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THE INFLUENCE ON THE STUFFING BOX OF THE FORCES GENERATED BY PACKING THERMAL EXPANSION

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ABSTRACT

This paper introduces a test device and a protocol that simulates a stuffing box to evaluate the packing expansion under different temperatures. This test device enables the measurement of axial forces at the bottom of the stuffing box and at the gland follower, the torque generated upon shaft turning and the influence of the thermal expansion on these measurements. It also enables comparisons between different braiding yarns materials such as e-PTFE, e-PTFE with fillers, Flexible Graphite and others. Test results showing these comparisons and correlations are reported.

NOMECLATURE

τ - Shaft torque
r - Shaft Radius
K - Lateral Deformation Factor
μ - Friction Coefficient
N - Number of Packing Rings
A - Contact area between the Packing and the Shaft
σ - Axial Stress
σ_i - Axial Stress on ith Ring
σ_1 - Gland Stress
$\Delta\sigma_1$ - Gland Stress Increment due to Temperature Increase
$\Delta\tau$ - Torque Increment due to Temperature Increase

INTRODUCTION

The number and size of braided packing rings used in pumps for different applications slightly varies from one manufacturer to another. However the type of packing materials used for different types of media, pressure and temperature varies greatly from one application to another. The influence of the number of packing rings, material and installation stress on stem torque and sealability was subject of previous studies [1] and [2]. On these diverse scenery it can be noticed that the installation procedures and recommended practices [3] are also different from one pump manufacturer to another as from one packing manufacturer to another and that they do not regard the influence of temperature.

Laboratory tests and subsequent field observations performed with different packing styles, pumps and media showed that the temperature has a major influence on packing behavior. It was noticed that some packings would behave well during plant start up but as the temperature rose to regime the packing would overheat and extrude making leakage control after that nearly impossible.

It was decided to investigate this phenomenon under controlled conditions to unravel the role of thermal expansion on packing behavior. The correlations among thermal expansion, stuffing box stress and the shaft friction force for different materials were carefully studied.

GLAND STRESS AND TORQUE TEST RIG

A test rig that simulates a stuffing box for 7,9mm (5/16in) cross section packing with a 50,8mm (2in) diameter shaft was developed to perform the studies as shown in Figures 1 and 2. This rig has a load cell at the bottom of the stuffing box that measures the residual force at the bottom of the last packing ring. It is equipped with two gauged bolts that indicate the force being applied on the packing by the gland follower. The shaft is incremented with a built in internal electric resistance (Figure 1 Item 9), to simulate systems heating up or cooling down, that allows testing at different temperatures. A torque meter can also be attached to the shaft edge to measures the force necessary to turn it.

The gauged bolts and the load cell values are recorded indicating all changes in the stuffing box axial forces due to thermal expansion and relaxation over the time.

FIGURE 1 – TEST RIG

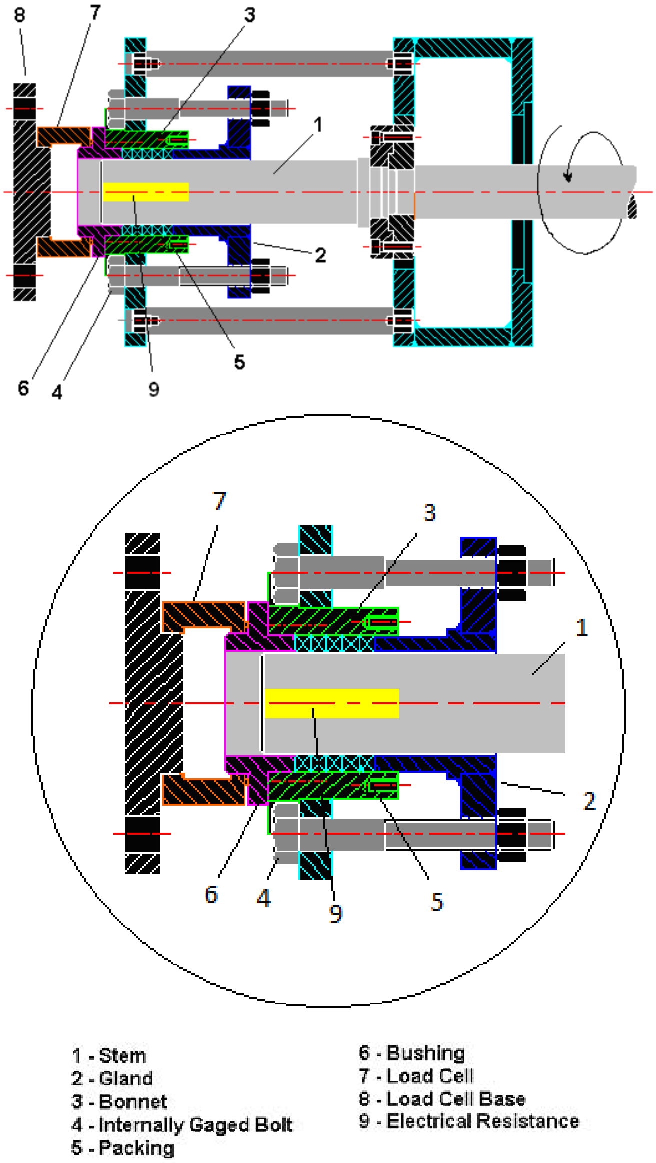

FIGURE 2 – TEST RIG SCHEMATICS

The shaft has a surface finish (R_a) of 0,8μm (32μin) and the stuffing box a surface finish (R_a) of 3,2μm (125μin). These values meet the requirements of surface finish for valves under API 600 [4], API 602 [5] and MSS SP 120 [6].

The bolts and the load cell service temperature throughout the test is less than 50ºC (125ºF). This temperature is 77% of their service limit once they are specified to endure temperatures up to 65ºC (150ºF). The working temperatures are show in Figure 3.

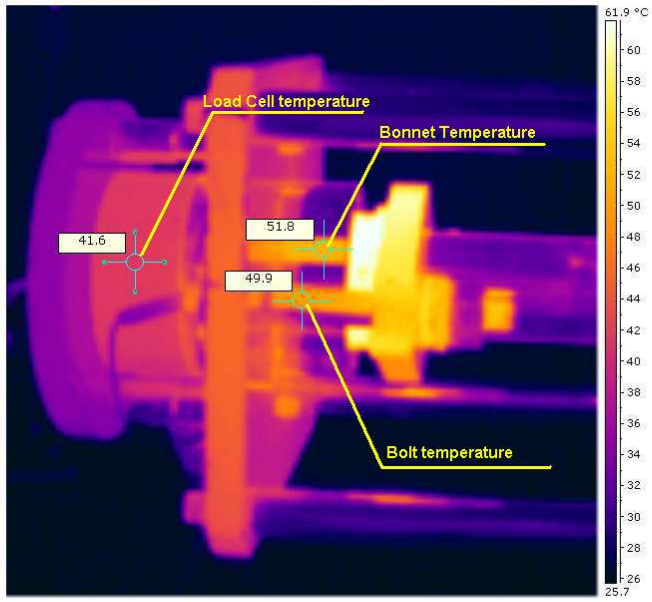

FIGURE 3 – TEST TEMPERATURES

TEST PROCEDURE

A test procedure was developed to analyze the different packing behavior when subjected to temperature cycles. This procedure enables an evaluation of the torque needed to turn the shaft and the axial stress variations due to temperature cycling:

1. The Rig is cleaned to assure that the shaft and the stuffing box are free from any unwanted material/dust.
2. Random loads are applied on a metal bushing to assure the load cell and the gauged bolts are correctly calibrated.
3. Five packing rings are installed with an initial stress of 50MPa (7252 psi) to seat the packing and the load on the last ring registered.
4. After one hour, the readings are registered and the gland bolts are relaxed to be again taken up until finger-tight.
5. The packing is allowed to relax for ten minutes and the loads on the gauged bolts and on the load cell are again recorded.
6. The temperature is increased to 100ºC (212ºF).
7. After a dwell time of twenty minutes the loads are registered.
8. The shaft torque is then measured using a torque meter. Four readings are made with a half-turn of the

shaft each. The first reading records the static torque while the three subsequent readings record the dynamic torque.

9. After the two complete shaft turns, the readings on the gauged bolts and on the load cell are registered.
10. The temperature is decreased to room temperature and steps 7-9 are repeated.
11. Increase the temperature 100ºC (212ºF) and repeat steps 7-9 to finish the test.

PACKINGS TESTED

The tests were performed for each of the packing styles described below, and their dynamic properties registered.

Packing Style A was built from 100% e-PTFE yarn.

Packing Styles B and C were built from Expanded PTFE (e-PTFE) yarns with Barium Sulphate as filler. The yarn used for packing Style C had more filler, in volume, than the yarn used for packing Style B.

Packing Style D was built from an e-PTFE yarn with Graphite filler. This packing Style has the highest quantity of filler in volume than all others.

Table 1 indicates the yarn and filler of each style tested while Table 2 indicates its approximate linear thermal expansion coefficients.

TABLE 1 – PACKINGS TESTED

STYLE	YARN	FILLER
A	e-PTFE	None
B	e-PTFE	Barium Sulphate
C	e-PTFE	Barium Sulphate
D	e-PTFE	Graphite

TABLE 2 – THERMAL EXPANSION COEFFICIENTS

MATERIAL	(10^{-5} K^{-1})
Steel	1
Barium Sulphate	1
Graphite	1
PTFE	12

The main difference between packing Styles A, B, C and D is the quantity of filler by volume. Packing Style A is made from pure e-PTFE and Styles B, C and D have fillers in ascending order by volume.

TEST RESULTS

GLAND STRESS x TEMPERATURE

The measurements of the gland stress recorded from the gauged bolts readings at the different steps of the test procedure are shown below. The number in parenthesis in the x-axis indicates which step the measurement refers to.

The tests were carried with two samples of each packing style. The results shown in Figure 4 indicate that there was a very small difference between one sample and the other and the results before and after torque. This was also true for all the other packings tested.

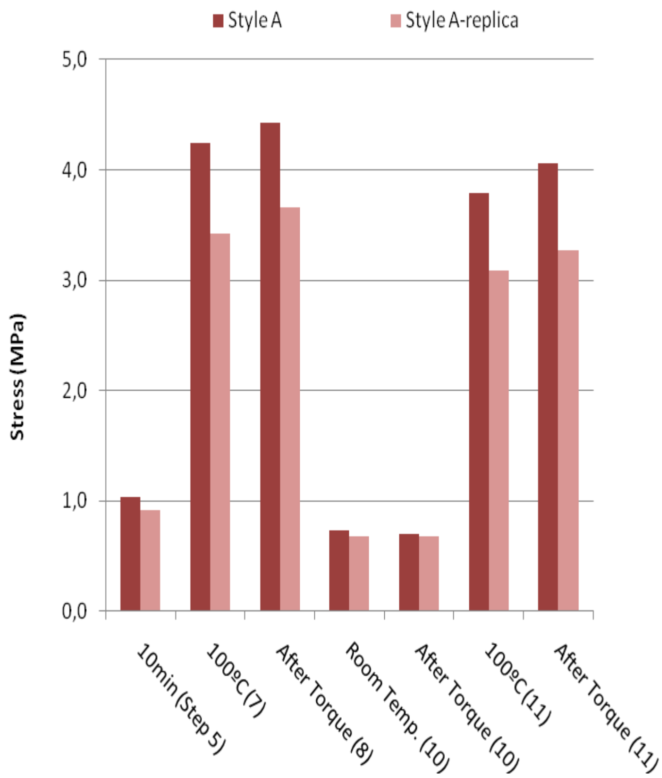

FIGURE 4 – GLAND STRESS x TEMPERATURE STYLE A: e-PTFE - FULL

In order to better analyze the influence of temperature on the different packing materials being studied and simplify the above Figure, the charts illustrated below were plotted (Figures 5 through 8) indicating only the gland stress measured at:

- room temperature (Installation Procedure Step 5);
- 100ºC (212ºF) (Step 8);
- room temperature after torque (Step 10) ;
- at 100ºC (212ºF) after torque (Step 11).

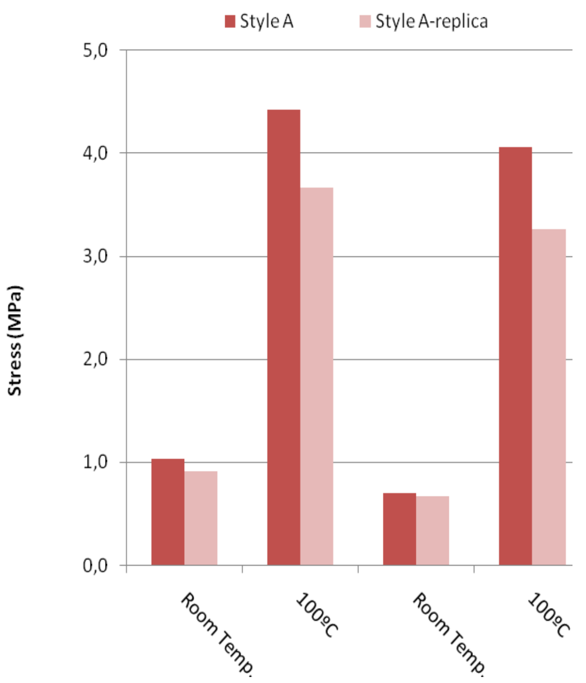

FIGURE 5 – GLAND STRESS x TEMPERATURE
STYLE A: e-PTFE
(100% PTFE in Volume)

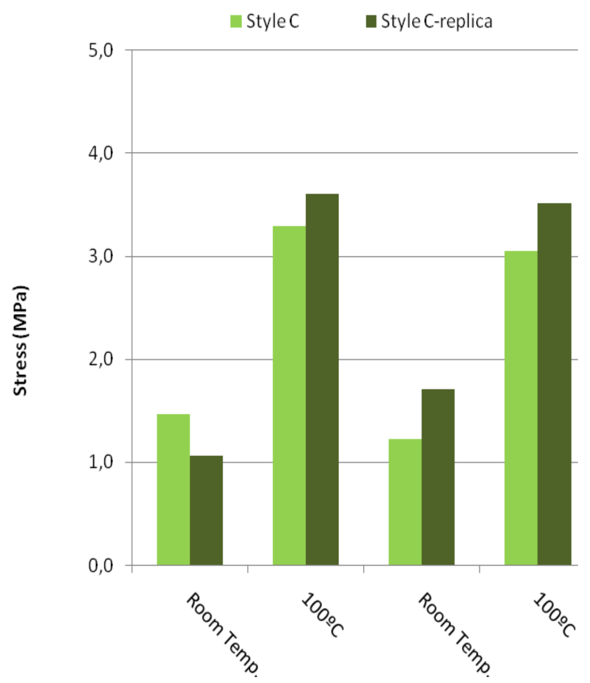

FIGURE 7 – GLAND STRESS x TEMPERATURE
STYLE C: e-PTFE
(Less PTFE than Style B in Volume)

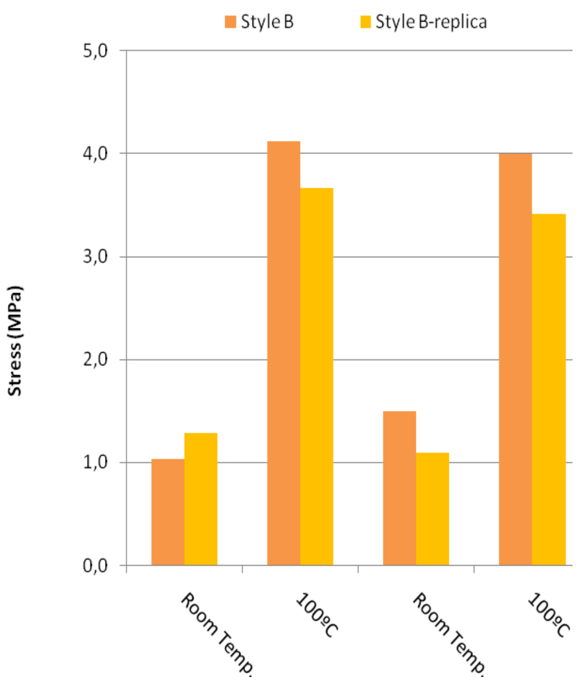

FIGURE 6 – GLAND STRESS x TEMPERATURE
STYLE B: e-PTFE
(Less PTFE than Style A in Volume)

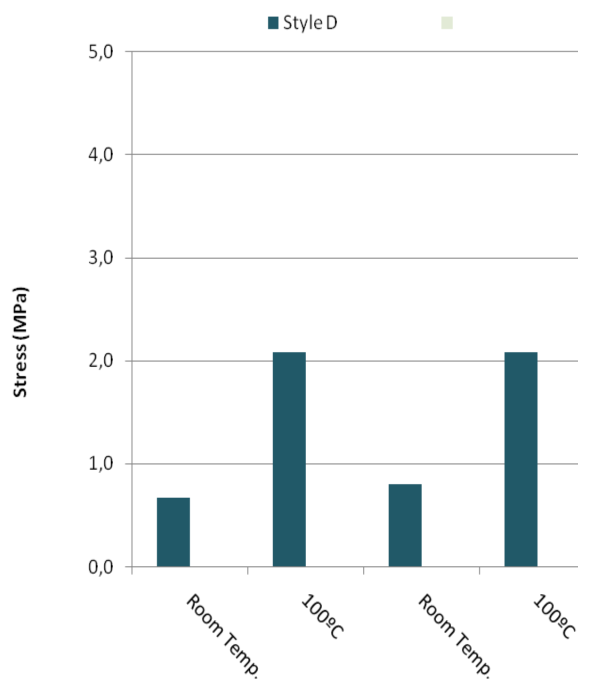

FIGURE 8 – GLAND STRESS x TEMPERATURE
STYLE D: e-PTFE
(Less PTFE than Style C in Volume)

Charts show that the gland stress increases as the temperature rises from room to 100ºC (212ºF). It can be also noticed that the stress for Style A is about four times greater at 100ºC (212ºF) than at room temperature. Comparing the e-PTFE yarn packings it can be observed that as the filler quantity increases the gland stress at 100ºC (212ºF) decreases.

SHAFT TORQUE x TEMPERATURE

In a previous PVP paper [2] the authors had proposed the following equation to calculate the shaft torque and determine $\mathrm{K} \cdot \mu$ with test rig being used in this study.

$$\tau = r \cdot \mathrm{K} \cdot \mu \cdot \sum_{i=1}^{N} \sigma_i \cdot A_i \qquad (1)$$

According to the formula above the variation of the shaft torque is directly affected by the gland stress, σ_1.

The increase in gland stress, $\Delta\sigma_1$, from room temperature to 100ºC (212ºF) is shown in Figure 9. This value is calculated by subtracting the gland stress value at 100ºC (212ºF) from the first measurement at room temperature. Both values are after torque measurement (procedure step 11 minus step 10).

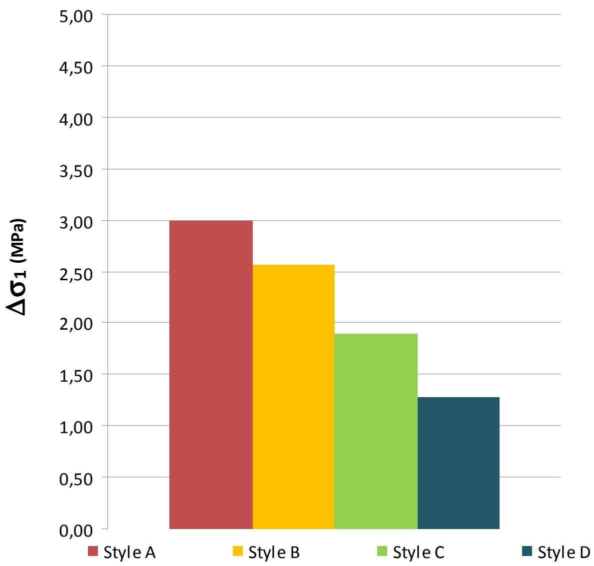

FIGURE 9 – GLAND STRESS INCREASE DUE TO TEMPERATURE INCREASE

The chart shows that Style A has a $\Delta\sigma_1$ nearly three times greater than Style D.

It also shows that Style D, the e-PTFE packing with the least PTFE content in volume, generated low thermal expansion forces.

From the chart it is also possible to see the direct correlation between the amount of PTFE that each packing and the gland stress increase with temperature. The higher the PTFE content (in volume) the higher the gland stress increase, $\Delta\sigma_1$.

The effects of these variations on shaft torque are shown in Figure 10.

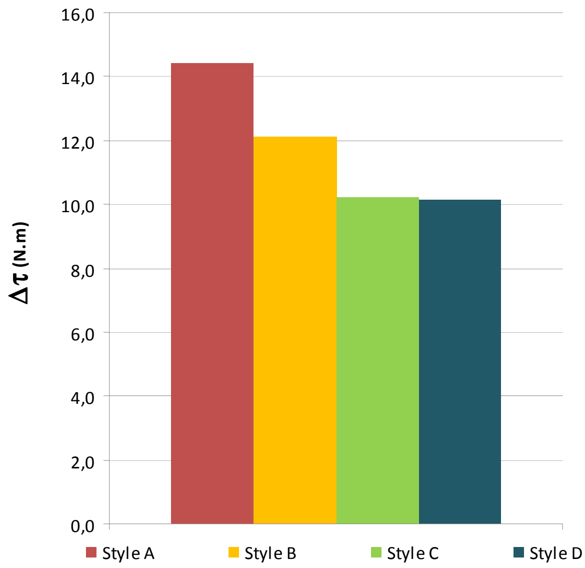

FIGURE 10 – TORQUE DIFERENCE DUE TO TEMPERATURE INCREASE

Comparing charts from Figure 9 and Figure 10 it can be observed that both, gland stress and shaft torque, exhibit the same behavior.

The above graphs illustrate the large influence of PTFE on packing expansion, on gland stress and shaft torque.

PUMP SIMULATOR TEST RIG

The packings were also tested in a Pump Test Rig that simulates the working conditions of a pump. The main packing performance parameters like leakage, power consumption and number of gland packing adjustments are monitored in a 100-hour test. A scheme of the Test Rig is illustrated in Figure 11 and the actual Rig is shown in Figure 12. The test parameters are shown in Table 3.

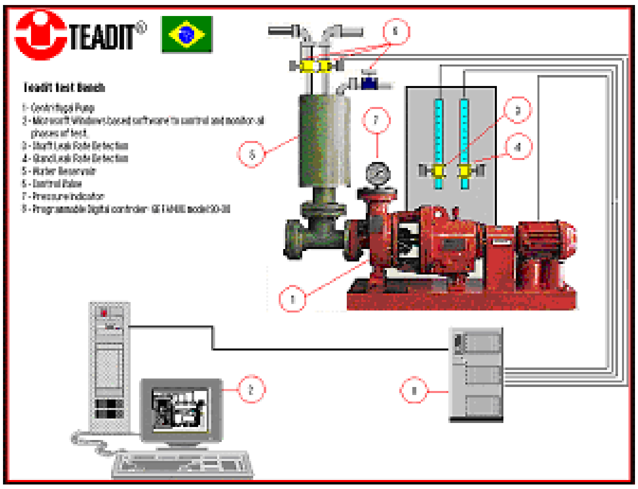

FIGURE 11 – PUMP SIMULATOR TEST RIG SCHEMATICS

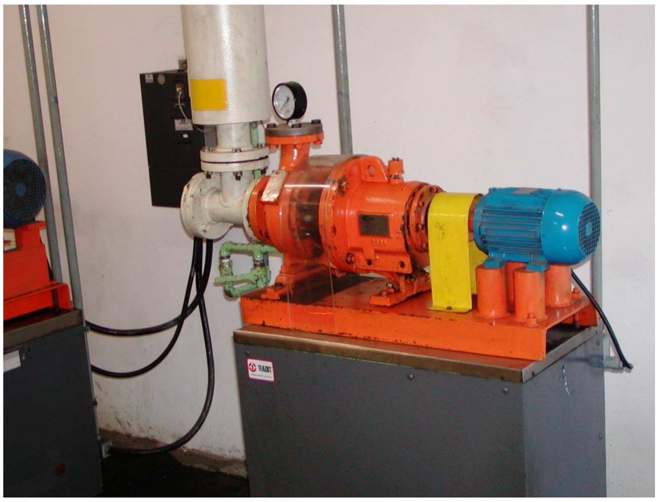

FIGURE 12 – PUMP SIMULATOR TEST RIG

TABLE 3 – TEST PARAMETERS

DESCRIPTION	PARAMETER
Shaft Speed (max.)	4.35m/s (14fps)
Shaft Size	47mm (1,8in)
Packing Cross-section	9,5mm (3/8in)
Number of Rings	5 rings
Test Media	Water
Media Pressure	6 bar (87psi)
Test Duration	100hours

The leak rates along the shaft side and along the stuffing box side were controlled at all times throughout the tests.

The pump test leak rate results for packing style A, B C and D are shown in Figures 13, 14, 15 and 16.

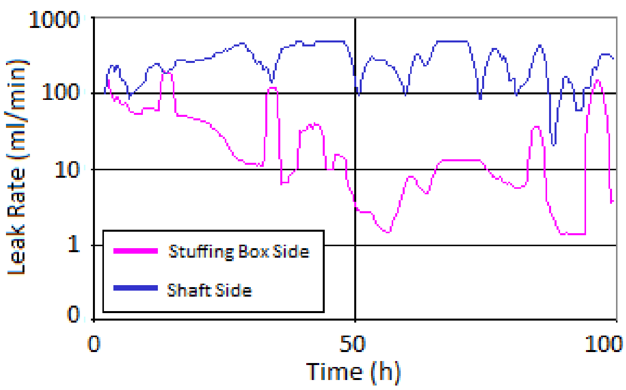

FIGURE 13 – STYLE A LEAKAGE TEST RESULT

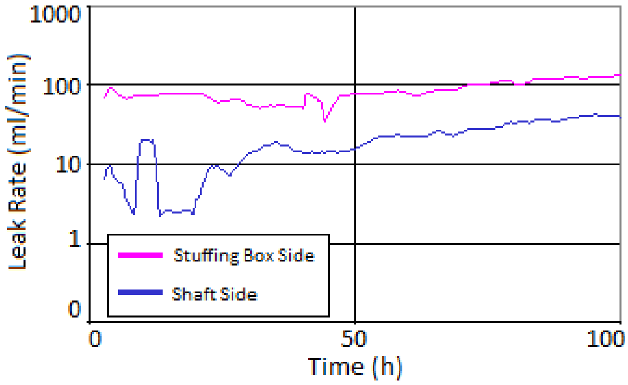

FIGURE 14 – STYLE B LEAKAGE TEST RESULT

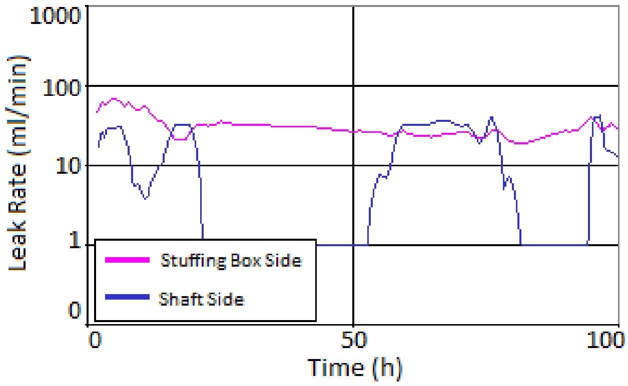

FIGURE 15 – STYLE C LEAKAGE TEST RESULT

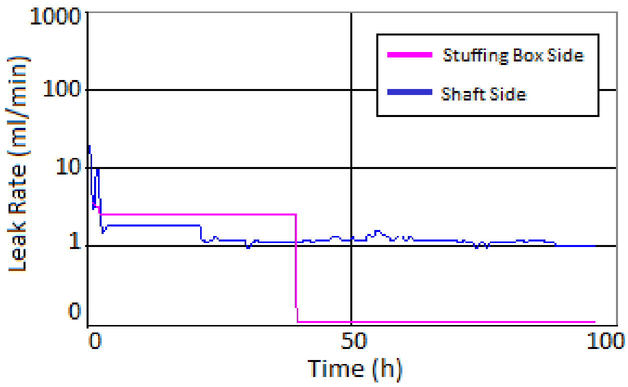

FIGURE 16 – STYLE D LEAKAGE TEST RESULT

Even under Laboratory conditions it was extremely hard to control the leak rate for Styles A and B. These packings showed very high leakages as every gland adjustment would lead to temperature increase and consequent scorch of the packing and leak rate increase. Style C demonstrated good performance reacting well to gland adjustments. Style D, as expected, had the best result of the four packings tested, keeping the leak rate under 3ml/min.

The Test summary chart can be seen in the table below (Table 4).

TABLE 4 – SUMMARY CHART

Packing Style	Average Leakage (ml/min)
A	313
B	107
C	44
D	3

CONCLUSIONS

The tests show that thermal expansion plays a major role on how packing will perform on pumps. Packing expansion due to temperature variations can greatly increase stuffing box internal stresses leading to high shaft torque and eventually scorching the packing. The opposite can also happen when during systems cool down, the reduction on gland stress leading to high leak rates.

Test results also indicate that higher the PTFE content (in volume) the higher the gland stress increase and the hardest it is to control leakage on pump applications.

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