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DEVELOPMENT OF A TEST RIG AND PROTOCOL FOR EVALUATION OF PACKING SEALABILITY AND DRAG FORCES ON KNIFE GATE VALVES

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ABSTRACT

Knife gate valves design is particularly special in terms of mechanical packing installation. In other valve types, the packing is installed in a round stem, which yields the packing to a ring-like format, while on knife valves the geometry of the gate requires that the packing be installed in a rectangular shape. The dynamic of the sealing, therefore, could be different from the usual, however, there is not much information available about this type of valves. This paper introduces a testing device and protocol to evaluate different packing styles performance on knife valves. The device enables the evaluation of sealability and the drag forces associated with packing friction. The testing varies the type of packing materials and the installation torque indicating how they correlate to packing drag and sealability. Test results are reported with comparative data among these configurations and the outcome should aid on packing design.

1. INTRODUCTION

KGV's were initially developed with isolation purposes in paper and pulp mills and to handle slurry in mining industry. The design of said valves is versatile and enables a great performance and reliability in many applications, when compared to conventional valves. Such characteristics led KGV's to become a good general choice when a mixture of liquid and solids is involved. Today, KGV's are widely used in mining, pulp and paper, chemical and petro-chem, waste treatment, steel, food and beverage, powder and bulk and other process industries.

The gate leakage on KGV's is usually handled with mechanical packings, which are installed around the knife in a rectangular manner. The basic concept of packing sealability is the same as for regular valves – where packings are installed around a circular shaft or stem: the packing must conform around the gate and fill all the voids that could become a leaking path. The rectangular form of the gate and stuffing box, however, promotes an unusual sealing environment that implicate on a different operation dynamic than what packing researchers and manufacturers are used to.

The evaluation of packing performance is becoming more important and more on focus since the regulatory demands are stricter every past year. Standards and guidelines are published, reviewed and updated intensively, providing approval criteria and test parameters that allow a proper evaluation. Specifically for KGV's, MSS SP-81 establishes manufacturing tolerances and through seat leakage acceptance criteria for these valves but gives no information regarding external leakage or packing requirements. Research and development of packings provide information on packing minimum seating stress, quantity of packing installed rings and packing thermal expansion correlation with its performance, internal pressure and sealing correlation for several packing styles and materials. Concerning KGV's, however, very little information can be obtained on how the packing behave and what influences its performance when subjected to rectangular stuffing boxes as opposed to a stem or a shaft.

In this paper, a testing device composed by a KGV and a testing protocol were developed to evaluate how different packing materials and installation stresses correlate to packing sealability and friction force exerted on the gate in this type of valve.

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2. TEST RIG

A 6” Class 150 modified knife gate valve composed the apparatus used to perform the study. The rig enabled the evaluation of both external leakage and the friction forces generated by the packing stress. The valve seat was removed to assure that there was nothing contacting the gate except for the packing and the test fluid. The resistive forces exerted on the gate will, therefore, consist of packing drag, gate weight and fluid pressure acting on the end of the gate. The valve details are described below:

- Size: 6” #150
- Gate: 6.5” x 0.30” (Sa = 1.95 in² gate area)
- Number of Rings: 4
- Packing Length and Cross-section: 15.3” and 0.375”
- Studs: 2 x ½”
- Actuator:
  - 2” bore cylinder
  - 1” Cylinder rod

Three pressure transducers were used to determine the gate drag, two installed on the hydraulic actuator and one on the pressurized system. Figure 1 below shows an image of the modified valve/actuator with two pressure transducers installed. The top transducer measures the pressure applied on the upper face of the actuator piston, while the bottom transducer measures the pressure exerted on the lower face of the piston.

Figure 1 – Modified Test Valve

The media used for the tests was clean water. Once the valve starts to cycle and the gate advances into the body of the valve, the movement implicates an increase of the system pressure, which would require the removal of excess fluid to keep the inner pressure constant. As the gate opens, on the other hand, the problem occurs on reverse, implying the need to supply make up fluid. Compressed air was then used to compensate the fluid displacement generated by the gate movement, minimizing the problem. Figures 2 and 3 below show and schematic of the rig installation and the test rig itself.

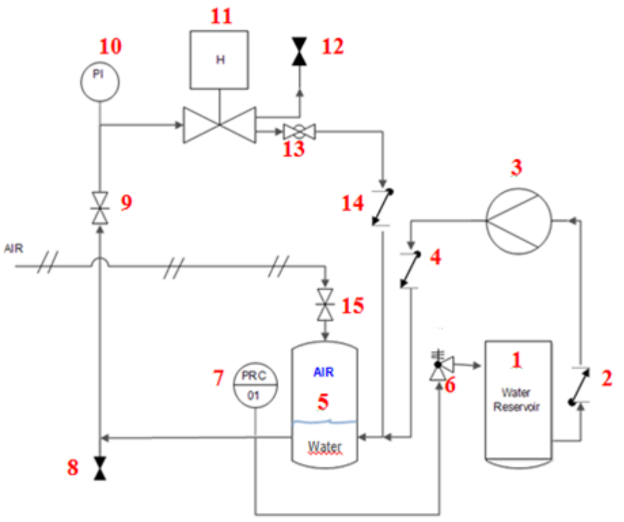

Figure 2 – Test Rig Schematic

Figure 3 – Test Rig

KEY:

1) Water Reservoir
2) Check Valve
3) Alternative Pump
4) Check Valve
5) Water/Air Pressure Vessel
6) Relief Valve
7) Pressure Register
8) Water Bleed Valve
9) Needle Valve
10) Pressure Indicator
11) Actuator and KGV
12) Air Bleed Valve
13) Ball Valve
14) Check Valve
15) Needle Valve
16) Pressure Register
17) Pressure Register
18) System Controller

As mentioned, the Water/Air Pressure Vessel (5) is partially filled with water and compressed air, and the rest of the rig is completely filled with water. With the feeder pump (3) the media pressure is increased to the desired test pressure. The Pressure Register (7) monitors the inner pressure and, if the pressure drops below a specified value, the System Controller (18) starts the feeder pump to compensate the media leakage.

To collect the data, the platform from National Instruments - NI LabVIEW® [6] was used. A program was developed exclusively for the valve and the module collected data at a rate of two samples per second. The program developed can be seen in Figure 4 below:

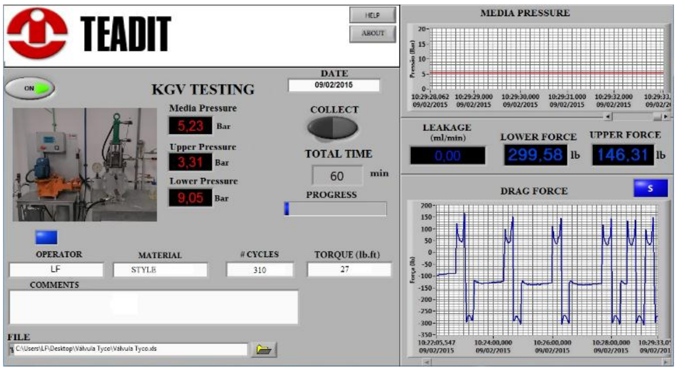

Figure 4 – KGV Testing Platform - Labview®

3. TEST PROCEDURE

The following test protocol was established to analyze the performance of the packing styles. The procedure was developed to evaluate the sealability and the force generated on the knife gate by the packing.

- The Rig shall be cleaned to assure that the knife gate and the stuffing box are free from any unwanted material/dust. The studs and nuts shall be lubricated before each test.
- The packing rings are cut with 45 degree angles and installed with the joints of successive rings 180 degrees apart.
- Once the third ring is accommodated the target load shall be applied.
- The fourth ring is then installed and the target load applied once again.
- The system is pressurized with 10.3 bar (150 psi) and the packing target load reapplied after 10 minutes.
- The test is then initiated. A total of 310 cycles are performed during a period of one hour.
- The pressure necessary to open and close the gate and the media pressure are recorded throughout the whole test by NI LabVIEW® [6] data collecting module.
- If the system pressure drops by 0.2 bar (2.9 psi) the pressure is restored by the feeder pump (3). This pressure drop is equivalent to approximately 100 milliliters leakage.

To determine relations between the applied packing stress and the test results, three different levels of stress were applied on the packings: 750 psi (5.2 MPa), 1125 psi (7.75 MPa) and 1500 psi (10.3 MPa). A torque wrench was used to apply the correct amount of stress on the packing rings and the resultant torque values were; 18 lbf.ft (24.4 N.m), 27 lbf.ft (36.6 N.m) and 36 lbf.ft (48.8 N.m) respectively. The study was developed with 4 packing rings.

4. PACKING STYLES

To perform the tests, packing styles widely used in the sealing industry were selected. The materials that compose those packing styles are very common and can be easily found in many applications. The styles selected are described below:

Style A-PTFE – Acrylic Fibers/PTFE impregnated
Style EG-PTFE – Graphite Filled ePTFE
Style E-PTFE – ePTFE w/ Barium Sulfate
Style E-PTFE-R – ePTFE w/ Rubber core

5. ACTUATING FORCES

The values of gate weight and system resistive forces were set as the baseline for the test results. To determine such values, the valve was cycled without any packing installed, fluid or system pressure.

The values collected by the pressure transducers installed on both ends of the hydraulic actuator were recorded throughout the tests. The data was used to calculate the actuating forces.

The force necessary to close the valve is given by

$$F_{sup} = P_{sup}.A_{sup}$$

where

$$A_{sup} = \frac{\pi}{4}\cdot\left(2^2\right)$$

The force to open the valve is given by

$$F_{inf} = P_{inf}\cdot A_{inf}$$

where

$$A_{inf} = \frac{\pi}{4}\cdot\left(2^2 - 1^2\right)$$

and force exerted on the gate end by the fluid pressure is determined by

$$F_{H2O} = P_{H2O}.(6.5.0.3)$$

The friction force exerted on the knife gate was then calculated as the resultant of the above given forces.

$$F_{DRAG} = F_{sup} - F_{inf} - F_{H2O}$$

The positive values of F_{DRAG} indicate the packing drag while the gate is moving downwards and the negative values indicate the packing drag during the upwards movement. Figure 5 indicates the movement actuating forces on the actuator/gate.

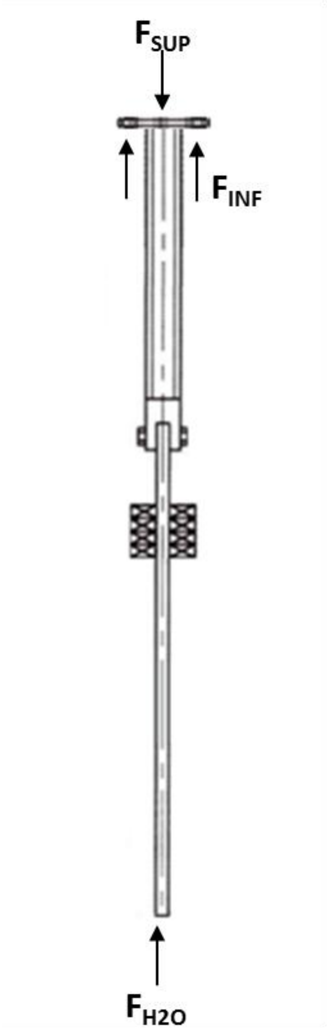

Figure 5 – Moving Forces

6. TEST RESULTS

6.1 INSTALLATION TORQUE EVALUATION

Three different levels of applied stress were tested. The packing styles were installed with 18, 27 and 36 lbf.ft nut torque. The results for styles A-PTFE and EG-PTFE were plotted and can be seen in Figures 5 to 8. Each figure shows the drag force/media pressure for the three installation torques. For the rig and media set for the tests, a pressure drop of 0.2 bar indicates the leakage of approximately 100 mL. The controller was set to restore the media pressure once the pressure drops below 0.2 bar the test working pressure.

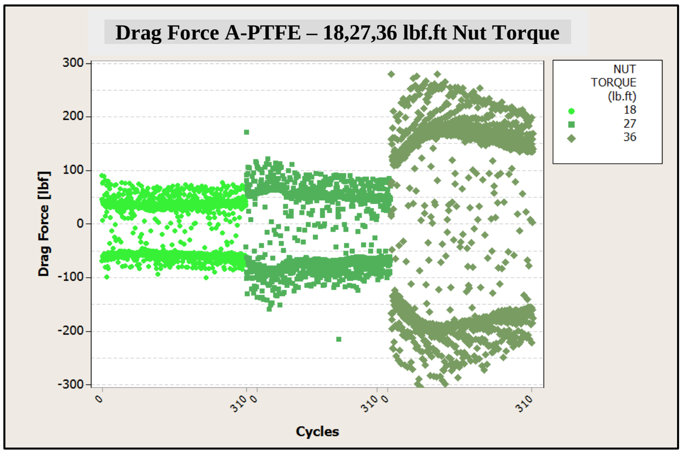

Figure 5 – Drag Force A-PTFE – 18, 27 & 36 lbf.ft

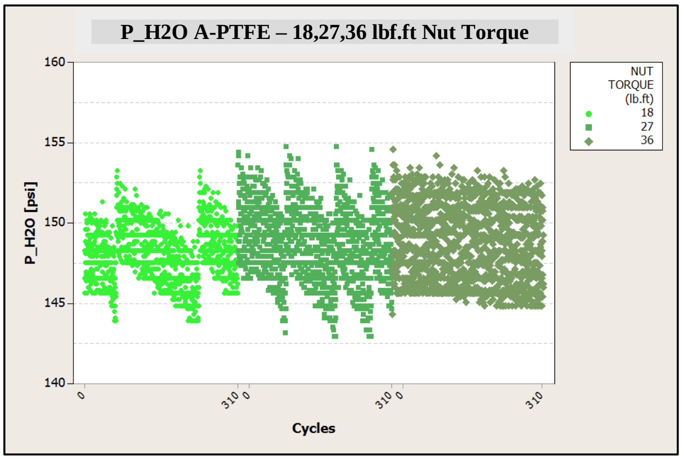

Figure 6 – Media Pressure – A-PTFE – 18, 27, 36 lbf.ft

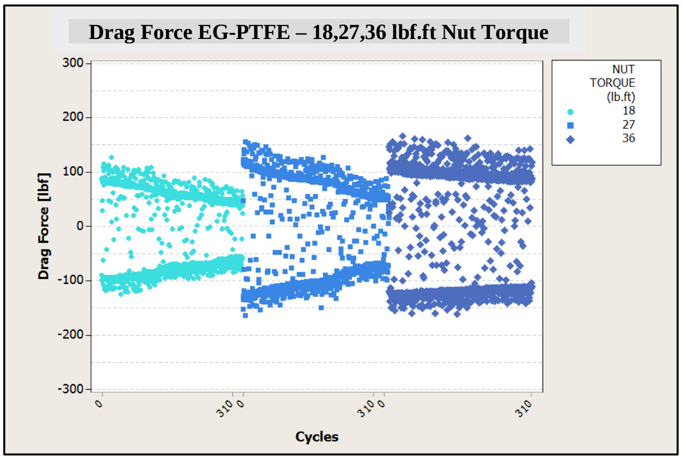

Figure 7 – Drag Force EG-PTFE – 18, 27 & 36 lbf.ft

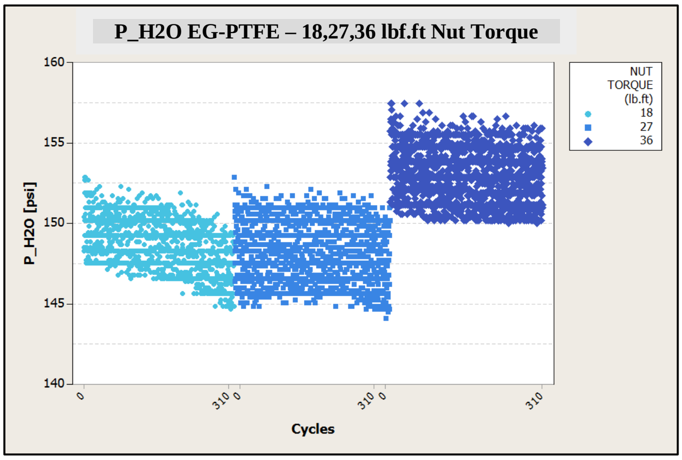

Figure 8 – Media Pressure – EG-PTFE – 18, 27 & 36 lbf.ft

Analyzing the results, Figure 7 shows no significant changes can be seen in drag behavior for Style EG-PTFE as the torque varies. On the other hand, by looking at the results for A-PTFE, Figure 5, it is noticeable a considerable increase in drag force values for 36 lbf.ft installation torque. The media pressure, Figure 6 shows an unsatisfactory performance of Style A-PTFE for applied torques of 18 and 27 lbf.ft, that had the pressure decreased and pump worked two times (feeding 200ml of water) and three times (feeding 300ml of water) respectively. Once the torque was increased to 36 lbf.ft, the pump did not feed at any time, which indicates that the minimum packing seating stress was reached. This could explain the changes in the drag behavior, since, according to Veiga [5], there is a direct correlation between the minimum seating stress and the drag results. Looking at the results for EG-PTFE, Figure 8, we can see that packing minimum seating stress has been achieved with the lowest applied torque.

The tests performed with 36 lbf.ft, however, lead the gland follower to bend, as can be seen on Figure 9 below. To prevent damages to the valve, no more tests were performed with this stress.

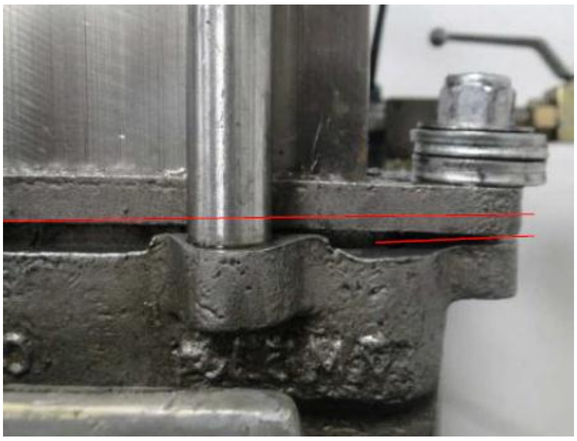

Figure 9 – Gland Follower Bending

6.2 STYLES COMPARISON

To enable material comparison, all styles were installed with 27 lbf.ft nut torque. For Style E-PTFE-R, when the installation was finished, the leakage was above any reasonable levels that could not be controlled. The test could not be started and was aborted.

The results of friction force were analyzed and showed two different levels of resultant drag forces. In one lower level – around 100 lbf drag force - were both A-PTFE and EG-PTFE, and on the other level – nearly 4 times as high, or approximately 400 lbf – were the results for the E-PTFE packing.

The results of internal pressure were plotted for each of the three styles and can be seen in following Figures 10 to 12. As expected, the results for Style A-PTFE were the worst. As seen before, the packing did not achieve the minimum seating stress until the applied nut torque was 36 lbf.ft, therefore could not achieve satisfactory sealing for applied torques of 18 and 27 lbf.ft.

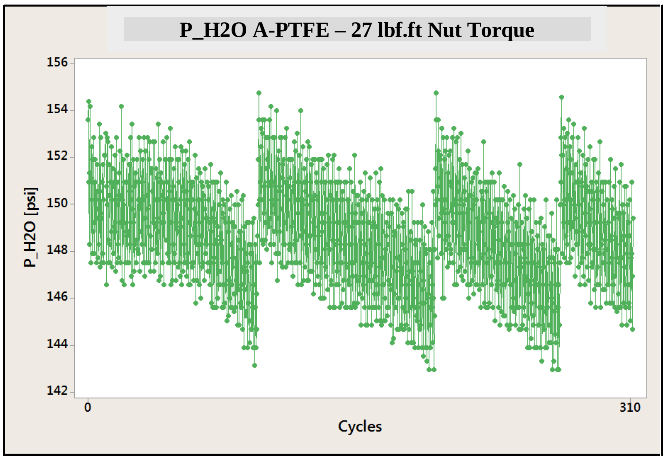

Figure 10 – Media Pressure – A-PTFE – 27 Lbf.Ft

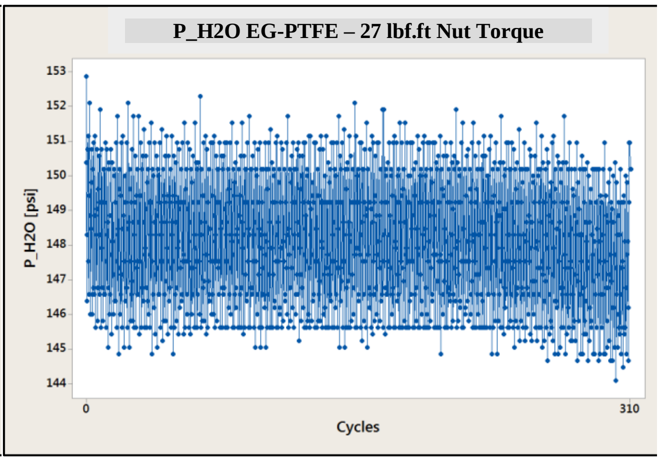

Figure 11 – Media Pressure – EG-PTFE – 27 Lbf.Ft

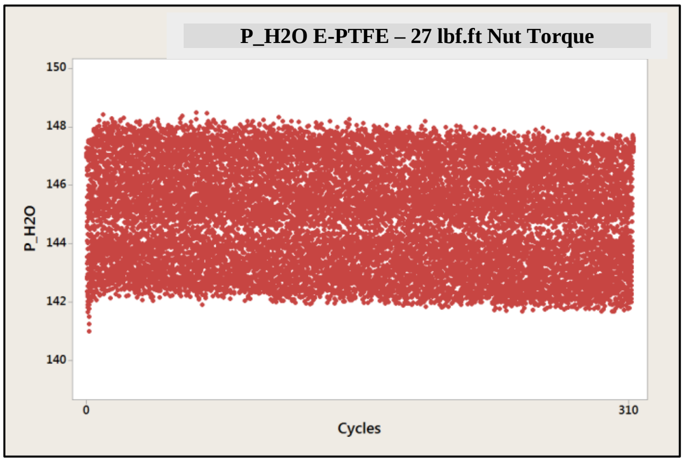

Figure 15 – Media Pressure – E-PTFE – 27 lbF.ft

Styles EG-PTFE and E-PTFE showed much better performance. The pump was not required to feeder water in neither of the tests, which indicates leakage rates lower than 100 mL/h. A-PTFE results show leakage rate over 300 mL/h.

Compression packings manufactured from PTFE yarns tend to be "softer" than styles manufactured from other materials, such as acrylic, phenolic, or synthetic fibers and graphite-based packings. Given this, it would make sense that the packing conform better around the stem or gate, filling the voids between stem and stuffing box more easily than for harder styles. Since KGV's are commonly used in operations with abrasive media, it is not recommended to use PTFE packings. The materials selected for such applications must have high resistance, to bear the extreme conditions imposed by the fluid.

6.3 SPECIFIC PACKING DEVELOPMENT

Acknowledging the situation described on the previous topic, the study focused on the evaluation of whether or not a specific packing, with a specially developed construction could perform better on knife gate valves. Two main objectives were drawn for the study: the packing must resist the wear imposed by the abrasive media and must have the sealability results similar to a PTFE based packing.

The selection of the composing material was made based on commonly used material for KGV application with abrasive media. The packing was manufactured from phenolic fibers, a strong material with high chemical, heat and flame resistance that handles well the wear imposed by the media.

The construction of the packing was developed in order to yield the packing with the desired properties. Samples of the packing manufactured according to this construction were tested at the valve, as well as samples of the packing manufactured with the regular construction, here identified as:

Style G-PHEN – Phenolic fibers impregnated w/ Graphite & PTFE
Style G-PHEN-KGV – Phenolic fibers impregnated w/ Graphite & PTFE & special construction

Two tests were performed with each of the Styles, and the mean results can be seen in following Figures 16 to 19.

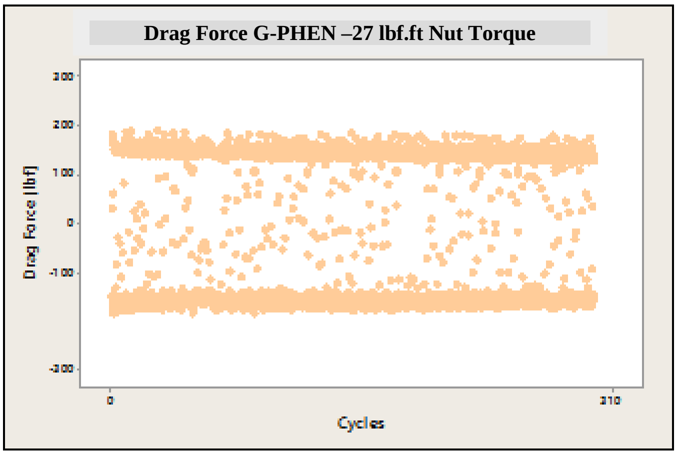

Figure 16 – Drag Force G-PHEN –27 lbf.ft

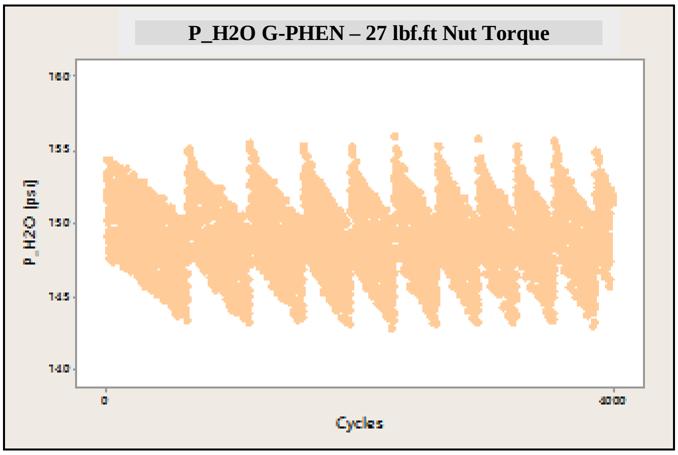

Figure 17 – Media Pressure – G-PHEN –27 lbf.ft

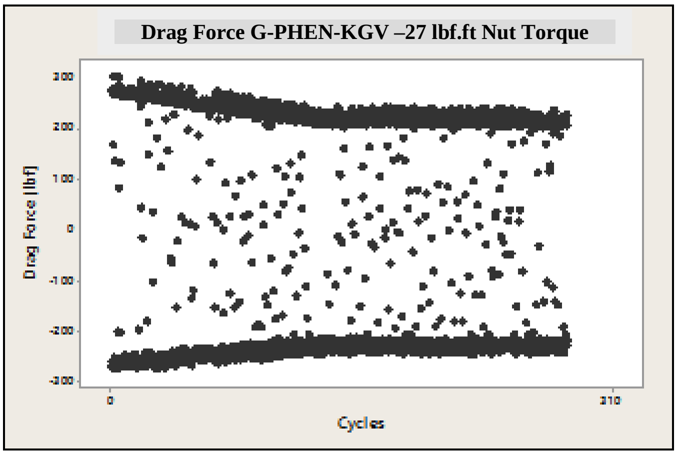

Figure 18 – Drag Force G-PHEN-KGV–27 lbf.ft

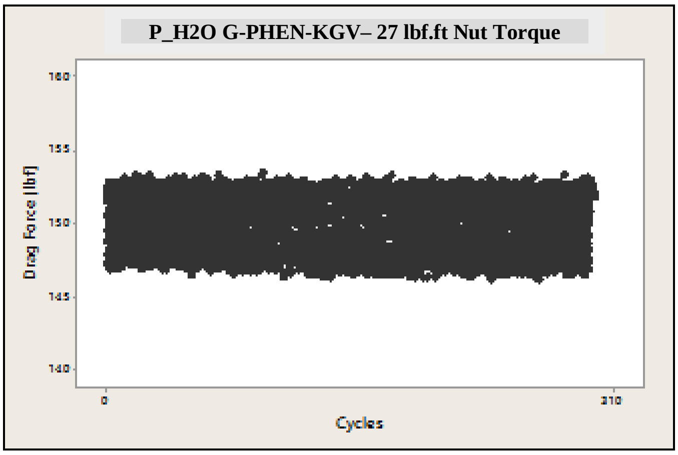

Figure 19 – Media Pressure – G-PHEN-KGV–27 lbf.ft

Analyzing the results, the packing manufactured with the regular construction generated a drag force on the gate of roughly 160 lbf and the feeder pump was activated 10 times. This indicates leakage above 1000 mL/h. The packing manufactured by the construction specially developed for KGV's, however, did not require the supply of make-up fluid, i.e, leakage rate lower than 100 mL/h and between 220~270 lbf friction force.

Based on the results, it is safe to assume that the objectives set were achieved. The construction developed yield the packing with the desired sealability, granting satisfactory performance regarding both leakage and drag resultant forces.

7. CONCLUSIONS

The rig enables the evaluation of drag forces and sealability of compression packings on Knife Gate Valves. Several styles could be tested and the results compared, enabling the evaluation of composing materials, applied stress and packing construction.

Veiga [5] suggests that the minimum seating stress has a strong relation with the drag force. Once the applied gland stress overcomes the packing minimum seating stress, the resultant drag force tendency is changed, showing a different behavior. The results for A-PTFE validate this hypothesis, since once the minimum packing seating stress was reached (>36 lbf.ft nut torque), the drag forces were two times as high as the previous installation torque (27 lbf.ft nut torque). When the nut torque was increased from 18 lbf.ft to 27 lbf.ft, however, the difference is much less noticeable, denoting a much different tendency on the packing drag behavior.

Styles A-PTFE and EG-PTFE showed friction force values above two times as lower as the results for style E-PTFE, which is composed mainly by PTFE, as opposed to the graphite and acrylic fibers present in the other two styles. The sealing ability of the two PTFE based styles, however, was much greater than for style A-PTFE, which could not keep the leakage rate below 300 mL/h, while the other two granted rates lower than 100 mL/h.

A compression packing specifically for application on Knife Gate Valves operating with abrasive media was developed. The packing had its construction specially developed to grant low leakage rates in Knife Gate Valves. The samples were tested in comparison with a packing manufactured with the same material but regular packing construction. The comparative results showed that the development was successful and the packing did have a better performance, regarding both drag forces and sealability. The leakage rate was kept in satisfactory levels throughout the whole test, and the resultant friction was lower for the developed packing.

For future work, the packing relaxation effects should be investigated in order to determine relationship between the packing material relaxation and drag forces.

8. References

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