Chapter C4

Axially Constrained Kalsi Seals

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Individual chapters of the Kalsi Seals Handbook[TM] are periodically updated. To determine if a newer revision of this chapter exists, please visit https://www.kalsi.com/seal-handbook/.

1. Introduction

Axially Constrained Kalsi Seals™ are designed for abrasive service applications with zero pressure differential or low levels of reversing pressure. The seals come in two different types. The 462 series seals have the same lubricant consumption rate as Standard Kalsi Seals™. The 673 series seals have a somewhat higher lubricant consumption rate, and the resulting increased interfacial lubrication allows 673 series seals to outperform 462 series seals.

2. Axially Constrained Seals™ address an aggressive wear mechanism

The skew-induced abrasive wear mechanism shown in Figures 1 and 2 is a leading cause of seal wear in zero differential pressure applications, and in applications having intermittent low level reversing pressure.

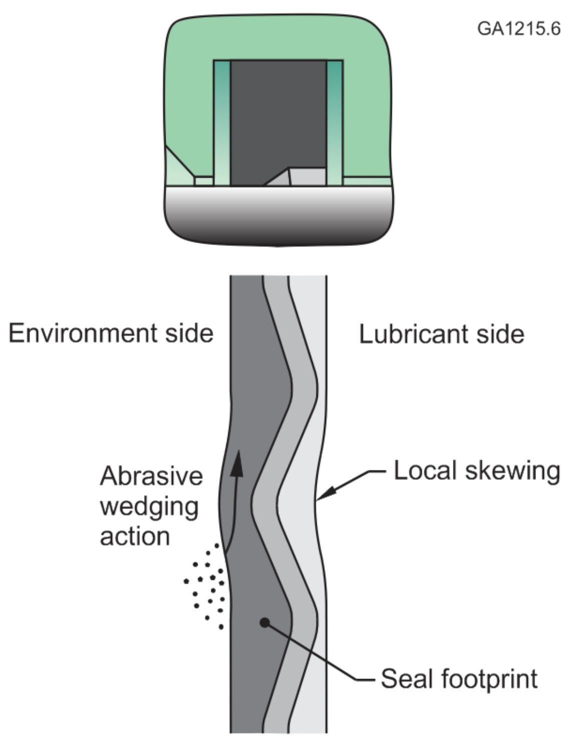

Figure 1
Skew-induced wear mechanism of non-axially constrained seals

Non-axially constrained seals can skew in low differential pressure conditions due to compression and thermal expansion. Rotation causes environmental abrasives to impinge at the skewed location, which can drive abrasives under the seal and cause accelerated seal and shaft wear.

For available seal sizes, visit kalsiseals.com.

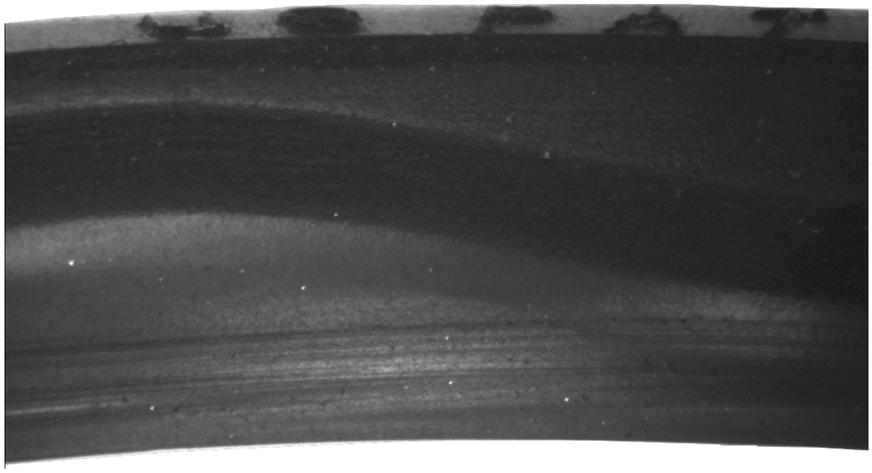

Figure 2
Example of skew-induced wear

This photo shows skew induced rotary seal wear. Note the skewed nature of the wear track relative to the exclusion edge of the seal. While in service, the seal was skewed and the wear track was circular.

The Axially Constrained Kalsi Seal (ACS)[1] is designed to contact both sides of the housing groove simultaneously (Figure 3). This contact effectively locks the seal body in place, preventing it from skewing within the groove. This significantly improves abrasion resistance while avoiding the complexity of providing the positive differential pressure or spring preloading that would otherwise be required to address skew. An exclusion edge chamfer is included on the environment side of the dynamic lip, improving abrasive exclusion in reversing pressure conditions.

For ease of assembly, the seal width is initially narrower than the gland. Insertion of the shaft causes the seal to expand axially into stabilizing contact with the groove walls. The seal geometry provides a significant void in the lubricant side of the gland that allows the seal to thermally expand without becoming over-confined.

Although the Axially Constrained Seal™ has the same nominal radial compression at room temperature as a similarly sized Standard Kalsi Seal™, the effective compression increases at elevated temperature due to the radial effect of axial constraint.

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[1] Covered by U.S. and foreign patents. “Axially Constrained Seal”, “Axially Constrained Kalsi Seal”, “ACS”, “ACS Seal”, “Kalsi Seal”, and “Kalsi Seals” are trademarks of Kalsi Engineering, Inc.

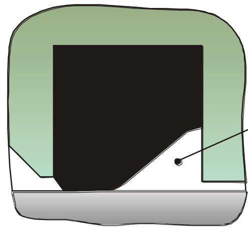

Figure 3
Axially Constrained Seals

Axially Constrained Kalsi Seals contact both groove walls simultaneously during operation to prevent skew-induced wear. A large lubricant side void is provided to accommodate thermal expansion.

The Axially Constrained Seal was initially developed for applications such as oilfield mud motor floating pressure compensation pistons, where the lubricant pressure may fluctuate slightly above or below the environmental pressure due to friction of the sliding piston seals.

3. Seal implementation considerations

Axially Constrained Seals are available in various diameters, for 0.250" (6.35 mm) and 0.309" (7.85 mm) radial gland depths, however the larger gland depth is preferred. Hydrodynamic pumping-related leak rates and running torque of Axially Constrained Seals are comparable to that of Standard and Wide Footprint Kalsi Seals™. A dxf file that includes artistic renditions of installed Axially Constrained Kalsi Seals is available on our website for incorporation into customer assembly drawings.

Due to thermal expansion considerations, the gland width for an Axially Constrained Seal is wider than normally used for Standard and Wide Footprint Kalsi Seals. Existing glands can be widened by machining to accommodate Axially Constrained Seals. If it takes an unusually high amount of force to install an Axially Constrained Seal on to a shaft, check to make sure that the gland width was manufactured correctly. If the gland width is too narrow, rotary performance will suffer.

Nickel-based tungsten carbide coated shaft surfaces are recommended for maximum shaft surface life due to the elevated interfacial contact pressure associated with axial constraint.

4. Swell testing of HNBR Axially Constrained Seals

To evaluate compatibility with environments containing swell-inducing media, an Axially Constrained Seal manufactured with an 85 to 90 durometer HNBR (–11 compound) was tested at 300°F (148.9°C) using IRM 903[2] as the environment. IRM 903 is a low analine point swell inducing fluid recommended by ASTM for swell testing. The seals were run for 147.7 hours with a lubricant pressure of 15 psi (103.4 kPa) and a rotary speed of 345.6 ft/minute (1.76 m/s). At the conclusion of the test there was a slight swell-induced bulge at the environment side of the seal near the ID, where the seal was directly exposed to the IRM 903 reference oil. Despite the slight swelling, the exclusion edge chamfer was still clearly visible. The compression set of the seal was less than Axially Constrained Seals that were tested with an air environment. From this test, it was concluded that Axially Constrained Seals are capable of being exposed to high concentrations of swell-inducing environmental aromatics for extended periods of time without overfilling the gland.

5. High pressure testing of 462 series HNBR Axially Constrained Seals

Axially Constrained Seals are not ordinarily recommended for high differential pressure service due to the elevated contact pressure associated with axial constraint.

To help to determine the pressure-retaining capability of Axially Constrained Seals, a series of elevated pressure tests of 2.75” (69.85 mm) PN 462-49-11 seals was performed at rotary speeds of 166 and 480 rpm (119.5 and 346 ft/minute) with a lubricant temperature of 162°F (72.2°C). At the conclusion of the 500 and 750 psi (3.45 and 5.17 MPa) differential pressure tests, the seals were in excellent condition and properly lubricated. At 480 rpm (346 ft/minute) the seals were properly lubricated when exposed to 1,000 psi (6.89 MPa) pressure differential, but suffered some extrusion-related damage. An ISO 320 viscosity grade lubricant was used in the testing. Torque was found to increase with increasing pressure, which suggests that a somewhat higher viscosity lubricant would be preferable. High pressure testing at higher temperatures has not been performed.

Axially Constrained Seals are not recommended for high reverse pressure

Axially Constrained Seals are not considered suitable for applications where the environment pressure can be significantly greater than the lubricant pressure. Because of the large lubricant side void, the seal would undergo significant distortion if the environment pressure were significantly greater than the lubricant pressure. For

2 IRM 903 is the replacement for ASTM Reference Oil #3; see ASTM D 5964-96.

example, an Axially Constrained Seal should not be used in the seal position within an oilfield rotary steerable tool that is exposed to temporary high reverse pressure if the wellbore collapses.

6. Lubricants for 462 series Axially Constrained Kalsi Seals

Lubricant recommendations for –11 Axially Constrained Seals

To assure adequate lubrication, low viscosity lubricants should be avoided with –11 Axially Constrained Seals, especially at higher operating temperatures, slower speeds or higher differential pressure. In low pressure (15 psi) qualification testing with –11 Axially Constrained Seals with a 162 to 300°F (72.2 to148.9°C) lubricant temperature and 119.5 to 346 ft/minute (0.61 to 1.76 m/s) surface speed, an ISO 320 viscosity grade lubricant provided adequate lubrication even at the lowest test speed (119.5 ft/minute). In the 346 ft/minute (1.76 m/s) low pressure testing, the running torque was insensitive to changes in temperature. In the 119.5 ft/minute (0.61 m/s) low pressure testing, torque increased significantly as the temperature was increased. This suggests that the lower end of the performance envelope was being approached with that speed/temperature/viscosity combination, and a higher lubricant viscosity would be preferred. An ISO 32 viscosity grade lubricant failed to provide the –11 Axially Constrained Seals with adequate lubrication at low speeds and at higher operating temperatures.

In 162°F (72.2°C) 119.5 to 346 ft/minute (0.61 to 1.76 m/s) testing with 750 psi (5.17 MPa) lubricant pressure, an ISO 320 viscosity grade lubricant provided –11 Axially Constrained Seals with adequate lubrication even at the lowest test speed (119.5 ft/minute)[3]. Torque was found to increase with increasing pressure, which suggests that a somewhat higher viscosity lubricant would be preferred. High differential pressure testing of Axially Constrained Seals has not yet been performed at higher temperatures.

Lubricant recommendations for –10 462 series Axially Constrained Seals

In low pressure (15 psi) qualification testing of –10 Axially Constrained Seals with a 162 to 250°F (72.2 to121°C) lubricant temperature and 119.5 to 346 ft/minute (0.61 to 1.76 m/s) surface speed, an ISO 32 viscosity grade lubricant provided adequate lubrication. When the lubricant temperature was raised to 300°F (148.9°C), the seals performed well at a surface speed of 346 ft/minute (1.76 m/s), but were not adequately lubricated at 119.5 ft/minute (0.61 m/s). This testing suggests that a lubricant with a higher viscosity than ISO 32 viscosity grade is necessary for –10 Axially Constrained Seals.

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3 Lubrication with an ISO 320 viscosity grade lubricant was also adequate at 346 ft/minute (1.76 m/s) with 1,000 psi (6.89 MPa) differential pressure, but the seal suffered moderate extrusion damage.

7. New advancements in 462 series Axially Constrained Seals

As a result of several years of development and significant level of financial commitment, most of the tooling that produces 462 series Axially Constrained Seals was upgraded in 2014 to produce an improved seal geometry that performs better at the upper end of the HNBR temperature range. The new geometry also allows 0.335" (8.51mm) cross-section Axially Constrained Seals to be used at temperatures up to 340°F (171.1°C) with the -30 FKM material, as described below. This new generation of seals has the same level of hydrodynamic pumping related leakage as the previous generation.

80 Shore A -30 FKM rotary tests of 0.335" cross-section Axially Constrained Seals

Prior to the advent of the -30 FKM material and the upgraded Axially Constrained Seal geometry, it was not practical to make a satisfactory Axially Constrained Seal for service temperatures above 302°F (150°C). Rotary screening tests of 0.335" (8.51mm) cross-section PN 462-49-30 ACS Seals™ were performed using the standard 0.309" (7.85mm) groove width, in order to determine if the seals could be used in existing hardware without modification. An overview of the tests is provided in the table below.

PN 462-49-30 Axially Constrained Seal test conditions							
Parameter	**Test #1**	**Test #2**	**Test #4**	**Test #6**	**Test #28**	**Test #31**	**Test #32**
Pressure, psi	18	0	0	16	17	17	200
Speed, fpm	337	349	349	349	247	247	33
Temp., °F	300	162	162	300	340	337	110
Time, hours	40	110	114	160	56	205	71
Oil, ISO VG	680	680	680	680	1000	1000	32
Environment	Air	Mud	Mud	Air	Air	Air	Air

Tests #2 and #4 were performed to evaluate the abrasion resistance of the 462-49-30 seals when exposed to drilling fluid. These screening tests were targeted at a minimum of 100 hours. A water based "spud" type mud with abrasive particles of varying sizes and shapes was used. The 162°F (72.2°C), 0 psi differential pressure condition is considered to be a challenging abrasion test due to the relatively low level of axial constraint. Tests #2 and #4 ran to completion. The front seals were exposed to the mud, and the rear seals were exposed to air. The mud exposed seals are in good condition after the tests, as seen in Figures 4 and 5. The air side seals were also in good condition.

Figure 4
Before (left) and after (right) of the mud side seal from Test #2

The right hand photo shows the condition of the PN 462-49-30 Axially Constrained Seal from Test #2 after running 110 hours against oilfield drilling fluid at 162°F (72.2°C). The test was run at 337 ft/minute with 0 differential pressure using an ISO 680 viscosity grade lubricant.

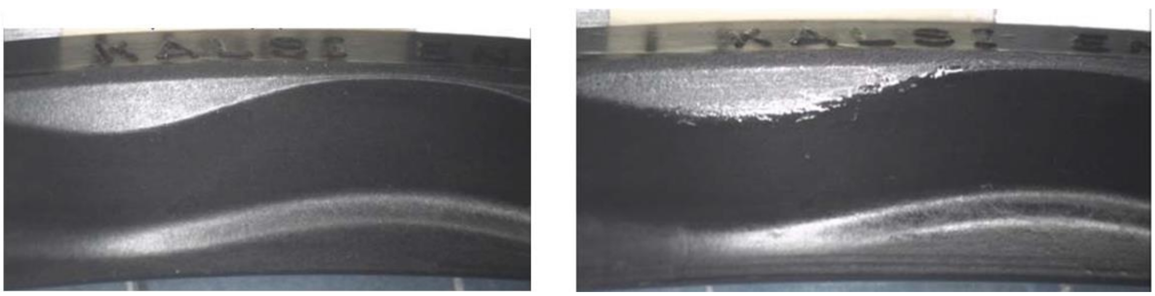

Figure 5
Before (left) and after (right) of the mud side seal from Test #4

The right hand photo shows the condition of the PN 462-49-30 Axially Constrained Seal from Test #4 after running 114 hours against oilfield drilling fluid at 162°F (72.2°C). The test was run at 337 ft/minute with 0 differential pressure using an ISO 680 viscosity grade lubricant.

Tests #1 and #6 were directed at bulk lubricant temperatures of up to 302°F (150°C), and were performed without drilling fluid, solely to test interfacial lubrication. Test #1 ran 40 hours and was stopped to evaluate the seal condition. The condition of the used seals after 40 hours of operation at 300°F (148.9°C) is very good, as seen in Figure 6. Based on the condition of the seals from Test #1, Test #6 was performed with a duration target of 100 hours. Test #6 concluded as planned, and the used seal condition was very good, as shown in Figure 7.

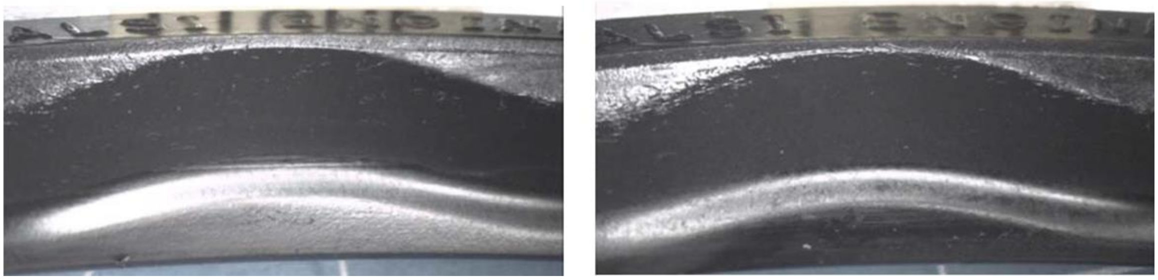

Figure 6
Front (left) and rear (right) seals from Test #1

These photos show the used condition of the PN 462-49-30 Axially Constrained Seals from Test #1 after running 40 hours at 300°F (148.9°C) at 337 ft/minute in a 0.309" (7.85mm) wide gland. The lubricant was an ISO 680 viscosity grade at 18 psi. Both seals were exposed to air.

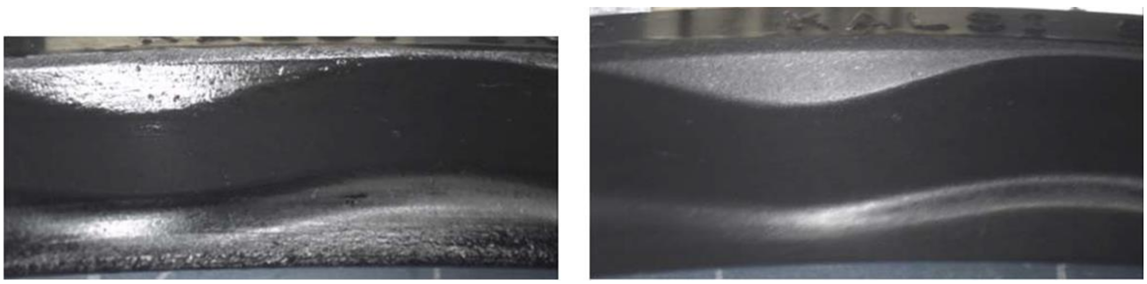

Figure 7
Front (left) and rear (right) seals from Test #6

These photos show the used condition of the PN 462-49-30 Axially Constrained Seals from Test #6 after running 160 hours at 300°F (148.9°C) at 337 ft/minute in a 0.309" (7.85mm) wide gland. The lubricant was an ISO 680 viscosity grade at 18 psi. Both seals were exposed to air.

Tests #28 and #31 were directed at bulk lubricant temperatures of up to 340°F (171.1°C), and were performed without drilling fluid, solely to test interfacial lubrication. Test #28 ran 40 hours in the standard 0.309" (7.85mm) gland, and was stopped to evaluate the condition of the rotary seals. The condition of the seals after 40 hours of operation is very good, as shown in Figure 8. Based on the condition of the seals from Test #28, Test #31 was performed with a duration target of 200 hours using a seal carrier with an adjustable gland width. There was little change in seal running torque as the gland width was decreased from 0.320" to 0.309" (8.13 to 7.85 mm). The 0.335" cross-section seals ran a majority of the 205 hours with a 0.309" (7.85mm) gland width. The used seals are in good condition, as seen in Figure 9. These high temperature seal test results are only applicable to 0.335" cross-section Axially Constrained Seals.

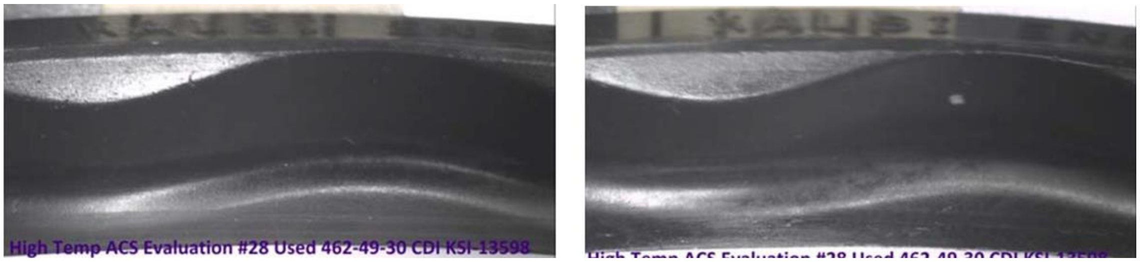

Figure 8
Front (left) and rear (right) seals from Test #28

These photos show the used condition of the PN 462-49-30 Axially Constrained Seals from Test #28 after running 56 hours at 340°F (171.1°C) in a 0.309" (7.85mm) wide gland. The surface speed was 247 ft/minute. The lubricant was an ISO 1000 viscosity grade at 15 psi. Both seals were exposed to air.

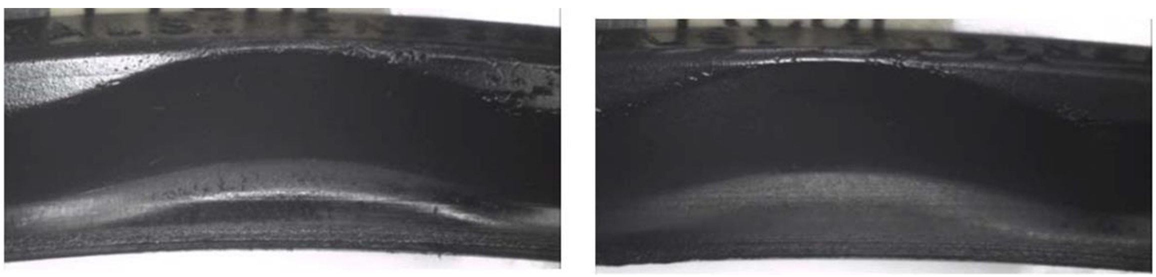

Figure 9
Front (left) and rear (right) seals from Test #31

These photos show the used condition of the PN 462-49-30 Axially Constrained Seals from Test #31 after running 205 hours at 337°F (169.4°C). The gland width was variable, but most of the test was performed using a 0.309" (7.85mm) wide gland. The surface speed was 247 ft/minute. The lubricant was an ISO 1000 viscosity grade at 15 psi. Both seals were exposed to air.

Test #32 was directed at low speed applications that use low viscosity lubricants with moderate lubricant pressure. The test ran 71 hours with rotation and had 5 start-stops. The used seals are in excellent condition, as seen in Figure 10.

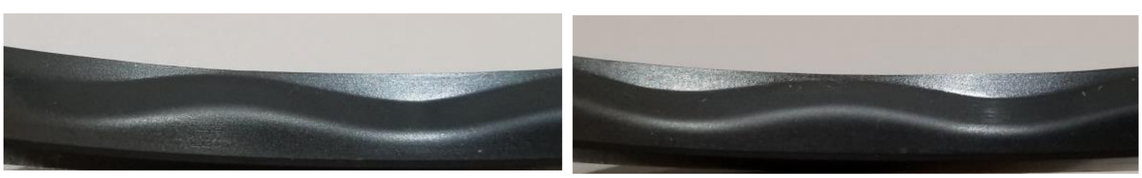

Figure 10
Front (left) and rear (right) seals from Test #32

These photos show the used condition of the PN 462-49-30 Axially Constrained Seals from Test #32 after running 71 hours at 110°F (43.3°C) with five start-stops. The surface speed was 33 ft/minute. The lubricant was an ISO 32 viscosity grade at 200 psi. Both seals were exposed to air.

Chemical resistance of the -30 FKM material

The -30 material has improved chemical compatibility/resistance with many chemicals found in drilling muds, which attack or deteriorate the Kalsi -10 and -11 materials. For example, the compound has less swell than HNBR in highly aromatic diesel and hydrocarbon environments. For additional information, see the materials section of this rotary seal handbook.

The -30 material should not be used directly against formate brines. HNBR Axially Constrained Seals or axially spring loaded FEPM seals are suggested approaches to dealing with formate brines. Alternately, a spring loaded FEPM lip-type barrier seal could be used outboard of a -30 FKM Axially Constrained Seal.

8. The new 673 series Axially Constrained Seals

The same research that produced the improved line of 462 series seals has also resulted in a new line of higher performing 0.335” (8.51mm) cross-section Axially Constrained Seals: The 673 series. This new series offers improved abrasive exclusion performance over 462 series seals in conditions where the pressure of the abrasive environment is greater than the pressure of the seal lubricant. The 673 series seals are also compatible with lower viscosity lubricants, compared to 462 series seals. Although the 673 series has a higher hydrodynamic pumping related leak rate than 462 series, the higher leak rate is compatible with the reservoir size of many oilfield mud motor designs.

The 673 series seals consume more lubricant than 462 series seals

Although the 673 series was developed for the same applications as the 462 series, and fits in the same groove, it was given a different series number because of the difference in leak rate. The 673 series is recommended over the 462 series for mud motor sealing, and similarly demanding applications, whenever the reservoir size of the equipment can tolerate the higher leak rate.

The hydrodynamic pumping related leak rate increases as temperature decreases. For this reason, we performed 15 psi (0.103 MPa) characterization testing of 673-1-11 seals at 162°F (72.2°C), which is considered to be a relatively low temperature for mud motor sealing applications. At 345.6 ft/minute (1.755 m/s), the leakage per inch of circumference was 0.166 ml/hr with an ISO 320 viscosity grade lubricant, and 0.194 ml/hr with an ISO 680 viscosity grade lubricant. In tests of 673-1-11 seals with an ISO 320 viscosity grade lubricant at 302°F (150°C), lubrication was excellent.

Improved abrasion resistance in reversing pressure conditions

Figure 11 shows a used a 673 series Axially Constrained Seal that was tested with a relatively low lubricant viscosity, and a rather high drilling fluid pressure, compared to the capabilities of a 462 series seal. The pressure of the drilling fluid was 90 psi greater than the pressure of the seal lubricant. The seal was tested with an ISO 150 viscosity grade lubricant at a bulk temperature of 162°F (72.2°C), to simulate a targeted non-oilfield application. The shaft velocity was 288 feet per minute, and lubricant consumption was 0.043 to 0.072 ml/hr per inch of circumference. As the figure shows, the used seal is in excellent condition following the ~100 hour test, with no abrasive invasion.

Figure 11
A used 673 series Axially Constrained Seal

This 673 series Axially Constrained Seal was tested with drilling fluid that was 90 psi higher than the pressure of the 162°F ISO 150 grade lubricant. This is a greater differential pressure and a lower viscosity lubricant than recommended for 462 series Axially Constrained Seals.

Characterization tests of HNBR 673 series seals have been performed at temperatures as high as 300°F (150°C), and with lubricants ranging from ISO 150 to 680 viscosity grade. This new seal design is also compatible with the -30 FKM material, for service up to 340°F (171.1°C). Contact us for additional information, so that your organization can take advantage of this new advancement in rotary sealing.