White paper

SKF sealing solutions Austria test results for hydraulic oil

Contents

Managing particulate contamination in hydraulic oils

The primary function of a hydraulic oil is to transmit power. It is, however, also critical for maintaining the smooth operation of the wider system: lubricating moving parts, cooling the system by transporting heat from areas of high load, preventing corrosion of components and removing contamination from critical surfaces. A maintenance strategy for a hydraulic system therefore needs to start with maintaining the oil in good condition.

Hard particle contamination

Abrasive wear is typically found in mechanical systems where there is relative motion between two surfaces – be it reciprocating, oscillating or rotary motion. It is caused by hard particles grazing the surfaces while in motion. Particulate contamination like dust, metal particles, rubber and fibres can all act as abrasives in the system – accelerating the wear of mechanical components like pumps, bearings, rods, pistons, and seals. Intuitively, removing these particles from the oil corresponds with a reduced wear rate and longer service life of the system. But how is this accomplished?

The problem with nano particles

Conventional filtration systems excel at removing larger particles – from high-speed separators which are rated to >5 microns, to coated filters rated at >2 microns, and electrostatic filters rated at >1 micron. But is this sufficient? Emerging evidence suggests that smaller particles also have a significant role to play, directly affecting oil degradation and thus causing impact on the system performance.

Oxidation

Often viewed as a function of the aging process of an oil, oxidation can lead to the formation of varnish. If left unchecked, varnish can cause issues like valve stiction, obstruction of heat transfer, blocked filters, and impaired lubrication properties.

Two conditions must be present for oxidation to occur in an oil: oxygen and temperature. The lubricant must also have a catalyst present to initiate the reaction and produce free radicals to propagate the reaction. Particulate contamination acts as a catalyst for the oxidation process. But if the oil is already filtered then why do oils still oxidize?

The answer to this question lies with a more insidious or hidden problem – nanoparticles. A key parameter influencing the speed of the oxidation reaction is the surface area of the catalyst. And some 80% of the contaminant surface area in an oil is associated with nanoparticles. But conventional filtration is constrained to removing larger particles – and standard lubricant condition monitoring does not monitor for these smaller particles.

The industry standard is instead to supply oil with antioxidant additives. These additives are sacrificial in their nature - releasing antioxidants to combat the free radicals associated with the oxidation reaction. But as the process continues, these additives will be depleted, until eventually oxidation will proceed unhindered.

A more sustainable approach is to prevent the oxidation reaction from occurring to begin with. Removing the catalytic nanoparticles from the oil is one approach to achieving this end. To address this very issue, SKF RecondOil have developed Double Separation Technology (DST). With solutions for both continuous and batch treatment, DST removes nanoparticles from industrial oils – halting the oxidation process at the initiation stage. The benefit of this treatment is that it inhibits the aging process of the oil, significantly extending the service life of the hydraulic oil, and reducing the need for regular oil monitoring. In short, the DST treated, nano-clean oil can lead to more reliable machines and more stable operations.

Understanding hydraulic seals

Seals are one of the most important components in hydraulic systems, keeping oil in, and contamination out. Very much the unsung heroes – without seals hydraulic systems simply would not be able to operate.

There are many types of hydraulic sealing concepts to choose from. Selecting the suitable seal design and material requires consideration of operating conditions, such as temperature, pressure and hydraulic fluids involved.

The chemical composition of hydraulic fluids can impact the seal life and performance depending on compatibility with the seal material(s). Absorption and reaction of the seal material(s) with non-compatible fluids can cause, for example:

- change in seal material volume – "swelling" or "shrinking" and the impact on seal contact force and friction,
- hardening and embrittlement of the seal material,
- softening, loss of strength or dissolving of the seal material,
- crosslinking or degradation of the polymer chains, which can cause the material to fatigue or lose resilience,
- discoloration of the seal material.

Generally, these changes are accelerated by higher temperature. To avoid these changes and the resulting damage to seal function and life, careful consideration should be taken to ensure compatibility between the fluid and all seal materials, as well as the temperature and mechanical loads on the seal material.

SKF has a long history and an extensive database of test results concerning compatibility of various seal materials and fluids, as well as unparalleled expertise in developing materials to meet customers' needs for chemical resistance of seal materials. Out of these developments, two main polyurethan materials have evolved: ECOPUR as premium sealing grade for sealing applications in mineral oils and H-ECOPUR as grade with improved hydrolysis and chemical resistance at elevated service temperatures.

Table 1 summarizes the compatibility rating for the most important fluids and materials used in the fluid power industry. It provides general guidelines for new, clean fluids. Fluids vary by manufacturer, additives and contaminant levels. The guidelines cannot substitute for testing the compatibility of a seal in the actual fluid and under actual operating conditions.

Temperatures higher than specified in **table 1** can lead to degradation of the basic fluid or its additives. This can cause deterioration of the seal material. In addition to the specified hydraulic fluid, seal materials can be attacked by exposure to other fluids from other parts of the machinery (e.g. greases, fuels, coatings), environmental factors (e.g. humidity or radiation) and degradation and reaction with the fluids, additives and contaminants in the system producing additional chemicals.

Table 1

Material	ECOPUR X-ECOPUR		H-ECOPUR X-ECOPUR H		ether-based TPU		PTFE	NBR		FKM	
Hydraulic fluids	<60 °C	<100 °C	<60 °C	<100 °C	<60 °C	<100 °C	all	<60 °C	<100 °C	<60 °C	<100 °C
Mineral oils (HL, HLP, HLVP)	A	B	A	A	A	B/C	A	A	A	A	A
ATF (automatic transmission fluids)	A	B	A	A	A	B/C	A	A	A	A	A
HETG (triglycerides, rape seed oil)	A	B/C	A	A	A	C	A	A/B	A/B	A	A
HEES (synthetic esters)	A	B/C	A	A	A	C	A	A/B	A/B	A	A
HEPG (polyalcylene glycols)	B	D	A	C	B/C	D	C	A	A/B	A/B	C/D
HEPR (polyalphaolefines)	A	B	A	A	A	B/C	A	A/B	A/B	A	A
Fire resistant fluids, water-based	<40 °C	<60 °C	<40 °C	<60 °C	<40 °C	<60 °C	all	<40 °C	<60 °C	<40 °C	<60 °C
Water	B	D	A	A	A	B	A	A	A	A	A
HFA-fluids (oil in water)	B	D	A	A	B	B/C	A	A	A	A	B
HFB-fluids (water in oil)	B	D	A	A	B	D	A	A	A	A	A
HFC-fluids (water-glycol)	C	D	A	B/C	B	B/C	A	A	A	A/B	B/C

Legend: **A** - Excellent **B** – Good **C** – Limited **D** – Not recommended

Noria Corporation on the costs of hydraulic oil contamination

At first glance, it might seem that cleaner hydraulic oil or better performing seals would have only a minor impact on the total cost of owning a hydraulic asset. But there are many costs associated with the performance of hydraulic oils and seals. In addition to direct costs like maintenance and material costs, there are also indirect or downstream costs to consider.

Component wear and failure costs

When hydraulic oils are contaminated, they cause increased wear, adhesion, fatigue, and corrosion of various hydraulic components. This ultimately leads to increased incidence of failure in hydraulic assets. If a critical hydraulic asset fails, the cost per day or even per hour can be astronomical, especially if production is affected.

Labour costs

Cleaner hydraulic oil can also decrease labour costs. Because the cleaner oil can remain in service longer (or even indefinitely in some cases), fewer oil drain and fill procedures are needed. The cost of maintenance labour can also be reduced when contamination-related wear and failure decreases.

Environmental costs

When seals are performing better, they stop oil from potentially spilling into groundwater. A single leak dripping at the rate of one drop per second amounts to 1 900 litres of oil over a 12-month period. Even if that spilled oil is absorbed and cleaned before it impacts the local environment, it has still been consumed. To replace it, new oil must be purchased, shipped, and stored at additional costs to both the asset owner and the environment.

Lifecycle costs

A hydraulic asset is an investment. The service life of hydraulic equipment is a major factor in the success of that investment. It has been shown that cleaner hydraulic fluid can extend the service life of hydraulic assets significantly. Higher oil cleanliness levels can multiply the life of a hydraulic machine by as much as ten times versus a machine using dirty oil.

Safety costs

Hydraulic leaks also pose a safety risk to employees. They contribute to slip and fall accidents, which are among most common types of workplace injuries in the manufacturing sector. Even before a leak has occurred, contaminated hydraulic oil can lead to unexpected and dangerous hydraulic equipment problems. When particle contamination is high, a phenomenon known as silt lock may occur. Silt lock is caused by small particles in hydraulic fluid building up within hydraulic valves. When these valves fail, hydraulic equipment may move erratically or stop suddenly, endangering operators or nearby staff.

Reducing the cost of contamination

Ultimately, dirty hydraulic oil is either the root cause of or a contributing factor to all of these costs. By improving contamination exclusion and removal, it is possible to increase the service life of hydraulic oils, seals, and the equipment they protect. Still, even the best conventional filters leave one problem unsolved: nanoparticle contamination.

For all these reasons, it is of vital economic interest to keep hydraulic oil in optimum condition at all operating times.

SKF internal performance tests

The European product testing team in Judenburg (Austria) performed what is known as “accelerated lifetime tests for hydraulic systems” to evaluate the performance of SKF RecondOil’s Double Separation Technology (DST) process. The following chapters in this paper deal with test procedures and test results, showing that the service life of a commercially available hydraulic oil could be extended by using the DST process.

Prior to the accelerated life test, investigations were performed on the selected hydraulic oil HLP46 from a premium manufacturer. These investigations revealed that with only a single pass through an SKF RecondOil DST system, cleanliness of a “dirty” or contaminated oil sample could be improved from a particle count of 21/19/16 (ISO 4406:99) to an impressive 13/12/8 (ISO 4406:99) – even cleaner than the virgin oil, which clocked in at 17/15/10 (ISO 4406:99).

And, of course, the ISO 4406:99 particle count standard only considers particles greater than 4 microns. Removing particles smaller than 4 microns is where DST excels and where the true gains regarding life extension would be expected to be achieved.

In order to detect a service life extension of hydraulic systems (seals and oil), highly sensorized test rigs are needed to continuously record all relevant data as friction force of seals, system pressure, oil temperature, external leakage and oil aging. A performance change of the oil caused by degradation can be easily seen by a strongly varying friction force of seals, increasing leakage and strong discoloration of the oil. **Figure 1** shows an SKF internal rod seal test rig which was used for these tests.

Figure 1. Reciprocating hydraulic seal test rig.

Test program

The service life of a hydraulic fluid is limited by how often the oil is used in the range of its upper temperature limit. An SKF-internal test procedure, referred to as a heavy-duty test, is used to evaluate seal materials at elevated temperature levels. The heavy-duty test can also be used to accelerate the aging process that would normally occur over time due to oxidation and particulate contamination of the oil.

The heavy-duty test shown in **figure 2** can be divided in two test cycles. The first cycle is a moderate 10-day test with an operating temperature of 80 °C. It is used to check the oil and the seal performance under common application conditions. The second test cycle, with an increased oil temperature of 110 °C, is used to evaluate the limits of the hydraulic system.

Under normal testing operations, the oil needs to be changed regularly to ensure a constant quality of the test results. If not changed periodically the oil degrades, causing a negative impact on test results such as friction force and wear performance of the seals. The changing intervals are different and vary depending on which test programs are run. **Figure 3** shows an example of a fully degraded oil caused by a too long interval time.

In order to evaluate the DST process from SKF RecondOil, the heavy-duty testing program was run several times in row with the same oil, until the end of its product life cycle. Normally, the oil would be removed and disposed of regularly due to reaching the end of its lifetime. In this investigation, however, half the oil was removed after the third test and shipped to SKF RecondOil for regeneration in their DST process. The other half of the oil was used to run a fourth heavy-duty test; partly in order to show the effect of degraded oil, and partly to quantify the regenerating effect of the DST process. As soon as the oil that was sent to SKF RecondOil had been regenerated in the DST process, it was shipped back to Judenburg for further testing.

It is important to know that each single test was started with new premium seals from SKF and new piston rods to ensure constant testing conditions. **Figure 4** shows the overall procedure which was used for the evaluation of the DST process. The results from the Baseline Tests (Test 1-3) with the original mineral oil have been compared with results from Test 4-6 where the oil was regenerated in the DST process.

Seal type:	SKF S1S Premium U-CUP Seal	
Seal housing:	ø50 x ø65 x 10 mm	
Seal material:	ECOPUR	
Extrusion gap:	0,15 mm (radial)	
Stroke speed:	0.25 m/s	
Stroke:	400 mm	
Test medium:	Commercial mineral oil - HLP 46	
	Test Cycle 1	**Test Cycle 2**
Pressure:	200 bar (constant)	315 bar (constant)
Oil temperature:	80 °C	110 °C
Distance:	200 km	60 km

Figure 2: Test Parameters.

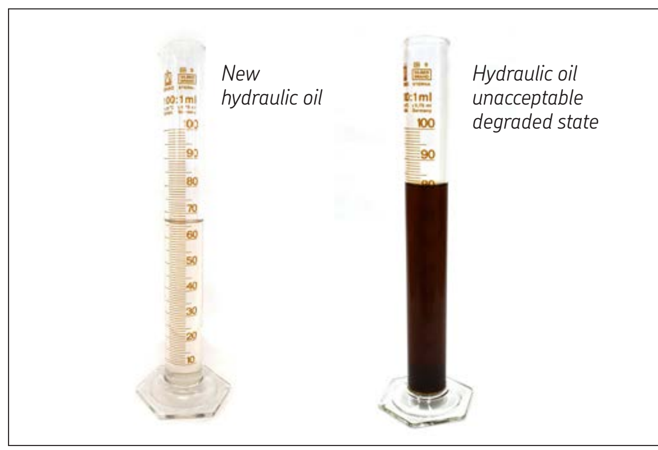
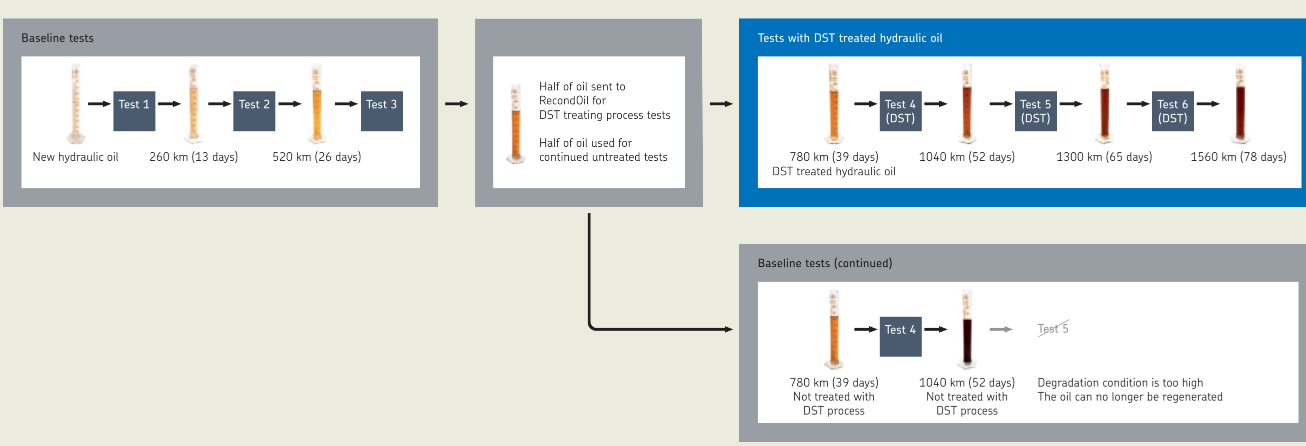


Figure 3: Degradation of the hydraulic oil.

Figure 4

Procedure for DST process evaluation.



Test results

The DST process could extend the lifetime of the hydraulic oil in this test. The leakage performance of the seals observed during the baseline test series was on a similar level compared to the seals which were used during the second test series with the regenerated oil. Other important key performance criteria, like compression set of the seal material or wear and extrusion resistance, were also comparable between both test series.

The biggest and most noticeable difference could be seen in the measured seal friction. The friction of seals is an important indicator of the overall performance of the sealing system. It is a result of the interaction between the sealing system (influenced by seal design and seal material), the test conditions, the hydraulic fluid and the counter surface. In general, a machine operates more smoothly and more efficiently in terms of energy consumption with lower and less scattering friction force. As counter surface and seals were exchanged after each single test to exclude any possible variations, the improvement of the seal friction most likely originates from the DST treatment process on the hydraulic fluid.

The improvement in the coefficient of friction could be clearly seen when comparing the friction plots from the tests. **Diagram 1** shows the average friction characteristic of **test 1** (new hydraulic oil) and **test 3**. Both charts show a typical friction characteristic of seals when they are tested with the heavy-duty testing program. During the 1st test cycle the friction level is quite constant. Looking into the 2nd test cycle the friction level and the friction band are increasing, which is caused by the significantly increased oil pressure and by the higher oil temperature. During the second part of the program, the seals and the hydraulic fluid are extremely stressed. Nevertheless, from repeatability- and quality point of view, the constant seal friction behavior comparing **test 1** against **test 3** can be highlighted.

Diagram 1

Friction characteristic of the 1st and 3rd baseline test.

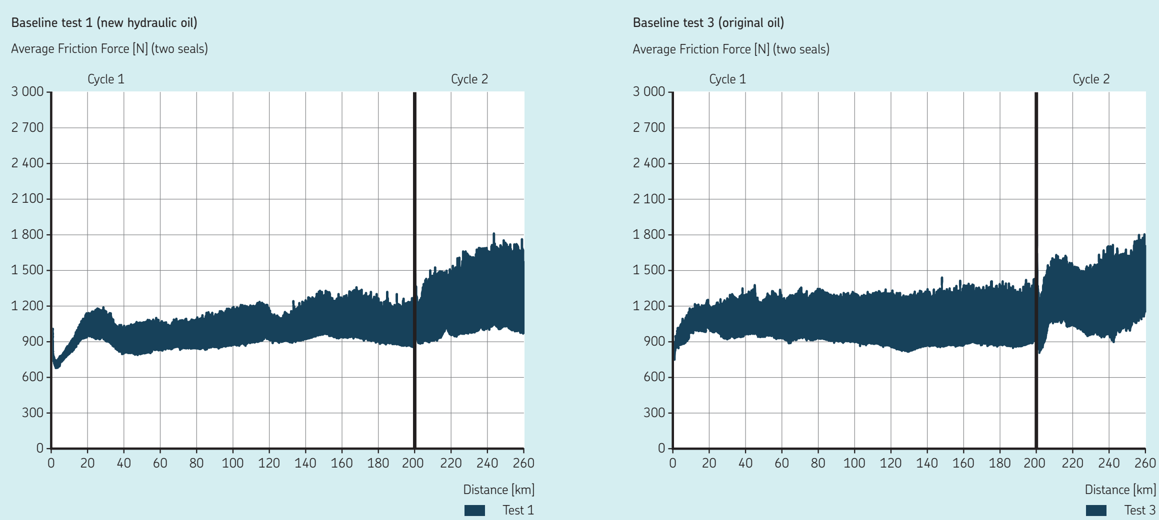
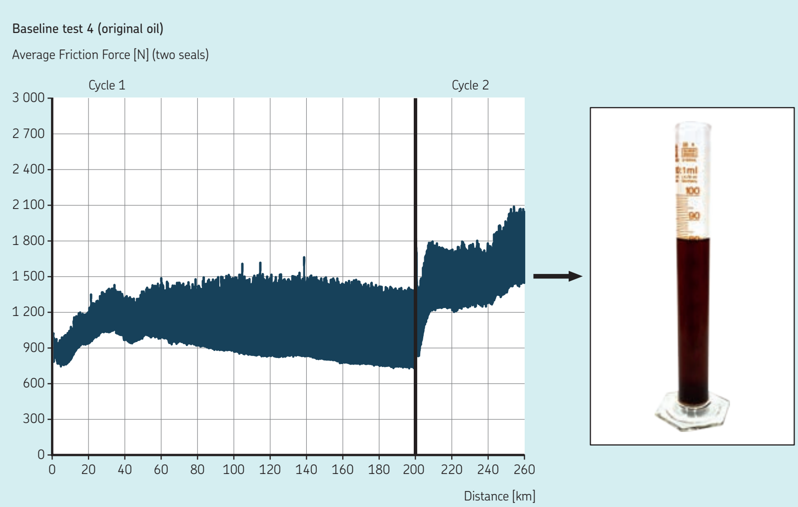


Diagram 2

Friction characteristic of the 4th baseline test with the original oil.



Even if **diagram 1** shows that the hydraulic oil has not reached its end of lifetime after the 3rd test, this can change quickly. Just one additional test with the same oil (**Test 4**) shows the dramatic effect of an oil past its lifetime. The average values of the friction band and the friction level were higher comparing them with the values from the first three baseline tests. **Diagram 2** additionally shows a sample picture of the heavily discolored oil taken after **Test 4**.

A direct comparison of the seal friction from **test 4**, executed with the original oil versus **test 4**, done with the DST treated oil, can be seen in **diagram 3**.

The commercial hydraulic oil from the baseline **test 4** showed a very poor seal friction, whereas the **test 4** using the DST-treated oil shows an excellent performance. Considering the same operational prehistory of both oils prior the DST treatment (3x heavy-duty tests), the performance improvement and lifetime extension of the oil by using the DST process is clearly visible.

Diagram 4 shows the friction performance of **test 4 and 6** using the DST treated oil. Comparing them with the friction results from the baseline tests, an improvement of the friction level and the friction band can be seen. Another interesting observation is the constant behaviour of the DST-treated oil during three tests. It is not clear how long the regeneration effect would persist after **test 6** as the test series were stopped afterwards. To better understand the long-term performance of the DST-treated oil, further in-house tests are currently running (results not available yet).

Diagram 3

Friction characteristic of the 4th baseline test and the 4th test with regenerated hydraulic oil.

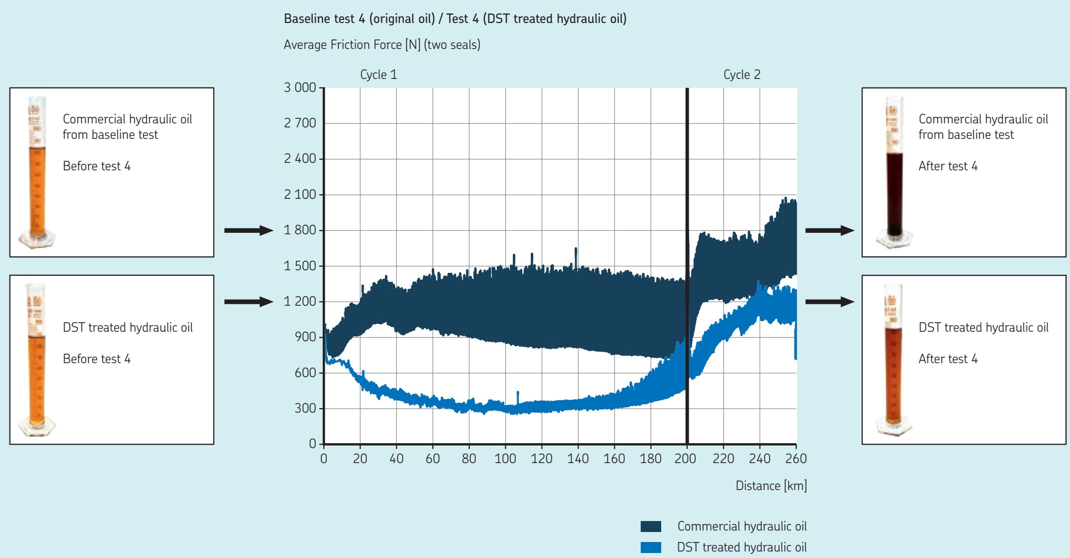
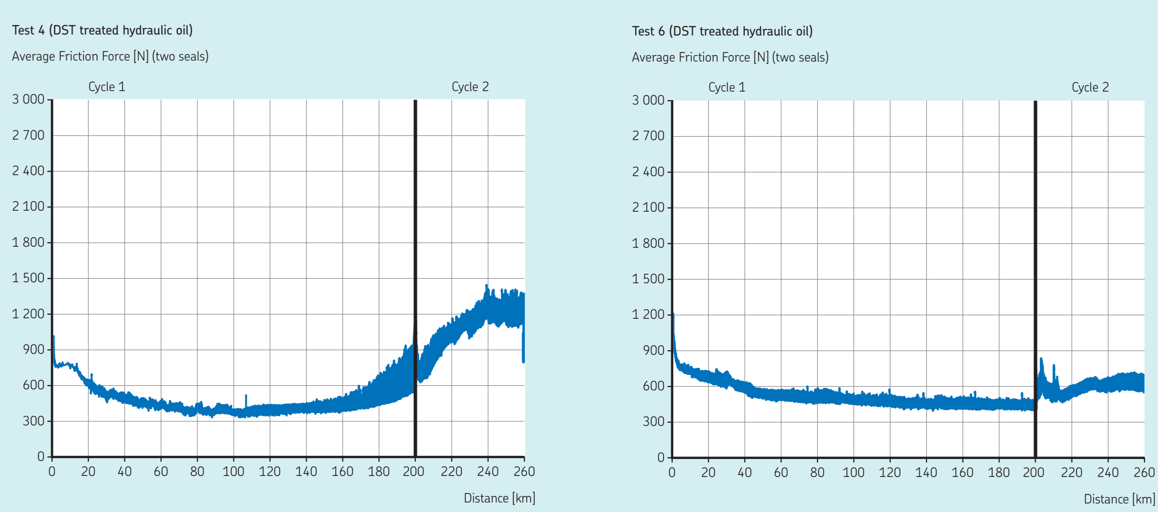


Diagram 4

Friction characteristic of two tests using the DST treated oil.



Conclusion

Through careful control of particulate contamination and oxidation catalysts, it is possible to prevent premature wear of hydraulic systems and extend the life of hydraulic oils. Conventional filtration systems have their limitations however – they fail to address nano-particle contamination.

The DST-treated, nano-clean hydraulic oil is not only able to significantly extend the lifetime of the original hydraulic oil, but at the same time offers an improved lubrication performance. This results in a lower friction level and smoother operation, which can be seen in a very narrow friction band. One explanation of the improvement is the removal of very small particles (< 4 microns). This could also explain why the seal friction in **test 4**, run with DST-treated oil, is even smaller than the friction in **test 1**, run with virgin oil, where larger particles could be found during particle counter investigations according to ISO 4406:99.

Extensive in-house tests showed the positive effects on the friction performance of seals when hydraulic oil was regenerated with the Double Separation Technology process from SKF RecondOil. These tests highlighted a clear correlation with reduction in friction by using regenerated oil – which in turn will reduce machine wear, reduce potential for cross-contamination and extend the life of the oil in service. Reliability and availability of machines will improve, and maintenance intervals could potentially be extended – which of course will result in less variation in operation and a more stable process.

In this investigation, the lifetime of the hydraulic oil could be at least doubled by the DST treatment's nano-cleaning process. The lifetime extension of industrial lubricants by removing nanoparticles from oil and preventing oxidation from occurring opens a paradigm shift – no longer treating oil as a consumable but as an asset. The same oil can be used again and again. A small change in oil can yield significant strategic results.

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