WEAR EVALUATION OF ELASTOMERIC SEALS USED IN AN OIL WELL STUFFING BOX

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Abstract. *A beam pumping unit (commoly referred to as horsehead pump), used in petroleum production, converts the rotary mechanism of an electric motor to a vertical reciprocating motion to drive the pump shaft, through sucker rod lines. The pump is located underground in the oil reservoir and raises deriving fluids to the surface. In this work, an experimental test rig was built to simulate the sealing circumstances of the tribological pair rod-seal package of a oil pumping unit in a 1:1 scale. A friction evaluation was carried out by fitting an axial and circumferential mesh of thermocouples to the stuffing box with the objective to get a thermal mapping of cylindrical external surface and thus mapping the temperature field around the seals. The interrelation between the temperature field and the contact pressure of rod-seal is discussed. The work attempt to identify eventual misalignment of the polished rod in relation to stuffing box what may cause a oil leakage. Scanning Electron Microscope (SEM) analysis of seal contact surface were carried out before and after experimental tests trying to associate the severity of thermal cycles with wear mechanisms in elastomeric compounds.*

Keywords*: Tribology, wear, elastomeric seals, thermal mapping*

1. INTRODUCTION

The beam pumping unit (commonly referred to as horsehead pump) is the most used artificial elevation method in the world. This pumping unit converts the rotary mechanism of an electric motor to a vertical reciprocating motion to drive the pump shaft, through sucker rod lines. The pump is located underground in the oil reservoir and raises produced fluids to the surface.

These rods work in abrasive and corrosive environments. They are subject to cycling loadings, since the fluid weight above the pump is supported by the rod string during the upstroke movement and during downstroke movement the weight is supported by the production column. Due to this stress alternation the rod lines become a critical point in the entire system. The section of a rod string subject to a highest tension stress is in the polished rod, since it supports the following loads: rod string weight, hydrostatic force, acceleration force, friction force and fluid weight.

The polished rod is the first rod at the top of the string and it has this name due to its polished surface. The objective for its utilization is to promote together with the seal package the sealing between the pumping unit and the wellhead.

Misaligned wells usually cause a high friction between the rod string and the stuffing box and cause loading increase in the polished rod, besides a premature wear of seal and the polished rod, in high stress regions. The result of this excessive friction and the consequent seals wear is a failure in the sealing system, which promote a production stop for repairs, beside the environmental pollution due to the leakage od production fluids.

This work attempt to establish a method to locate the regions where occur the higher thermo mechanical efforts from a thermal mapping of the stuffing box.

The high temperature resistance is a critical factor in seal packages used in pumping units, since the highest temperature is located in the dynamical interface of sealing and besides, this interfacial temperature is very difficult to measure and predict during operation. All elastomers are affected in a such way by high temperatures and the seal life is reduced with the raise of this temperature. (KALSI, 2001).The first effect of high temperature in elastomers is the softening of the compounds, in other words, a modification in their physical properties. The temperature-hardness-wear correlation is therefore no longer verified (FOUVRY *et al*, 2007).

Such an application necessitates specific material properties such as thermomechanical and tribological behaviours. These requirements led to investigate relationship between properties and tribological behaviour of filled elastomers. (THOMINE *et al*, 2007). In this way, besides the SEM, the seal hardness was used as a parameter for wear evaluation. The wear rate would be the quantification method normally used, however, in the specific case of a oil pumping unit, the volume of worn material can be covered by the absorption of oil by the seals.

2. MATERIALS

A package with three acrilonitrile-butadiene rubber (NBR) seals, filled with silicon dioxide (SiO2), was used in the experiment, with dimensions of 0,05715 m X 0,03175 m X 0,02222 m and a Shore A hardness of 85. An AISI 316 stainless steel polished rod, with diameter of 0,003175 m and 1,0 m long, with a roughness R_a = 0,43 µm is used against the seal package. Both elements are shown in Fig. 1.

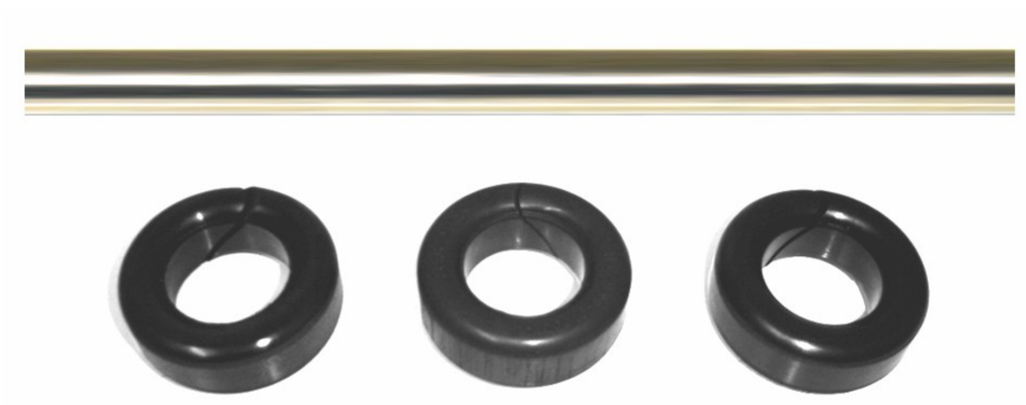

Figure 1. AISI 316 stainless steel polished rod and NBR seals

3. EXPERIMENTAL TECHNIQUES

An experimental test rig with reciprocating motion was developed to simulate the tribological behavior of the sealing elements of a beam pumping unit. The sealing elements of the test rig were the same of a real beam pumping unit.

The developed test rig is shown in Fig. 2. It is powered by a three phase electric motor (1,5 CV and 1700 RPM). This rotation is reduced by a reduction gearbox (ratio of) and a chain drive and it resulted in a final ratio of resulting in a final rotation of 39 rpm. The rotating movement is converted to a vertical reciprocating motion using a crank mechanism.

Scanning Electron Microscope (SEM) analysis were carried out before and after experimental tests in order to investigate qualitatively the wear evolution in seal contact surface of seals.

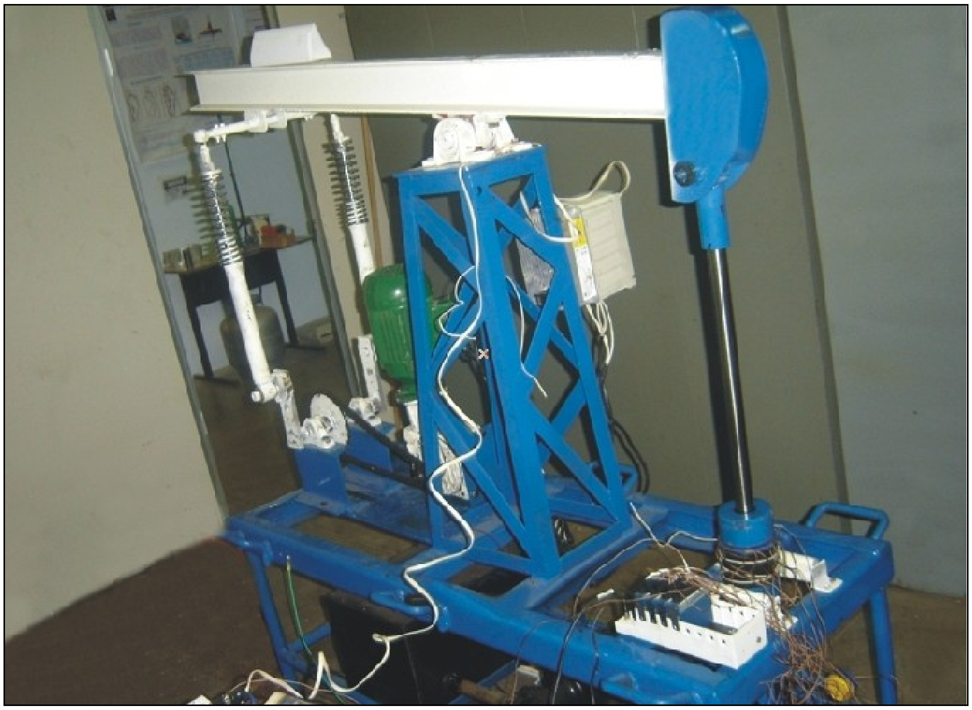

Figure 2. Experimental test rig with reciprocating motion

The thermal history was measured and collected using a data acquisition board, NI USB4350 model, connected to computer, with a sample rate of 1.0 point/second. Twelve J-type thermocouples were connected to the board, as shown in Fig. 3, and one thermocouple was used to register the room temperature. During the test, the laboratory temperature was kept constant in a range of 299 ± 0,5 K.

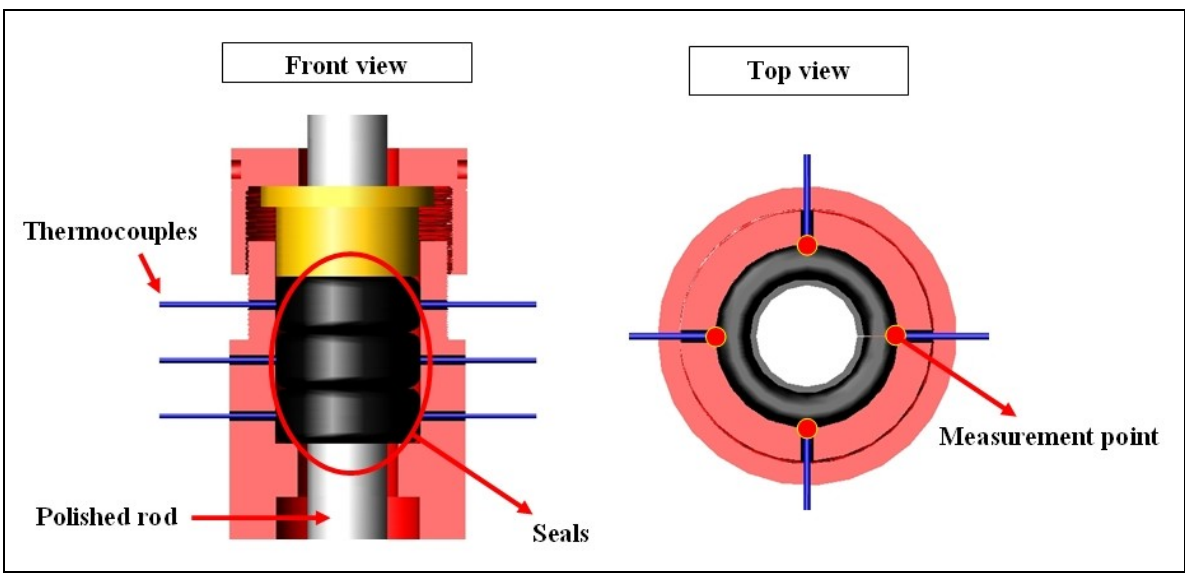

Figure 3. Thermal mapping of stuffing box

The reciprocating motion test rig has a petroleum circulation system to simulate real operating conditions.

The hardness of seals was measured before and after tests in order to investigate a possible change in this propriety indicating some type of wear.

4. RESULTS AND DISCUSSION

4.1. Scanning Electron Microscopy on seal

The SEM images of internal surface of the top seal, as no used condition, are shown in Fig. 4. The parallel vertical lines, as shown in all images, are marks derived from the manufacturing process of the seal mould (machining for example). The clearer points present in all the images indicate the presence of fillers. However, the amount of these particles is not distributed uniformly across the sealing surface; the position 9 has the larger amount of filler and the position 12 has the least amount. Filler particles with 50 μm were observed when a 500x zoom was used.

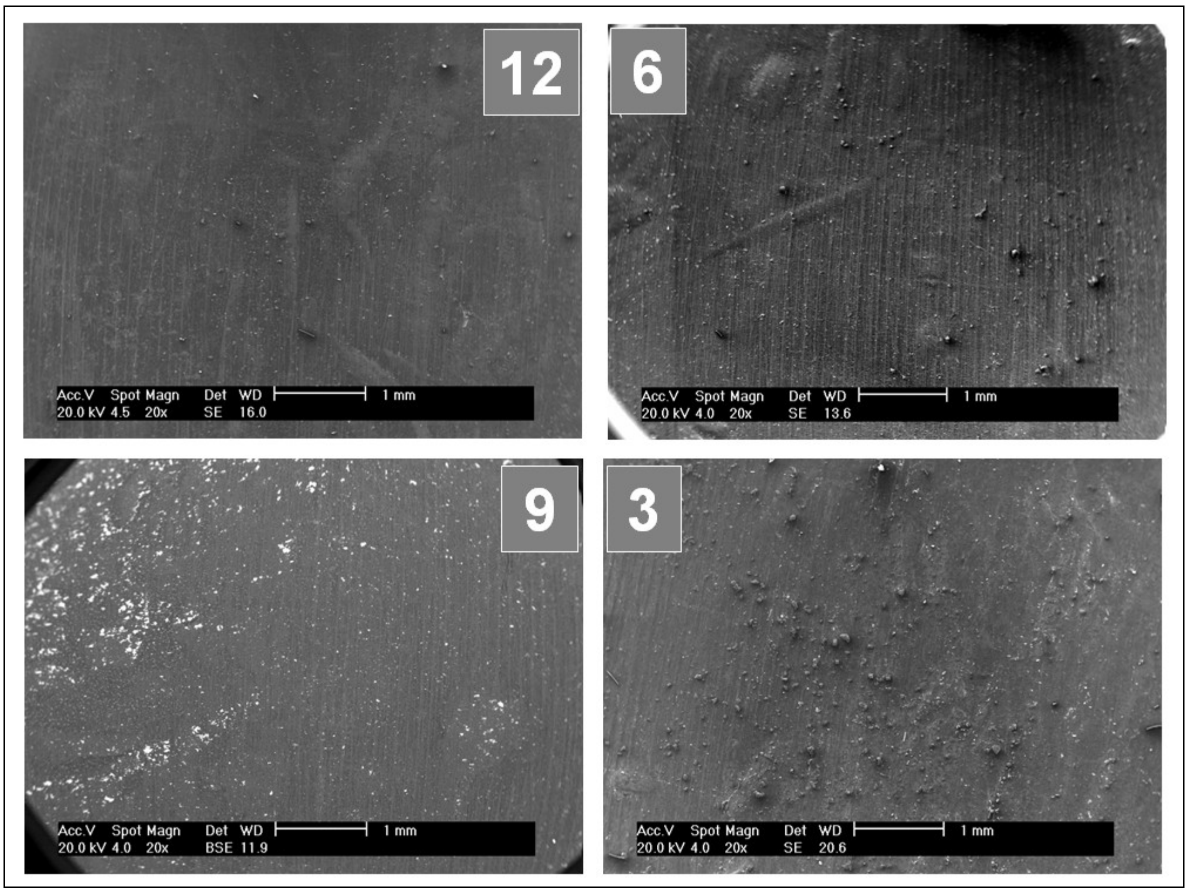

Figure 4. SEM images of internal surface of the top seal, as worn condition

The SEM images of internal surface of the top seal, as worn condition, are shown in Fig. 5, in the same positions of figure 4. The vertical lines observed when the seal was not used were eliminated as seen in all images. Horizontal lines in sliding direction were observed after the tests. A more severe wear in position 9 is evident followed of position 3. The positions 12 e 6 did not present wear.

The damage in position 9 allowed the petroleum flow to the contact interface, what configures a oil leakage in real operating conditions. In order to stop the leakage, the oil well production would be interrupted to maintenance.

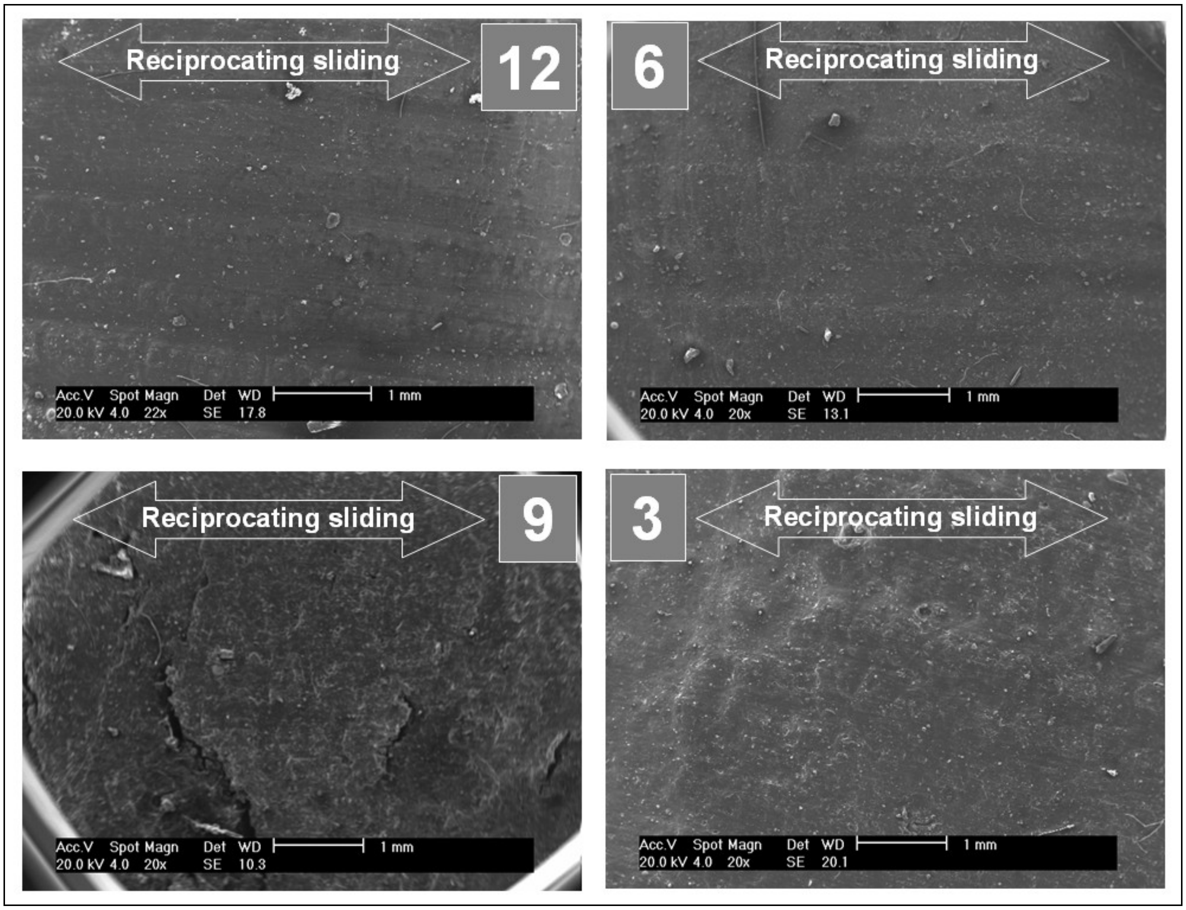

Figure 5. images of internal surface of the top seal, after test

4.2. Thermal mapping at stuffing box

A misalignment was set purposely between the polished rod and the stuffing box. The objective of thermal mapping is to identify this misalignment. Fig. 6 shows this misalignment in stuffing box region.

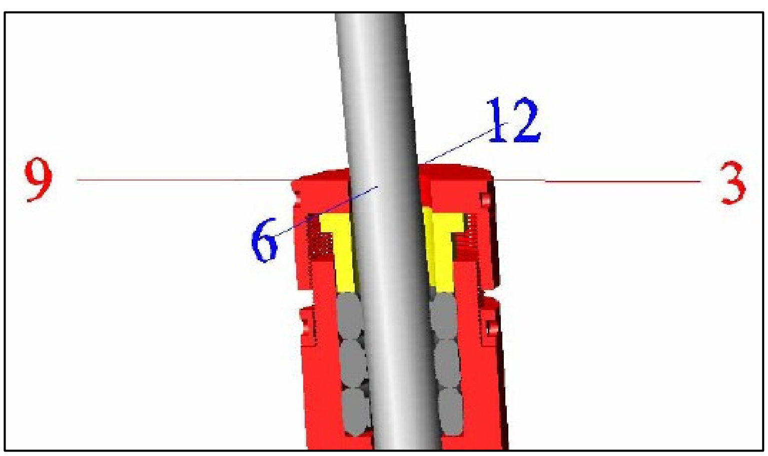

Figure 6. Misalignment in stuffing box region

The graphic present in Fig. 7 shows the thermal history of stuffing box. The curves indicate the registered temperatures in positions: top 12, top 3, top 6, top 9, center 12, center 3, center 6, center 9, low 12, low 3, low 6 e low 9. These curves show a similar behavior for all positions. The low curve indicates the room temperature behavior.

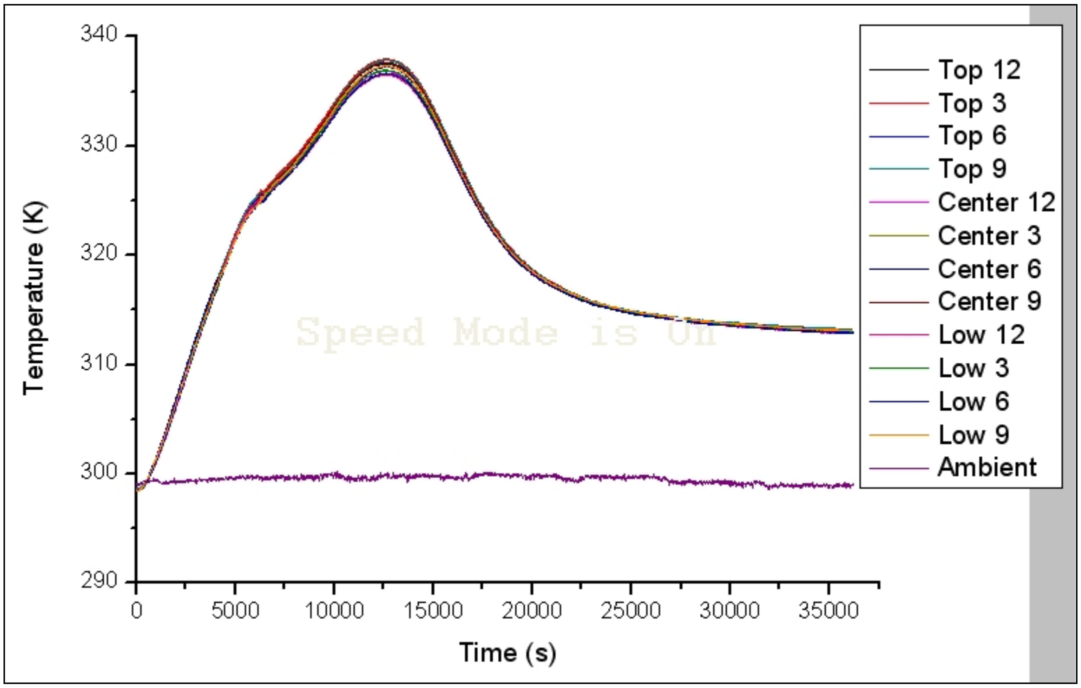

Figure 7. Thermal history of stuffing box

In this graphic a running-in period can be indentified up to the first 13000 seconds. After that the seal package failed and then a oil leakage happened. This event cool the contact surface what reduced the registered temperatures along the test until reach a steady-state period, after 35000 seconds. This situation determined the end of test criteria. The seal packing failure is observed in Fig. 8 which shows the smoke generated in contact surface, resultant of the fusion of the sealing surface of top seal.

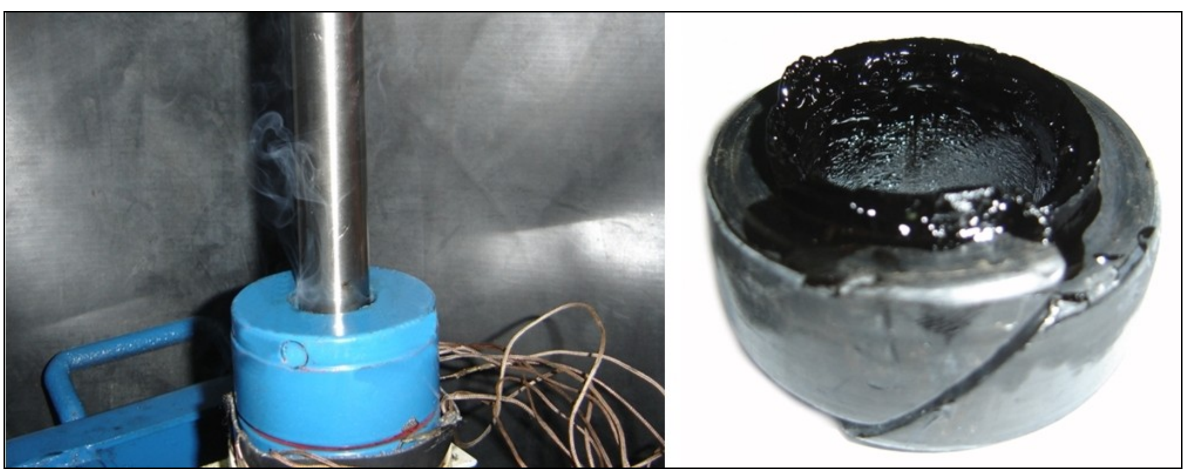

Figure 8. Smoke generated in contact surface, and fusion of the sealing surface of top seal.

In order to make the visualization of registered temperatures easier, the graphic in Fig. 7 was edited in figure 9, where different region temperatures (3, 6, 9 and 12) were separated. It is observed clearly for all regions that the top seal was the most affected thermally, followed by the center seal and the least affecter was the low seal.

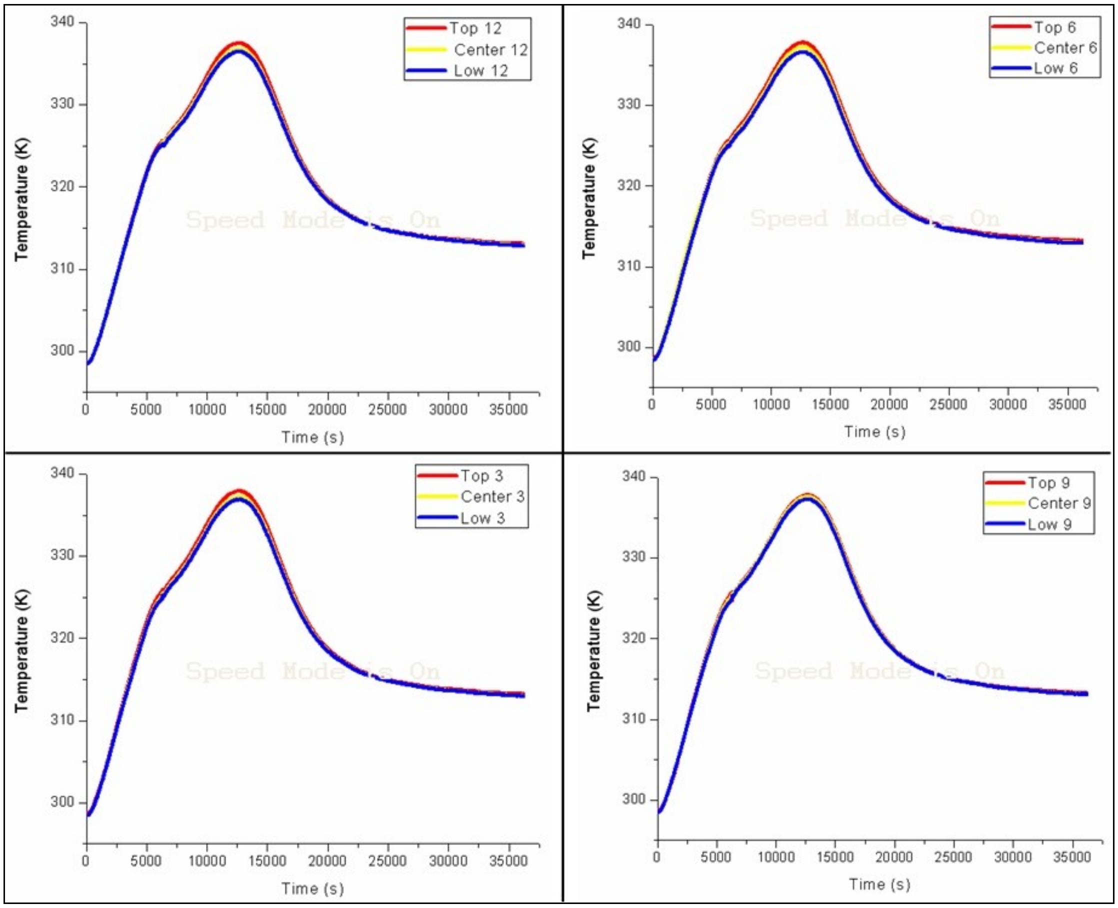

Figure 9. Thermal story of stuffing box separated by regions

The graphic of Fig. 7 was edited again in Fig. 10 in order to improve the visualization of the regions most affected thermally. The graphics only show the steady state period at the end of the test, however this behavior kept similar along the test. In this figure is observed that the 9 – 3 direction is the most affected thermally, mainly the region 9. In otherwise, the 12 – 6 direction is the least affected thermally. This variation is due to the set misalignment between the polished rod and the stuffing box. In the region where the seals are more compressed, the friction force is consequently higher, and the registered temperature is higher too.

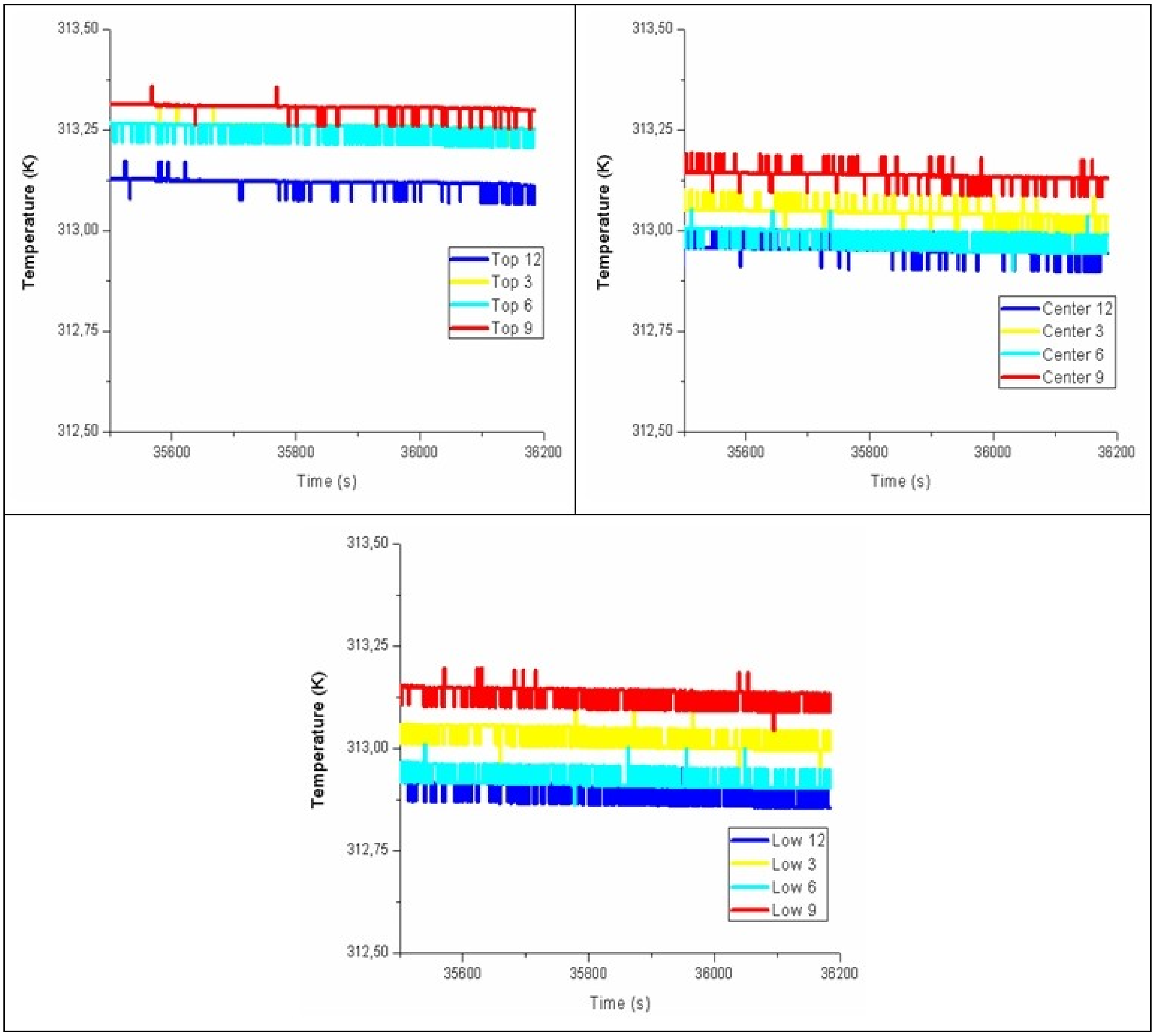

Figure 10. Thermal story of stuffing box separated by seals

4.3. Variation hardness of the seals

The hardness of the seals before and after test is shown in chart 1.

Table 1. Variation hardness of the seals

Seal	Hardness
Top – not used	85 ± 0,25
Center – not used	85 ± 0,25
Low – not used	85 ± 0,25
Top – after test	78 ± 0,25
Center – after test	81 ± 0,25
Low – after test	82 ± 0,25

The Shore A hardness of the NBR seals were affected significantly after all tests. The top seal hardness was reduced by 8,23% , the center seal hardness was reduced by 4,70% and the low seal hardness was reduced by 3,53%. This behavior was confirmed by PARKER O-ring Handbook which defines the hardness loss as the first effect oh high temperature on elastomers and confirms the wear occurrence.

5. CONCLUSIONS

1. The adopted thermal history, SEM analysis and hardness lost of the seals were an efficient approach to determinate the seal damage caused by the misalignment between the polished rod and the stuffing box;
2. The laboratory test rig developed in this work reproduced successfully the contact pressure and seal temperature role under reciprocating conditions of the tribological pair seal-polished rod without necessity to stop the oil production.

6. ACKNOWLEDGEMENTS

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