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Prescreening hydraulic fluids for vane pumps: a ranking method

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State of the art on vane pump testing
Hydraulic systems are widely used in the manufacturing, construction, forestry, mining and transportation industries. Over the years, systems for the transmission and distribution of power have become more complicated, their applications more numerous and their operating conditions more demanding. So hydraulic fluids need to get better to match the increasing industrial demand and requirements. Despite a large variety of commercial hydraulic fluids, pump manufacturers and users often have no comparable information on friction and wear properties of these fluids, due to a lack of efficient tribological techniques that simulate accurately the in-field conditions of a pump.

The current state-of-the-art for testing fluids for vane pumps is mainly the Conestoga-Vickers Vane Pump stand *(ASTM D7043 - DIN 51389 - ISO 20763)* or similar component testers. Standardised pump stands would provide the best possible representation of actual working conditions, but have their practical limitations. Apart from the investment cost of such pump stands, a critical issue is the test duration : 100 hrs for the ASTM D7043 method and 250 hrs for the ISO 20763 method. Also a large quantity of hydraulic fluids per test is needed *(30 L for ASTM D7043 and 60 L for ISO 20763*). These tests only measure wear losses, no information about frictional behavior of the tribosystem are measured. In 1996, G.E. Totten presented an overview of bench tests for Hydraulic Fluid performance, and came to three important conclusions: 1) none of the obvious laboratory tests (Four Ball test, Pin & Vee Block, SRV, Timken) provided any correlation with the standardised Vane Pump test; 2) a predictive test must reproduce the actual wear mechanism in the hydraulic pump and 3) be sufficiently reproducible. Earlier attempts to use a cyclic stress vane-on-flat methodology with a Falex Multispecimen machine were not satisfactory because the 2nd criterion wasn't met: the test parameters didn't reproduce the same wear mechanisms. In this paper, we have revisited the parameters of the cyclic stress vane-on-flat test to simulate the working conditions of a vane pump. A key feature of this approach was to fine-tune experimental conditions and specimens to accelerate wear without changing the wear mechanisms. To achieve this, we compared wear mechanisms and weight losses of the Falex MultiSpecimen vane-on-flat tester with the ones obtained from Conestoga Vickers Vane Pump tests. The outcome is a promising prescreening method that produces a reliable ranking of hydraulic fluids comparable to those of Conestoga tests, but in a significantly shorter test time, using less fluid and with additional information on the frictional behavior of the tribosystem.

Prescreening for vane pump simulation: Cyclic-stress vane-on-flat Falex Multispecimen?

The Falex MultiSpecimen Test Machine (**Figure 1a**) is a versatile commercial system for evaluating friction, wear, and abrasion characteristics of materials, coatings, and lubricants. Standard Test Methods and Application Specific Custom testing programs are possible due to user selected contact geometries, motions, velocities, temperatures, contact pressures, and test specimen materials. One test apparatus meets many test specifications and simulates a broad range of field applications. Applications include research and development, quality control, product qualification and the evaluation of physical and performance characteristics of materials, coatings, and lubricants. Based on this machine a vane pump prescreening setup was developed by using a special vane-on-disk test configuration (Figure 1b) and a hydraulic fluid recirculation system.

To simulate the compression/de-compression pressure pattern contact conditions in the actual vane pumps, a new standardised test disk was designed, **Figure 2**. This standardised sample is made of 52100 steel and has a hardness of 58-63 HRC and an average roughness Ra of 0.23-0.38 µm. The grooves on this sample create the variable pressures encountered by the vanes in a pump during each cycle. In particular three different areas can be discerned on these disks, as indicated in **Figure 2**. Area A corresponds to the area of the highest pressure, area B to medium pressure and C to the lowest pressure. The grooves also allow a proper re-lubrication of the sliding contact, similar to pump behavior. As counter materials three high stress M-2 tool steel vanes having a hardness of 58-63 HRC, average roughness Ra 0.15-0.30 µm and a 6.35 mm radius **Figure 2**. This design was optimised to represent the pressure peaks and the refreshing of the contact as it occurs in the wane pump tests, by rescaling the geometry of the actual test. Prior to each test, the disk and vanes were cleaned with heptane in an ultrasonic bath for 10 min, dried and then weighted in an electrobalance with an accuracy of ± 0.1 mg.

Fig 1. *(a)*
FALEX MultiSpecimen tester

Fig 1. *(b)*
Vane-on-Disk contact configuration

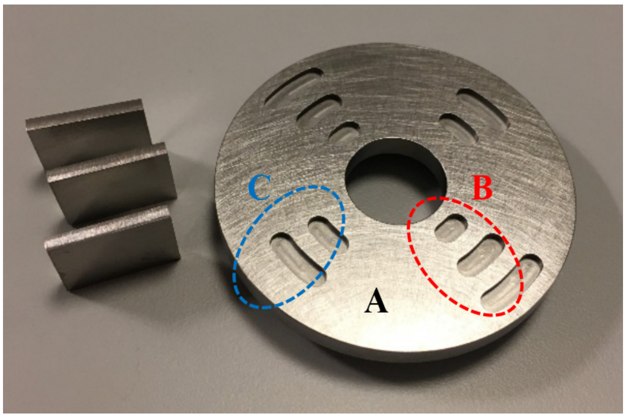

Fig 2. *Cyclic stress disk and Vanes for Falex MultiSpecimen vane pump setup*

To avoid any possible contamination of the tested oils, before each series of tests (for the same oil), the recirculation system, the vane holder adapter, the chamber table and the test chamber assembly were thoroughly cleaned with an appropriate solvent. Several rinses may be necessary to completely remove all remaining test fluids from the previous run. The setup was then dried by dry air and visually inspected to insure that it is free from any used test fluid, solvent, wear particles or other surface contaminants that might influence the test outcome. Afterwards, the recirculation system was flushed with 1 litre of test fluid for 5 minutes to remove all traces of cleaning solvent. The test fluid used for flushing the system was then drained and discarded. Notice that several flushes may be required to completely remove all traces of the cleaning solvent. If solvent is detected in the recirculation system, then the system should be flushed again.

Test Parameters	
Speed (rpm)	1500
Load (lbf)	100 up to 800
Time (h)	1 up to 25
Loading rate (lbf/s)	20-30
Oil volume (L)	3
Flow rate (LPM)	2

Table 1. *Experimental parameters for the Falex MultiSpecimen vane pump setup*

Possible test parameters are summarised in **Table 1**. During each test the temperature, load and speed were accurately controlled, and the measurement of temperatures of oil and test surfaces, as well as frictional torque were continuously monitored and recorded. In order to establish a correlation between Vane pump tests and the cyclic-stress vane-on-flat test, we performed ISO 20763 Conestoga Vickers vane pump tests on a number of hydraulic fluids. The test setup along a schematic of the pump assembly are given in **Figure 3**. The testing parameters for the Conestoga Vickers vane pump tests are given in **Table 2**. The wear loss of both the ring and vanes was evaluated by weight loss measurements in an electrobalance.

Fig 3. *(a) Conestoga Vickers vane pump tester*

After tests on both systems, the wear mechanisms are compared by scanning electron microscope (SEM), and the testing parameters of the Falex Multispecimen system were adjusted until the same wear mechanisms were obtained.

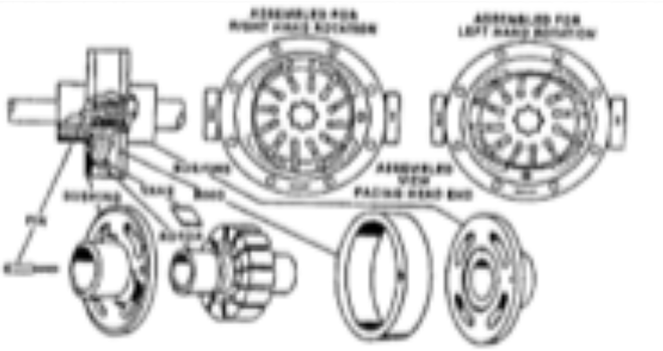

Fig 3. *(b) components and assembly of Conestoga Vickers vane pump*

Test Parameters	
Speed (rpm)	1500
Pressure (MPa)	14
Time (h)	250
Oil volume (L)	50
Flow rate (LPM)	25
Temperature (°C)	70

Table 2. *Experimental parameters for ISO 20763 vane pump tests*

Advantages of this prescreening method

This methodology allows for in-situ monitoring of the evolution of friction and temperature near the contacting surfaces. When the hydraulic fluid fails, and a change in wear mechanism takes place, this can be identified during the test by the sharp increase of coefficient of friction **Figure 4a**. The test can thus be stopped and time can be saved. In contrast, the Conestoga vane pump method only gives a wear rate at the end of test, and thus a pass/fail result without further information on the time of failure. The prescreening method furthermore allows for different hydraulic fluids to be compared in terms of frictional performance and evolution **Figure 4b**.

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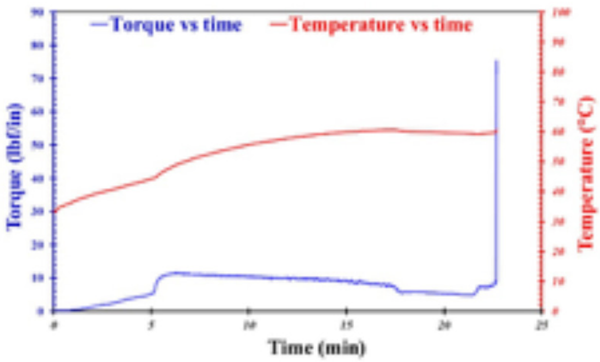


Fig 4. *(a) Evolution of coefficient of friction and test temperature as a function of sliding cycles at 800 lbf, failure after 22 minutes*

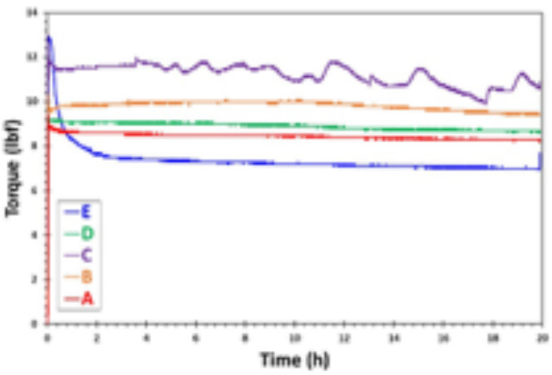


Fig 4. *(b) Comparison of the frictional behavior of five hydraulic fluids at 150 lbf for 20 hrs*

The flexibility of this technique also allows to run tests of increasing duration and to plot a wear evolution. An indicative graph of this wear evolution (**Figure 5**) shows that good repeatability is achieved. In addition, a running in period can be identified during the first few test hours. With this information, we can justify the duration of a sufficiently long test (e.g. 20 hrs) until steady 'state conditions' are reached.

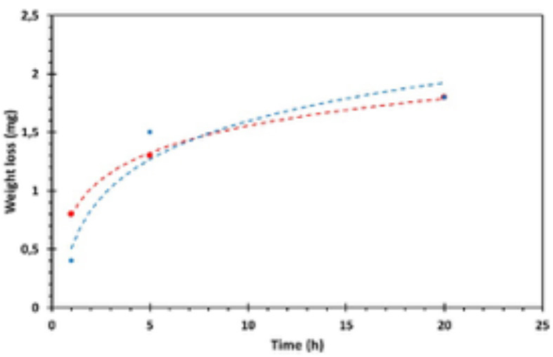


Fig 5. *Repeat test, evolution of weight loss for vanes + disk of a hydraulic fluid at 200 lbf load*

Testing under relevant conditions

As already stated in the introduction, it is essential to prove correlation with the 'actual' application. The test parameters have to be adjusted to result in the same wear mechanism. A failure map is plotted with the help of a SEM analysis where we compare vanes and disk from prescreening tests with vanes and rings from Vane pump tests (ISO 20763). **Figure 6** shows that the wear in a Conestoga vane pump consists of very mild abrasion and some oxidative wear. When the prescreening is done under correct conditions, the wear mechanisms will look the same. Based on such SEM comparison and weight loss measurements, we can identify 3 different regions on a load-time failure map (**Figure 8**). In the green area, similar wear mechanisms as with the Conestoga Vickers tests can be obtained **Figure 6**. In orange, weight gains are observed, indicating build-up or transfer of material from disk to vane. In red, the wear mechanism changes from mild abrasion and oxidative wear to severe deformation on both the vanes and disk (**Figure 7**). These conditions do not match actual conditions. Taking into consideration this failure map, it is clear that an accelerated wear test has its limits, as load can not be increased above the failure load. The same is true for trying to accelerate the test by increasing temperature: this will lead to a failure, rather than mild wear and is not representative for the wear mechanism in a Vane Pump.

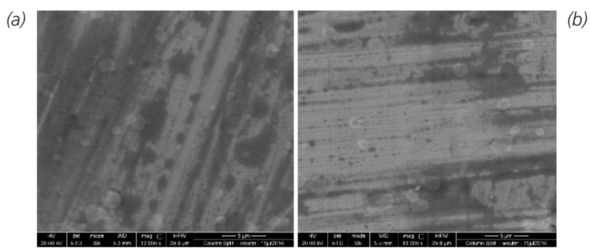


Fig 6. *SEM microstructures of vanes after testing in (a) MultiSpecimen tester at 200 lbf for 20 hrs and in a Conestoga vane pump tester for 250 hrs. (Green area of Figure 6)*

These observations and tests prove that the most common methods for 'accelerated testing,' namely increase of load and/or temperature, will lead to a dramatic change of the wear mechanism and become pointless as a prescreening test. For this reason, most 'simple' laboratory bench tests are irrelevant as they typically apply too high loads or contact pressures.

(a) (b)

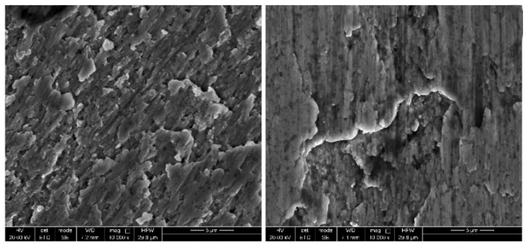


Fig 7. *SEM micrographs from (a) disk and (b) vane after MultiSpecimen testing at 1.2 GPa (800 lbf) for 1 h. (Red area of Figure 6)*

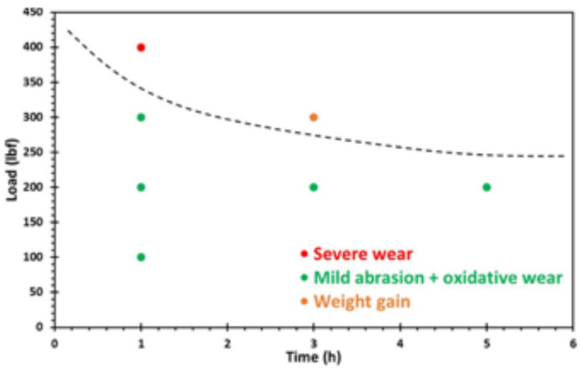
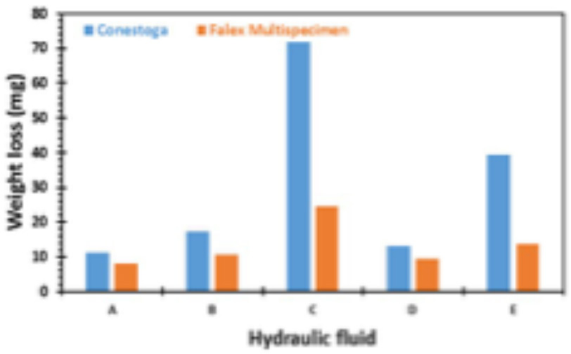


Fig 8. *Failure map for test conditions of MultiSpecimen vane pump tests*

Correlation with Conestoga Vickers Vane pump test

After confirming that the test methods produces repeatable data and that it generates the same wear phenomena as in the Conestoga Vickers Vane pump test, a correlation study was performed on 5 modern performance fluids, with ISO 20763 test results ranging between 10 and 70 mg. **Figure 9** (average of minimum 2 tests) shows an excellent ranking correlation, indicating that this technique can be effectively used for the comparison and ranking of hydraulic fluids. The test results do not yet match quantitatively with those of the ISO Vane pump test but are extremely useful to pre-screen and complement the pump test. Thanks to the proven correlation, lubricant manufacturers can now evaluate variations of a product on smaller volumes and in shorter test time.



(b)

Ranking	*Conestoga Vickers*	*Falex MultiSpecimen*
1	A	A
2	D	D
3	B	B
4	E	E
5	C	C

Fig 9. *(a) Comparison of weight loss and (b) ranking of five different hydraulic fluids, obtained from Conestoga Vickers (ISO 20763) and Falex MultiSpecimen tests (20 hrs, 150 lbf)*

A further ranking of the examined hydraulic fluids can be achieved by comparing their frictional behaviour and in particular of the evolution of the tribosystems torque as a function of testing time (see **Figure 4b**). What is interesting is that the hydraulic fluids with the lowest weight loss (**Figure 9**) also brought about a lower torque in the tribosystem (**Figure 4b**). Only exception was hydraulic fluid E, which despite having the lowest 'steady state' torque, resulted in an average ranking in terms of weight loss. However, we should notice the high torque recorded during run-in might be linked to a higher initial wearing off of the surface of the vanes and disk. This is another clear indication that these prescreening tests should be performed at longer testing times (based on this work we advise for at least 20 hrs of testing). In addition, a fluctuation of the torque around an average value was observed for hydraulic fluid C during these tests. We believe that this fluctuation could be attributed to several phenomena. First during these tests wear particles (debris) are formed at the contacting interface and especially in this case where a higher weight loss was recorded for the tribosystem (**Figure 9**). Indeed, in the 'world of Tribology' it is widely known that in the generation of debris in a sliding contact can cause localised abrasion, localised sticking due to particle agglomeration, formation and break-off of tribofilms due to particle compaction etc. and thus they can alter the frictional behaviour of the system. In addition, we should consider that due to the wearing off of the vanes and the disk, their surface roughness will also change. However, changes in roughness can have a significant influence on the thickness of the lubricating film (as indicated by Stribeck[2]). Film breakdown leads to local asperity contacts that can cause metal to metal adhesion and influence the friction and wear.

Summary

To help readers compare between the standardised Conestoga Vickers and the prescreening Falex Multispecimen tests a Summary table is prepared and is presented in **Table 3**.

	ISO 20763 (ASTM D7043)	Falex Cyclic stress vane-on-disk
Duration	250 h (100 h)	20 h
Typical delivery time test result	+2 weeks (+1 week) including setup and rinsing procedures	2 days including setup and rinsing procedures
Oil volume needed (including rinsing)	120 l (60 l)	5 l
Wear mechanism	Mild wear, abrasive and oxidational	Mild wear, abrasive and oxidational when below failure load
Online measurements	Oil temperature, pressure, speed	Oil temperature, load, speed + friction, disk temperature
Correlation	SAME RANKING – SAME ORDER OF MAGNITUDE WEAR RESULTS	

Table 3. *Summary table comparing standardised Conestoga Vickers and Falex Multispecimen prescreening tests.*

The obvious advantages of the new methodology on the Falex Multispecimen machine, with cyclic stress vane-on-disk tests are the in-situ monitoring of evolution of friction and temperature near the contact surface, and the shorter and repeatable measurement requiring less lubricant volume.

The key feature of this methodology, however, is that similar contact conditions and wear mechanisms are obtained in the MultiSpecimen and Conestoga Vickers tests, leading to a similar ranking of hydraulic fluids and a correlation between the pump stand and the bench test. It is believed that this method can be an ideal technique to compliment standardised Conestoga measurements and a useful tool for the investigation and further development of hydraulic fluids.

Conclusions

- Prescreening of hydraulic can be performed with a modified Falex Multispecimen tester. This method was developed to simulate the working conditions of a vane pumps, by using with a vane-on-disk configuration and a hydraulic fluid recirculation test chamber. In addition, standardised test disk with specialised grooves that create the variable pressures encountered by the vanes in a pump during each cycle were developed.
- The advantage of this method is that the duration of the test is much shorter (20 h compared to 250 h) and a smaller quantity of hydraulic fluids (3 L compared to 60 L) than the ISO 20763 Conestoga Vickers test is needed. In addition, it allows for an in-situ monitoring of the evolution of friction and of the temperature near the contact surface, so that a correlation between the friction and interfacial temperature can be obtained. This also enables us to compare the frictional performance of hydraulic fluids as information on the torque evolution during each test can be used for further analysis and evaluation of hydraulic fluids.
- A key feature of this prescreening method is that similar wear mechanisms occur as in the standardised Conestoga Vickers tests. This concept was clearly illustrated by the failure map and it comes to show how important is to test tribosystems under 'relevant' conditions. Some lab tests can provide accelerated measurements but they do not always correlate with the actual application.
- What makes this prescreening method even more interesting not only in the research field but for end-user and manufactures of hydraulic fluids is that similar ranking in terms of weight loss as with Conestoga Vickers tests is obtained, whereas the results are repeatable. In addition, the significantly shorter testing time can allow for multiple tests and for a complete statistical evaluation of frictional and wear data. This is also one of the main drawbacks of the standardised tests, as their precision sometimes is not sufficient to distinguish between high performance oils (with an weight loss of less than 20 mg after 250 hrs of testing).
- The future goal of Falex is to propose a standardised method that will aid in the development of hydraulic fluids and will complement existing standardised Conestoga Vickers tests.

[2] *Tribologie-Handbuch 2. Auflage, Horst Czichos & Karl-Heinz Habig, 2003, ISBN 978-3-528-16354-9, p.225*