Experimental research regarding the tribological properties of a hydraulic oil

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Abstract. This paper presents the results of the interesting experimental research regarding the influence of the additives over a hydraulic oil i.e. HFE46 (produced by ChemTrend [10]). In this vein, were used two types of additives (resulting two variants of oils denoted as sample C and D respectively) and was carried out a gravimetric determination (using the Timken test) analysing the hydraulic oils lubricating properties. Also, measurements regarding the vibrations in the tribotechnical system - TTS were conducted.

1. Introduction

Hydraulic oils are used in today's world in a wide range of domains, such as - food and agriculture - in various farming machinery; in manufacturing engineering - for all types of mechanical machines, presses etc.; in constructions - for all sorts of cranes and other pieces of equipment including here buckets, crawlers, etc. In all these applications the pressurized hydraulic oil - is carried out through the associated hydraulic circuit from the pump (driven by a power source, i.e. an electric motor) - pipes - valves - and finally to the end element - an actuator to convert the energy of the fluid into mechanical force or torque, in order to perform various tasks. The pump and the control valves create flow and pressure which are transmitted throughout the pipes to the entire system resulting vibrations and noises with harmful effects on the system's components. For example, in aircraft industry vibrations conduct to almost half of the failure of the hydraulic system [1]. Therefore, the performance of the hydraulic system is highly influenced by the hydraulic oils.

There are a series of studies regarding the influence of the hydraulic oils upon the hydraulic systems. Chai L. et al. in [1] developed a new versatile and compact hydraulic pulsation attenuator for hydraulic piston - pump systems. Chenxiao and Zhang [2] studied the vibration and noise sources into the hydraulic hoist systems. Cristea and Haragâş in [3] and [4] presented two studies regarding the oil the viscosity influence over the vibrations and noises in heavy industry machinery. Changbin and Zongxia in [5] describes an optimal design for a 3 DOF Helmholtz resonator used for a certain type of aviation piston - pump system in order to reduce the flow pulsation. Ye-qing et al. in [6] carried out a vibration analysis using the 3D model of a linear-motor-driven water piston pump. Harrison and Edge in [7] developed a novel mechanism in order to reduce the flow ripple in the case of an axial-piston-pump system. Bettig and Han in [8] described a hydro-generator rotor dynamic model for determining imbalances and shaft misalignments by running vibrations measurements.

Next the authors introduce the gravimetric determination of wear (section 2) for the case of a tribotechnical system - TTS [9] in presence of a hydraulic oil i.e. HFE46 (produced by ChemTrend [10]) with two different types of additives (hereinafter refer as sample C and D respectively), after which the measurements carried out with a SVAN 974 vibrometer (section 3) are described. The fourth section contains discussions regarding the lubrication efficiency, about the variation of the friction coefficient with the speed (Stribeck curve). Finally, the authors conclude this discussion with some reflections and suggestions regarding the possible extensions of the present study.
2. Gravimetric analysis

The gravimetric analysis is the technique through which the amount of wear corresponding to a specific sample is appreciated by comparing the masses of the test specimen between and after the procedure. Obviously, the accuracy of this method depends on the precision of the measuring device (in here was used a digital analytical balance with 0.1 mg readability).

![Testing machines](image1.png)

**Figure 1.** The testing machines
(a) - the tribometer; (b) - the base body and counterbody analysed

In this paper the gravimetric wear analysis was carried out on a Timken universal wear and friction testing machine (figure 1,a).

| Lubricant type | Initial mass, $m_0$ (g) | Mass after the test period, $m_1$ (g) | Wear mass loss, $m_0 - m_1$, (g) |
|---------------|-------------------------|---------------------------------------|----------------------------------|
| Sample C      | 10.3023                 | 9.9071                                | 0.3952                           |
| Sample D      | 10.6226                 | 10.5858                               | 0.0368                           |

![Colour samples](image2.png)

**Figure 2.** Initial and final colour of the samples. On the left the colour before and on the right – after the wear process
(a) - sample C; (b) - sample D

The interfacial medium [9] i.e. the third element of the TTS as we already pointed out is represented by the HFE46 hydraulic oil in his two variants (i.e. sample C and D).
The other components of the TTS are the two cylindrical test specimens (with 16 mm diameter) which are in contact with a disc mounted on an electrical motor shaft having an input speed of ≈ 980 rpm. The rotary disc is made of 1C45 hardened carbon steel with 48 HRC. The tests are carried out for a total load of 227 N during 60 min. The experimental results are shown in Table 1.

As it can be observed from table 1 the quantity of material lost due to wear process in the case of sample D (0.0368 g) is ten times lower than in the case of sample C (0.3952 g). This means that the wear rate is ten times higher for the sample C. It is obviously from this analysis that the hydraulic oil denoted as sample D has superior proprieties over the sample C.

Another important aspect represents the oxidation stability (the aging test [9]). During these experimental tests the oil temperature reached about 80°C (in general the hydraulic oils are used up to 50 - 56°C). As a result of this, a pronounced oxidation occurred. In figure 2 are illustrated the initial and final colours for both samples of oils. From here it can be observed that the sample D has the final colour close to the original one which indicate a lower oxidation rate.

3. Vibration determination

In this section is described the method used for measuring the vibration of the TTS. In this vein a digital vibrometer i.e. SVAN 974 (figure 3,b) was used. It has a magnetic base which has been positioned on the tribometer according to figure 3,a (this position was used for both samples and was considered to be the most relevant in terms of transmission of vibrations to the tribometer’s housing).

![Image](image1.png)

**Figure 3.** Vibration determination

(a) - the vibrations measurement position; (b) - the SVAN 974 vibrometer

![Image](image2.png)

**Figure 4.** Peak-to-Peak (P-P) and Peak (P) acceleration for sample C
In here were measured Peak-to-Peak (P-P) (which represents the distance from a negative peak to a positive one) and Peak (P) accelerations. The graphs resulted after the measurements for both samples are presented in figures 4 and 5.

It is observed from the above graphs that the P-P accelerations corresponding to sample C varies from 150-250 m/s² while for the sample D the P-P accelerations are in the range of 100-150 m/s². Regarding the P accelerations, as it can be seen in figures 4 and 5, they vary between 100-150 m/s² for sample C and from 50 to 100 m/s² for sample D respectively.

Also, from these figures it can be seen that during 20 min of running the experiment the accelerations increase for both samples. After this interval of time for sample D the accelerations are dropping around the initial values while in the case of sample C the accelerations are continuously increasing (as a result of oil oxidation).

Regarding the vibration analysis it is clearly that in the case of the sample D they decrease considerably which means that this sample has superior lubricating proprieties over the other sample.

4. Lubrications state simulation
In this section were carried out a set of experiments on an MCR 102 tribometer (figure 6) in order to study for both the hydraulic oil samples (C and D) the lubrication efficiency. Also, in here was analysed the variation of the friction coefficient with sliding velocity (Striebeck curve).
In figure 7 the Stibeck curve is plotted. This curve is widely used [11] to describe the lubrication regimes, i.e. the boundary lubrication - \textit{BL}, mixed lubrication - \textit{ML} and hydrodynamic lubrication - \textit{HL}.

It can be seen from these curves that initially, in the case of boundary and mixed lubrication the coefficient of friction is higher for the sample D (possible due to a higher kinematic viscosity of this oil). Upon passing to fluid lubrication regime, the coefficient of friction is lower for sample D than sample C.

![Stibeck curves for both samples](image)

**Figure 7.** Stibeck curves for both samples

5. Conclusions

Experimental research carried out in this study for two hydraulic oil samples highlights the influence of additives used for hydraulic oils over their tribological properties. In this vein, in the case of gravimetric determination (using the Timken test) it was concluded that after the experiment the sample C was weighted 9.9071 g (the initial value was 10.3023 g) while the mass of the sample D was 10.5838 g (the initial mass was 10.6226 g). As compared with their initial masses it was observed that the wear rate in the case of sample C are ten times higher than for the sample D.

Regarding the vibration analysis, it is observed that the P-P accelerations corresponding to sample C varies from 150-250 m/s$^2$ while for the sample D the P-P accelerations are in the range of 100-150 m/s$^2$. The P accelerations, vary between 100-150 m/s$^2$ for sample C and from 50 to 100 m/s$^2$ for sample D respectively.

Also, after an initial interval of functioning i.e. 20 min in the case of sample D the accelerations are dropping around the initial values while in the case of sample C the accelerations are continuously increasing (as a result of oil oxidation). From here we can conclude that the sample D has superior lubricating properties over the sample C.

From the Stribeck curve analysis it can be seen that in fluid lubrication regime the friction coefficient had lower values for the sample D over the sample C.

6. References

[1] Chai L, Jiao Z, Xu Y, Zheng H 2016 A compact design of pulsation attenuator for hydraulic pumps, \textit{IEEE International Conference on Aircraft Utility Systems Beijing}, 1111-16

[2] Chenxiao N, Zhang X 2012 Study on vibration and noise for the hydraulic system of hydraulic hoist, \textit{Proceedings of 2012 International Conference on Mechanical Engineering and Material Science (MEMS 2012)}, 126-128

[3] Cristea F, Haragâş S 2018 The lubricants influence in transmission of vibration and noises from aluminum injection machines, \textit{PROC ROM ACAD SER A}, \textbf{18}, 1, 77-84
[4] Haragâş S, Cristea F 2017 Experimental research concerning the vibration of the hydraulic pump machine that injected aluminum, depending on the type of hydraulic oil used, Acta Technica Napocensis, series: Applied Mathematics, Mechanics and Engineering, 60, 171-74

[5] Changbin G, Zongxia J 2012 Modelling and Optimal Design of 3 Degrees of Freedom Helmholtz Resonator in Hydraulic System, Chinese Journal of Aeronautics 25, 776-83

[6] Ye-qing H, Song-lin N, Hui J, Shuang N 2016 Vibration analysis and experimental research of the linear-motor-driven water piston pump used in the naval ship, Shock and Vibration

[7] Harrison AK, Edge KA 2000 Reduction of axial piston pump pressure ripple, PROC INST MECH ENG I-J SYST C, 214, 53-64

[8] Bettig BP, Han RPS 1999 Modelling the lateral vibration of hydraulic turbine-generator rotors, Journal of Vibration and Acoustics - Transactions of the ASME, 121, 3, 322-27

[9] Grote KH, Antonsson EK 2009 Springer handbook of mechanical engineering, Berlin: Springer-Verlag

[10] https://www.chemtrend.com/

[11] Lin L, Chao Y, Yuanyuan S, 2018 Wear model based on real-time surface roughness and its effect on lubrication regimes, TRIBOL INT, 126, 16-20, ISSN 0301-679X