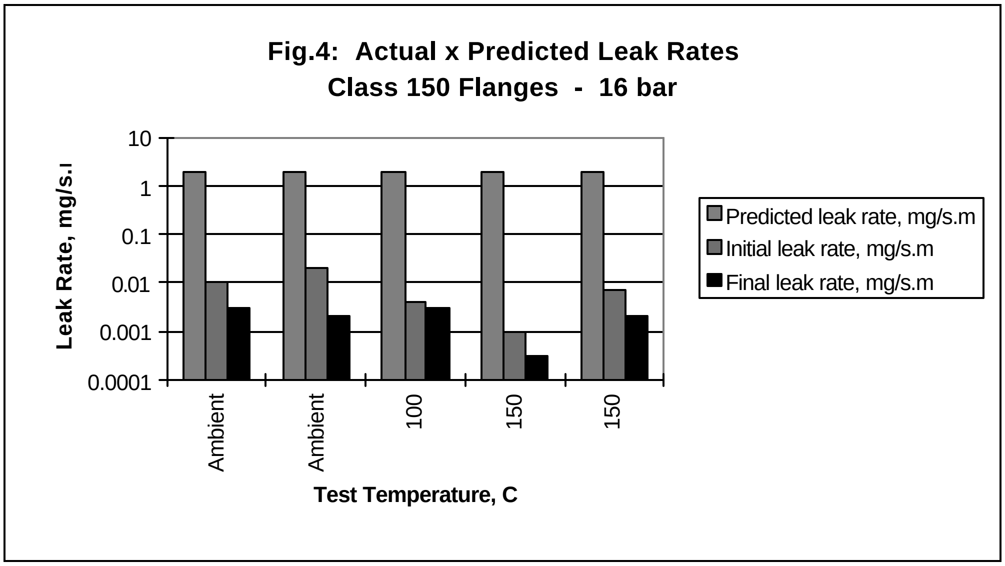


Fig.4: Actual versus Predicted leak rates for Class 150 flanges at 16 bar internal pressure.

Error! Not a valid link. Fig.5: Actual versus Predicted leak rate for Class 300 flanges.

DISCUSSION

Analyzing the data in Table 5 and with the help of Figures 4 and 5, we would like to point out and discuss some aspects that come into evidence.

Leak rate

The most evident fact is that the actual leak rate in all 15 samples and 36 tests are much lower than the predicted value. Actual leakage demonstrated to be an average of 3 decades or 1000 times lower than the predicted value that was used in the calculation of the gasket stress necessary for assembly.

At 150°C the average leakage difference reached the magnitude of 4 decades or 10,000 times.

Gasket creep effect

This leakage difference is even more dramatic if one considers the creep effect of temperature and time on the gasket material.

The gaskets were assembled using the calculated bolt stress and no re-torquing was applied at any further step during the test duration. Consequently all the leak rates measured after the initial measurement of the first step of each test run, were made at actual gasket stresses lower than the initial operating gasket stress of an amount proportional to the creep of the gasket at that point in time.

At the end of each test run bolt torque was evaluated and found to be approximately half of the initial torque and obviously also the gasket load was reduced accordingly.

Even with this lower gasket load, the final leak rate was better than the leak rate measured right after assembly. The improvement in gasket sealability with working temperature more than compensated the gasket stress reduction occurred as an effect of the creep behavior of the material.

These results confirm previous high temperature leakage measurements made in our laboratories. Similar conclusions have also been reported by Latte & Rossi (2).

Gasket assembly stress calculation

The utilization of the Exact Method for the calculation of gasket assembly load was preferred because it is the true mathematical expression of the gasket behavior theory that forms the basis of the new PVRC gasket constants.

The calculation procedure described in the current draft of the new ASME Code (Convenient Method) introduced several correction factors that are not supported by basic theory.

Despite these facts, we made a calculation using the PVRC procedure to determine what would the predicted leakage be by using the gasket load as calculated by the Convenient Method. The table in Annex 3 shows the calculation procedure used and the predicted leakage values.

The predicted leak rates using the PVRC calculation method resulted to be

1.6 mg/s.m for an internal pressure of 16 bar and

1.2 mg/s.m for an internal pressure of 32 bar.

These figures are only slightly different from the 2 mg/s.m, in comparison with the actual leakage figures found in the testing and confirm that there is a significant difference between actual and predicted leak rates when using the new gasket constants theory to try to make leakage predictions.

CONCLUSION

The utilization of the new gasket constants concepts to try to make leakage predictions and infer field performance of a bolted flange connection will be hardly feasible because:

- **The leak rate obtained in actual bolted joint connections is significantly lower than the predicted** in the torque calculation procedure, even when measured at the same temperature (ambient) used for the determination of the new constants.
- With time and temperature the gasket material modifies its internal structure and **even though the gasket load is reduced due to the creep effect, the actual leak rate still remains much lower than the predicted one and in most cases shows even better figures than the initial leakage.**

RECOMMENDATION

Considering the above facts it is recommended that the new gasket constants concepts and calculation procedure should not be used neither for leakage prediction nor for performance analysis type of calculation.

The utilization of the new gasket constant concepts and calculation procedure should be used exclusively for flange design purposes, as originally meant.

REFERENCES

1. Determination of Design Gasket Assembly Stress With The New Constants - Exact Method. A.C.Guizzo. The 6th Technical Symposium of The Fluid Sealing Association. Oct/96.
2. Survey and Development of Design Rules for Flange Connections since 1943. J.Latte & C.Rossi. The 1st. European Conference on Controlling Fugitive Emissions from Valves, Pumps and Flanges, European Sealing Association. Oct/95.
3. Rules for Bolted Flange Connections with Ring Type Gaskets. Preliminary Committee Draft. PVRC. 5/93.

Gasket Stress and Bolt Torque Calculation - Exact Method

Annex 1

				2" #150	2" #300	2" #150	2" #300
Gasket:	OD:		mm	91,9	91,9	91,9	91,9
	ID:		mm	60,5	60,5	60,5	60,5
	Ai:		mm2	2869	2869	2869	2869
	Ag:		mm2	3761	3761	3761	3761
Tightness factor, Tc:				1	1	1	1
Fluid pressure, P:			bar	16	16	32	32
Gasket constants, d:				0,57	0,57	0,57	0,57
		Gb:	MPa	13	13	13	13
		a:		0,25	0,25	0,25	0,25
		Gs:	MPa	0,44	0,44	0,44	0,44
Bolts:		Nr.:		4	8	4	8
		Db:	in	5/8	5/8	5/8	5/8
		Ab:	mm2	146	146	146	146
Assembly eff.	Ae:			0,85	0,85	0,85	0,85

1. Tpmin = Tc*P/(10*.1013)*(1/(.002*D))^d =	Tpmin:	41,5	41,5	83	83
2. f(Tpa) = Gb(Tpa)^a-Gs((Gb(Tpa)^a)/Gs)^(logTpmin/logTpa)-P/10*(Ai/Ag)=0	f (Tpa):	0,000	0,000	0,000	0,000
	Tpa:	42,8	42,8	88	88
3. Sga = Gb(Tpa)^a	Sga, MPa	33	33	40	40
4. Sgmin = Sga-P/10*(Ai/Ag)	Sgmin, MPa	32	32	37	37
5. Wmo = (AgSga)/Ae	Wmo, N	147177	147177	176358	176358
6. Torque = 0,2Db*25.4/1000*Wmo/N	T, Nm	117	58	140	70
7. Bolt stress = Wmo/N/Ab	Sb, MPa	252	126	302	151
	Sb, psi	36591	18295	43846	21923
8. Sga final = Wmo/Ag	Sgaf	39	39	47	47

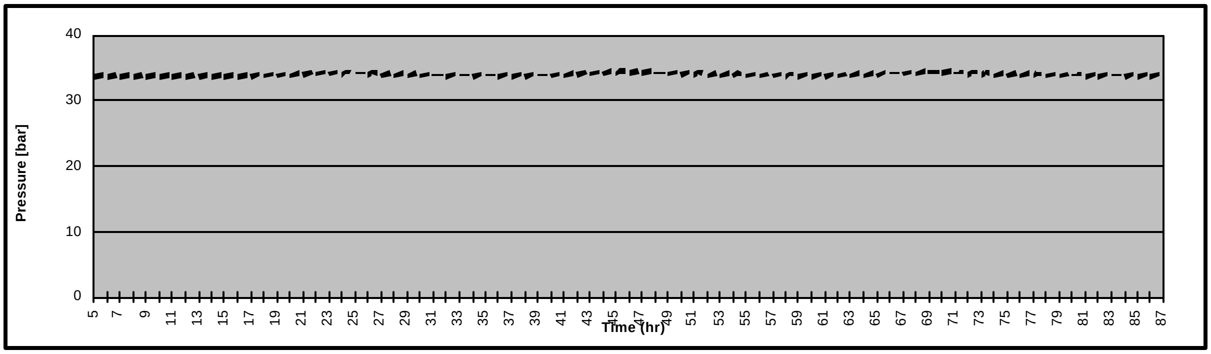
TEST DATA

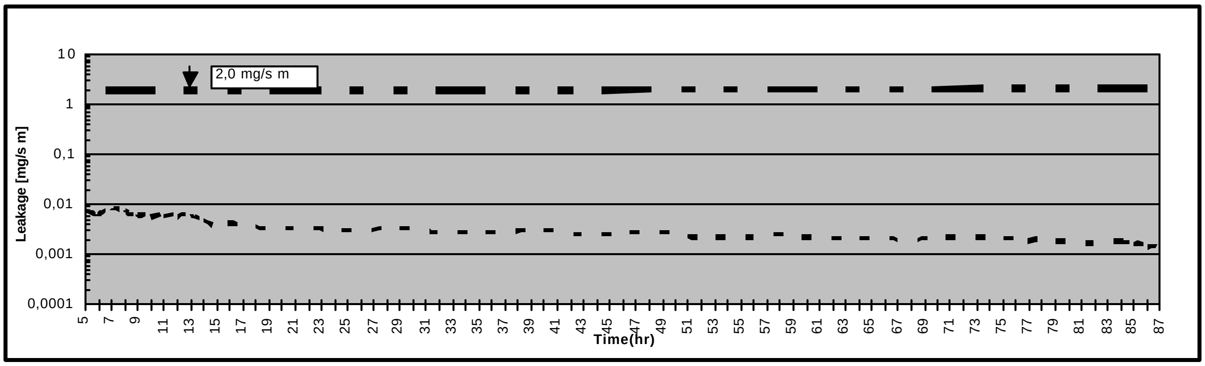
Annex 2

TEADIT - Laboratório Físico

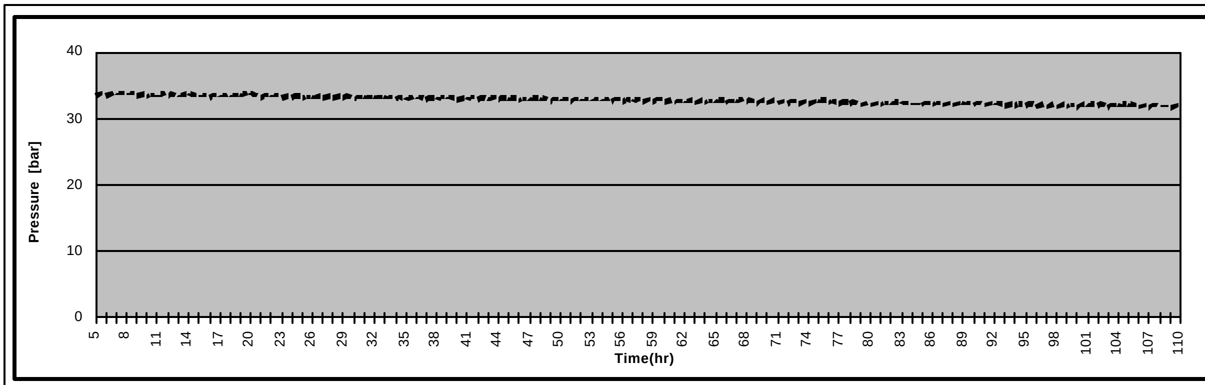
Test cell : Class 300 - T2 run 3
date : 08/97

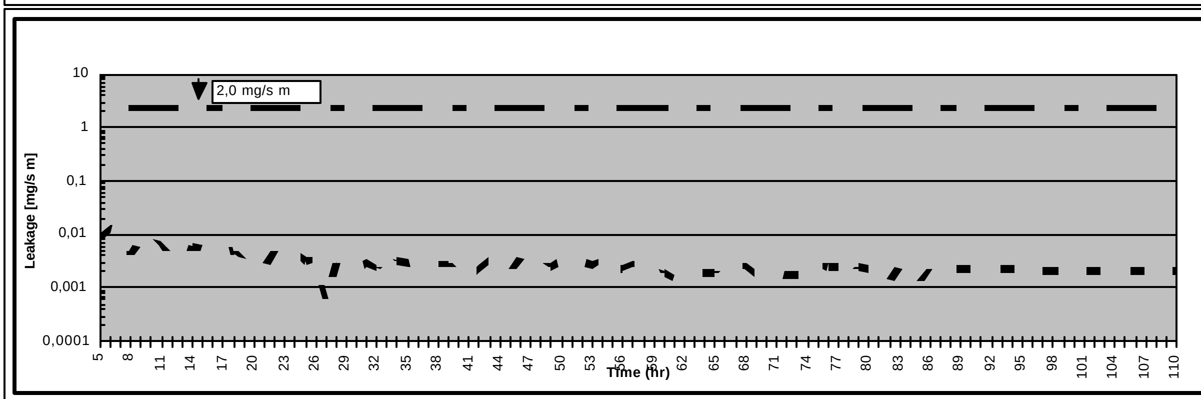
Ambient Temperature





260 °C





Leakage estimate, from a given gasket load

Annex 3

			2" #150	2" #300	2" #150	2" #300
Gasket:	OD:	mm	91,9	91,9	91,9	91,9
	ID:	mm	60,5	60,5	60,5	60,5
	Ai:	mm2	2869	2869	2869	2869
	Ag:	mm2	3761	3761	3761	3761
Tightness class, Tc:			1	1	1	1
Fluid pressure, P:		bar	16	16	32	32
Gasket constants, d:			0,57	0,57	0,57	0,57
	Gb:	MPa	13	13	13	13
	a:		0,25	0,25	0,25	0,25
	Gs:	MPa	0,44	0,44	0,44	0,44
Bolts:	Nr.:		4	8	4	8
	Db:	in	5/8	5/8	5/8	5/8
	Ab:	mm2	146	146	146	146
Assembly eff.	Ae:		0,85	0,85	0,85	0,85
A. Exact						
1. Wmo = (AgSga)/Ae		Wmo, N	147177	147177	176358	176358
2. Sga final = Wmo/Ag		Sgf, MPa	39	39	47	47
3. Sga = Wmo.Ae/Ag = Sgf*Ae		Sga, MPa	33,3	33,3	39,9	39,9
4. Tpa = (Sga/Gb)^(1/a)		Tpa	42,8	42,8	88,3	88,3
5. f(Tpmin) = Gb(Tpa)^a-Gs((Gb(Tpa)^a)/Gs)^(logTpmin/logTpa)-P/10*(Ai/Ag)=0		f(Tpmin)	2E-05	2E-05	-2E-05	-1E-05
		Tpmin	41,5	41,5	83,0	83,0
6. Lr = 1/((Tpmin*0,1013/(P/10))^(1/d))		Lr, mg/s	0,184	0,184	0,184	0,184
		Lr, mg/s.mm	0,00200	0,00200	0,00200	0,00200
Gasket constants, d:						
	Gb:	MPa	11	11	11	11
	a:		0,28	0,28	0,28	0,28
	Gs:	MPa	0,30	0,30	0,30	0,30
	Sl:	MPa	6,21	6,21	6,21	6,21
He = Fa + 4QMe/G			0	0	0	0
Ap			0	0	0	0
B. PVRC (Convenient)	Wmo, N		147177	147177	176358	176358
1. Smo = (Wmo-PAi-He)/(Ag+Ap)		Smo	37,9	37,9	44,4	44,4
2. Tpmin = (Smo*Ae/Gb)^(1/a)		Tpmin	46,5	46,5	82,0	82,0
3. Lr = 1/((Tpmin*0,1013/(P/10))^(1/d))		Lr, mg/s	0,1156	0,1156	0,1484	0,1484
		Lr, mg/s.mm	0,00126	0,00126	0,00161	0,00161
C. Ratio Exact/PVRC		Lr	1,6	1,6	1,2	1,2