Univerzitetna založba
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Pomen poznavanja dejanskega stanja hidravličnega olja kot osnova za strateška odločanja

DARKO LOVREC & VITO TIČ

Povzetek Običajna hidravlična olja na mineralni osnovi in turbinska olja, katera se uporabljajo na strojih in napravah imajo različno dolgo uporabno dobo. Ta je odvisna od vrste različnih faktorjev: od pravilnega vzdrževanja in uporabljen vrste nadzora in aktivnosti in od skrbne izbire vrste olja. Mehanizmi staranja hidravličnih olj in pa vzroki, zakaj jih je potrebno zamenjati so sicer zelo dobro znani uporabnikom, manj poznano pa je dejstvo, da so med posameznimi vrstami olj velike razlike glede njihove vzdržljivosti, ko so le ta izpostavljena delovnim pogojem stroja.

Vsako podaljšanje uporabne dobe hidravličnega ali turbinskega olja ponuja tako finančne kot okoljske prednosti, a predpostavlja poznavanje dejanskega stanja olja. Za namene ocene preostale uporabne dobe olja, je v prispevku predstavljena nova metoda za primerna za on-line nadzor stanja in za testiranje vzdržljivosti oz. oksidacijske odpornosti različnih hidravličnih olj. Rezultati takšnega testiranja uporabniku nudijo možnost strateškega odločanja pri postopku nabave najprimernejšega olja z dolgo uporabno dobo.

Ključne besede: • hidravlično olje • staranje • on-line nadzor • testiranje • strateško odločanje •

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The Importance of Hydraulic Oil Real-Condition Identification as a Basis for Strategical Desicion-Making

DARKO LOVREC & VITO TIČ

Abstract Conventional mineral-based hydraulic oils and turbine oils used within energy plants and machines have different long service-lives. This depends on variety of different factors: by proper maintenance, monitoring activities and strategies, and by careful selection of oil-type. Aging mechanism of hydraulic oils and the fact why they need to be replaced are well-known to the user, but lesser-known is the fact that there are great differences in the durability of hydraulic oils when exposed to machine-operating conditions.

Any extensions in the service-lifetimes of hydraulic or turbine oils can deliver both, cost savings and environmental benefits, but requires the knowledge of real oil-condition. In order to evaluate the service-life of oil, this paper proposes a novel method appropriate for on-line condition monitoring and testing the durability and oxidation stabilities of different hydraulic oils. The test results can be used for selecting the more adequate oil with a long service-lifetime.

Keywords: • hydraulic oil • aging • on-line monitoring • testing • strategical decision-making •

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1 Introduction

Increasing investment costs of machines incorporating fluid power combined with increased demands on mean time between failures put pressures on manufacturers to incorporate condition monitoring function into their systems [1].

Different energy plants, e.g. water, nuclear, thermal power plants or off shore wind energy regeneration plants, are operated in 24/7 cycle and in some cases far off any maintenance departments and stuffy, and with the expectation that they generate electricity all year round. The same applies to some production machines in complex production environments where reliability has to increase, while downtime and unscheduled breakdowns have to be kept at an absolute minimum. All these systems are using hydraulic drive technology with increasingly complex components that need to be monitored, as well as the hydraulic oil condition in the hydraulic system. Hydraulic oil can be changed when necessary and not at predetermined time intervals. Thus cost for the purchase, disposal and storage decreases with reduced consumption and sustainability of regrowing sources increases and natural resources last longer.

Typical characteristics of wear and failure rate, which applies to all technical components, are shown in Figure 14.1.

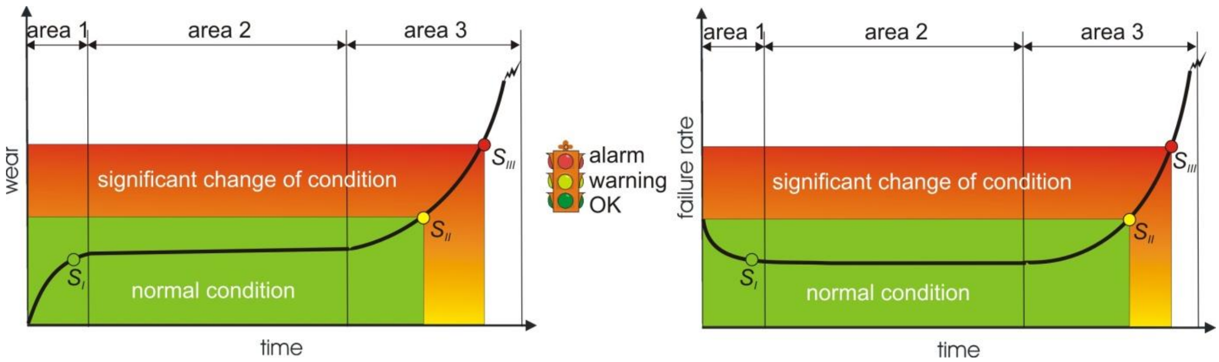
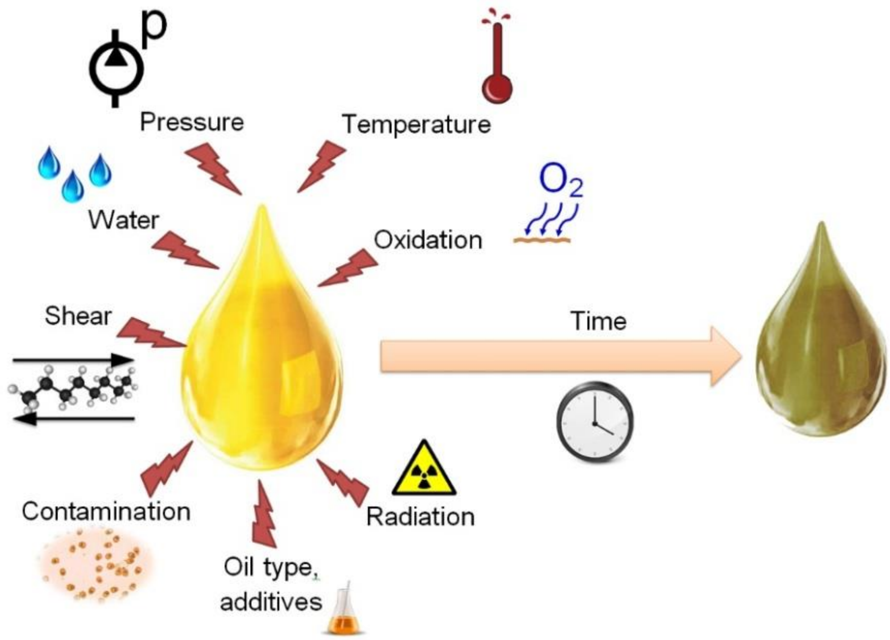


Figure 14.1: Typical characteristics of wear and failure rate [1]

Area 1 stand for increased wear or even early failures due to faults in material, poor tolerances, assembly errors, brought-in dirt or the use of incompatible fluids. A good quality control management system should take care of these early failures and prevent them from occurring. Area 2 comprehends the real system lifetime without much wear and any failures. It is followed by area 3 with gradual wear and failures and then self-enhanced demolition of a system failure. Here it becomes important for a condition monitoring system to recognize the failure and visualize counter measures for action items by the user.

The same course of changes also applies to hydraulic fluids - eg. the most commonly used mineral based hydraulic oils. But in this case the profile course concerns the changes relate to changes in physical and chemical properties of hydraulic fluid. In order to satisfy all requirements regarding the long service-lifetime, the different physical and chemical properties of the hydraulic fluid must remain within certain limits. Unfortunately, throughout its life-cycle the hydraulic fluid is subject to several physical and chemical operational effects [2], e.g. high pressures and temperatures, oxidation, mechanical and/or fluid contamination and others, as shown in Fig. 2. Consequently, over time the hydraulic fluid loses its abilities for performing the key functions and therefore must be changed.



Nowadays the lifetimes of the hydraulic fluids are still mainly determined by the machines' manufacturers, i.e. at certain fixed time intervals or number of hours [2]. In most cases these are empirically estimated time intervals with certain degrees of safety factors. The actual quality of a fluid is rarely taken into account, or the operating conditions of the machine. Therefore the quality of a fluid may be better than estimated and the fluid may be changed much earlier than actually needed.

All the above-mentioned depend of the type and "quality" of used hydraulic oil. Therefore it is very important to know what the durability of the used hydraulic oil is (under normal operational conditions). Different test methods are used to obtain this information.

2 Oil Degradation and ageing test

When properly maintained, mineral based hydraulic oils have relatively long service-lives from 5 to 10 years and in the case of hydraulic turbine oils even more than 20 years. Therefore it is reasonable to obtain data regarding physical and chemical changes using an accelerated-ageing test.

Due to the diversity of the base-oils, and the diversity of additives present within the oil, it is impossible to provide a precise and unique statement regarding the general mechanisms of oil ageing and on-going chemical processes. Hydraulic oils oxidise during "the performing their work" which is reflected in significant increases in friction and wear that affects the performance of the machine and consequently its reliability. The main effect of oxidation is a gradual rise in the viscosity and acidity of the oil.

As already mentioned mineral oils oxidise during their service-lifetimes and this causes significant increases in friction and wear that affects the performance of the machine. The main effect of oxidation is a gradual rise in the viscosity and acidity of the oil, as well as the formation of deposits, in form of sludge and warmish, which can cause the blocking the oil pathways inside the components.

The oxidation rates can be affected by temperature, metals in contact with the oil, and the amount of water and oxygen present within the oil. The temperature especially has a profound effect on oxidation rates, which can be doubled or even tripled by a temperature rise of 10 °C [3], [4]. This is why accelerated oil-ageing tests usually involve high temperatures, high pressures and the additions of different catalysts, and water.

The commonly used accelerated oil-ageing tests can be divided into two main groups: the mechanical ones and the thermal or chemical ones. The mechanically accelerated oil-ageing tests performed on specially built test rigs are otherwise closer to real conditions but they have very long testing times. Therefore these kinds of tests are performed using real hydraulic components under harsh, tougher usages: higher temperatures and pressures, smaller oil quantities, bigger pump-sizes, higher contamination with solid particles, higher water content or moisture, etc.

By using the so-called thermal oil ageing tests we obtain quicker information regarding the oil durability. There are several standardised accelerated-ageing tests available, mainly developed for the evaluation of oxidation stabilities regarding fresh and in-service hydraulic oils, e.g. [5], [6]. They are based on exposing the hydraulic fluid to high temperatures, air or oxygen, different contaminants such as water, copper, iron, that act as catalysts. A brief overview of the common tests and their operational conditions can be found in Table 14.1.

Table 14.1: Overview of standardised thermal oxidations tests

Test (ASTM)	Gas	Pressure	Temp	Catalyst
PDSC (D6186)	O_2	34.5 bar	180 °C	Fe
RPVOT (D2272)	O_2	6.2 bar	150 °C	Cu/Fe
UOT (D6514)	Air	Atmospheric	155 °C	Cu/Fe
UOT (D5846)	Air	Atmospheric	135 °C	Cu/Fe
TOST (D943)	O_2	Atmospheric	95 °C	Cu/Fe/H_2O

The listed tests are not suitable for further extensive research related to the determinations and identifications of variations in the physical and chemical properties of the tested oils, as they are tested on smaller quantities of oil, eg. RPVOT: 50 g and TOST: 300 mL. Therefore we were forced to develop our own thermal test for accelerated oil-ageing using a larger sample volume of 1,500 mL, which would suffice for all subsequent laboratory analyses (so-called the thermal dry LaOH test). Our own novel test is based on the more established and more frequently used standardised RPVOT and TOST tests. During our test, the oil is heated using a magnetic mixer to 160 ±0.1 °C whilst 3 ±0.1 L/min of air is being constantly induced. The test also includes a catalyst in the form of a 1.5 mm^2 copper wire of which 15 m is bent into a spiral.

The test is carried out under atmospheric pressure within a sealed chamber with a dedicated system oil extraction of oil vapour. As shown in Figure 14.3, the chamber allows for the testing of both single and multiple samples at the same time.

Figure 14.3: Thermal durability LaOH test for hydraulic oils

The used test does not have specific end-times because its main goal is to record the process of accelerated oil-ageing over its service-life. Thus multiple tests over various durations are carried out on one type of oil in order to achieve different degrees of oil-ageing and oxidation rates. So we obtain several different degraded samples on which we can carry out further laboratory analyses. After the test, all the samples are first measured using several on-line sensors and then sent to a laboratory for further in-depth chemical analysis.

Figure 14.4: Hydraulic mineral oil samples after the different testing hours; different degrees of ageing and oxidation; sludge formation on copper wire

The tests and laboratory analyses conducted (Figure 14.5) revealed, that the oil-ageing and oxidation processes can best be monitored and evaluated using the following parameters:

- colour (ASTM D 1500),
- viscosity (ASTM D 445),
- neutralisation number (ASTM D 974),
- FT-IR oxidation (ASTM E 2412),

shown as a function in regard to achieved test time.

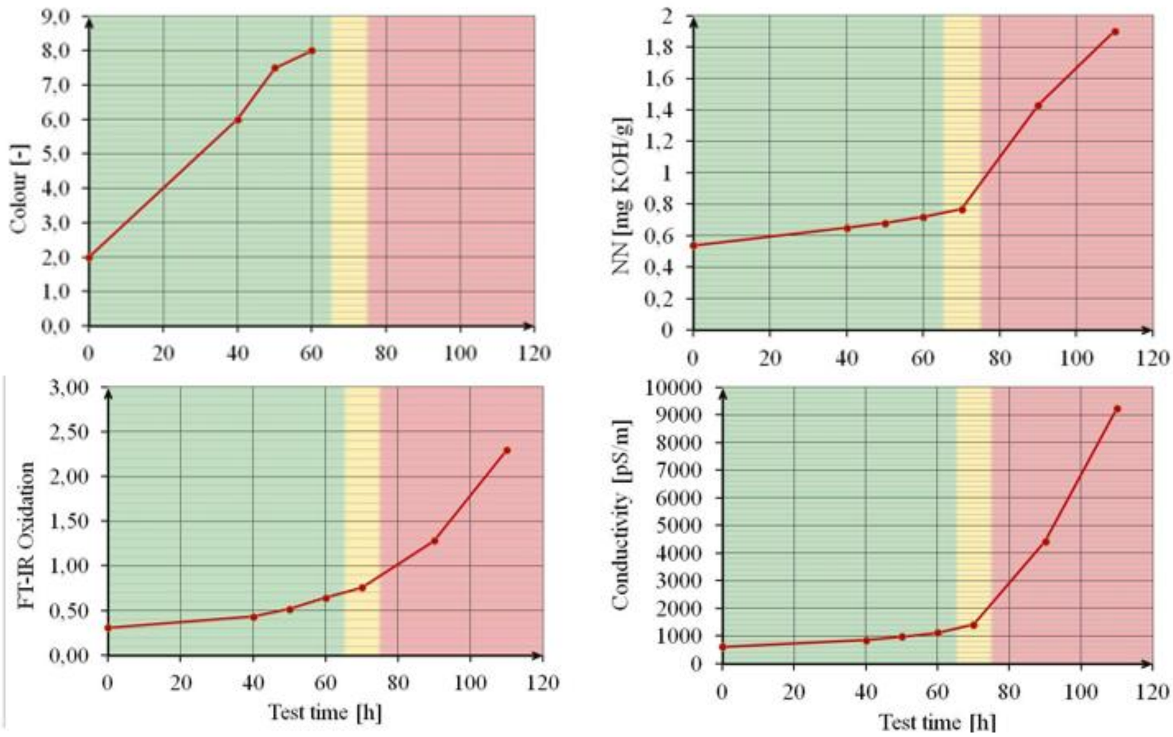


Figure 14.5: Accelerated oil-ageing test results

On the basis of the described test and after the detailed laboratory analysis of the more important physical and chemical parameters of the oil, comparative testing of three different turbine oils was carried out.

3 Determinatio of different turbine oil's lifetimes

In regard to testing the useful lifetimes or durability of hydraulic turbine oils three different turbine hydraulic oils types have been used: mineral turbine oil (TO1), pre-treated mineral turbine oil (TO2), and saturated synthetic ester as a turbine oil (TO3). All three types of turbine oils were tested according to the described procedure - the durability dry thermal test.
The tests and laboratory analysis conducted revealed that:

- Certain oils resist the oxidation and ageing processes much better than others and may have double or even several multiple extended service lifetimes.
- The results can be used for carefully selecting more appropriate high quality oils with high oxidation stabilities, which would have extended service -lives.

After the completion of a more detailed analysis using laboratory results for the physical and chemical parameters of the tested oils, the results revealed that oil-ageing can best be monitored and evaluated beside by colour, viscosity, neutralisation number and FT-IR oxidation with an electrical conductivity. The electrical conductivity as a physical-chemical parameter and as an oil-ageing degree indicator is especially appropriate for an on-line Condition Monitoring system.

A direct comparison between the results on the same graph certainly provides better insight into the changing of individual parameters during the testing times, using the same time-scale – Figure 14.6.

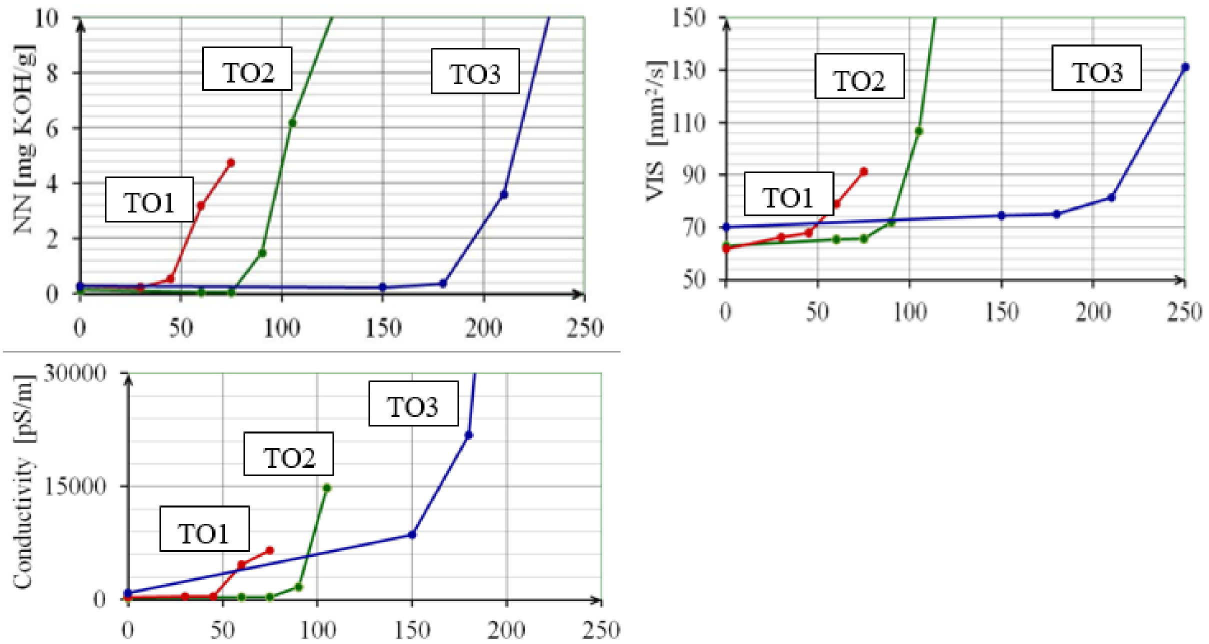


Figure 14.6: Different parameters of three turbine oils in direct comparison

If we take a closer look at the graphs shown in Figure 14.6, we can make comparisons between three different turbine oils' performances during the test. We can see the poor performance of mineral turbine oil TO1 (red) in every aspect. It lasted the least time until the values started to increase exponentially. A much better performance was achieved by the turbine oil TO2 (green line), which lasted almost twice as long as the TO1. The interesting thing is that they basically have the same price. Turbine oil TO3, which is a synthetic, saturated ester had the best performance but it‘s price is also higher than those of TO1 and TO3.

The neutralisation number (NN) and electrical conductivity are two very important or revealing parameters regarding the state of oil degradation were recalculated to 'real time' and 'real operating' conditions - at operating oil temperatures of 60 °C, as shown in Figure 14.7.

As known from the literature, at temperatures higher than 70°C for every 10°C the status changes by a factor of 2, and the same condition increases the time by a factor of 2. This should be at a temperature of 80 °C instead of 70 °C, and thus the lifetime of a mineral oil is halved. This can be written in the equation below:

$$f = 2^{\frac{T - T_{ref}}{10}} \tag{1}$$

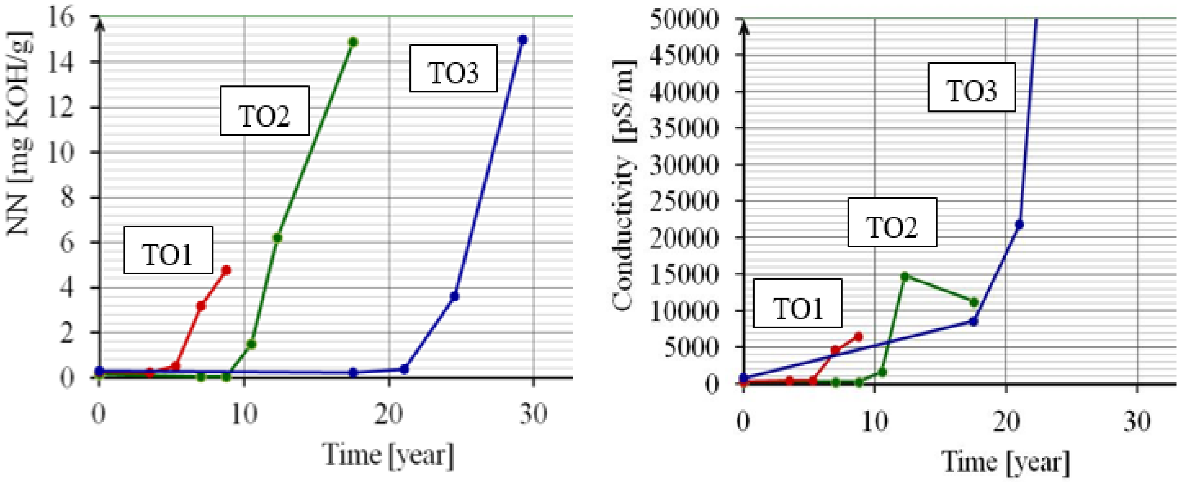


Figure 14.7: Results of measurements converted to real-time and real operating conditions

Both Figure 14.6 and Figure 14.7 show the differences between the various turbine oils' resistances to ageing and are very significant, even more than 4 times. The reason is, that saturated esters (TO3) do not readily react with oxygen and are, therefore, significantly more stable than non-saturated ester products. This is also a major factor in their 'lifetime fulfilling' characteristics.

4 Conclusion

The extensions of service-lives regarding hydraulic fluids is gaining prominence due to several considerations including environmental pollution, conservation of natural resources and the economic benefits associated with extended service-life. By using the enhanced fluid management techniques and hydraulic oil with the highest durability, several economic and environmental benefits can be obtained over a longer period of time.

The presented novel method for testing the durability and oxidation stabilities of hydraulic fluids can be simultaneously used in two ways. Firstly for comparing different hydraulic oils and for selecting more adequate oils with higher oxidation stabilities and longer service-lifetimes and secondly for the development of a prognostic model for an accurate prediction of an oil's condition and its remaining useful lifetime, which could help to extend the service life of the oil without concerns about damaging the equipment

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