Benefits of lubricant oil analysis for maintenance decision support: a case study

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Benefits of lubricant oil analysis for maintenance decision support: a case study

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Abstract. Often, maintenance managers face challenges in making maintenance decisions due to the lack of sufficient and accurate information. It's not uncommon for the current problem to be resolved, but the cause of the problem remains, which is why some types of failures often recur, reducing the equipment availability and generating additional costs. To overcome these challenges, modern maintenance principles are based on the application of the equipment condition monitoring techniques. One of these techniques is used oil analysis also known as lubricant condition monitoring, which yields an insight into the physical and chemical state of the lubricating oil, as well as the condition of the machine elements that come in contact with oil during routine operation. To illustrate the benefits of employing this technique, a case study of asphalt paving machine is presented. In the case study, four basic lubricant parameters (viscosity, water content, solid particulate content and acid number) for the hydraulic system were analysed. The results of the analysis show a sudden increase in the solid particles content, due to which certain maintenance interventions had to be taken to avoid failure of the system and unnecessary maintenance costs. Also, by oil condition monitoring, after two years, maintenance staff received information which is the base for making a decision on the appropriate replacement interval of hydraulic oil.

1. Introduction

Maintenance can be defined as a set of activities aimed at retaining or restoring to the functional state of any technical system to achieve its maximum working life. Traditionally, maintenance has been considered as a necessary evil, but in fact it is a profit centre rather than just unpredictable and unavoidable expense [1]. Effective maintenance policies, such as Condition Based Maintenance (CBM), can significantly reduce failure rate which resulting in considerable savings of money, time and company's reputation in the market.

In a modern organization's maintenance and operations, condition monitoring plays a crucial role in optimizing the maintenance activities, as a part of an effective maintenance policy. Condition monitoring ensures that maintenance decisions are made from substantive and corroborated diagnostic information, thereby determining a basis for cost-effective and logical decision-making [2]. Thus, condition monitoring and diagnostic technology are nowadays extensively employed in numerous industrial applications. The primary purpose of condition monitoring is to register any abnormalities of working parameters of the machine before the functional breakdown occurs. There are different

condition monitoring techniques in use such as: vibration monitoring, thermographic monitoring, ultrasonic monitoring, lubricant analysis, visual inspection and others. Most of the condition monitoring techniques to some extent are complimentary to each other but very robust individually.
In this paper, in-service oil analysis or used lubricating oil is advanced, to monitor the condition of the hydraulic system fluid/lubricant during its operation. Primary reason was to determine the most appropriate interval for oil change, and the secondary reason was to determine if the lubricant in use meets the lubricating requirements of the machine or application.

2. Methodology
This study incorporated a case study from the road construction company which has several equipment that have recurrent failures in the hydraulic systems. The study was motivated by the concern of the maintenance managers of the company on the frequent recurring and expensive failures in the hydraulic systems of their divergent equipment. Figure 1, illustrated several steps to be taken in the methodology.

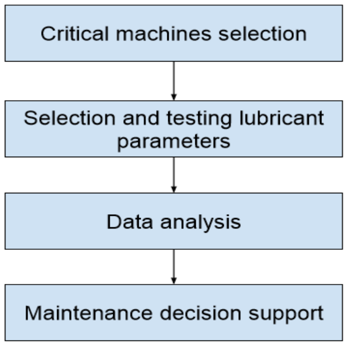

Figure 1. Steps adopted in the methodology.

The first step incorporates the selection of the critical machines to investigate in the context of maintenance. This was done by setting up a selection criterion consisting of factors to consider which was jointly set up by the maintenance team and the authors. The second phase invoked investigations to enable selection of the crucial lubricant properties to utilize in the investigation. This involved discussion with the maintenance team, review of the original equipment manufacturer's (OEM) recommendations and expert experience. This phase also involved setting up the study mission time, sampling intervals and testing the in-service lubricant. The third phase occasioned the analysis of the in-service lubricant tests to reveal embedded patterns that would assist in maintenance decision support. The last section involves the results discussion with the impact to maintenance decision making for the company.

3. Results and discussion
In this section, the results review is presented and discussions of the results following the methodological steps in Section 2.

3.1. Selection of critical machines
Since the company had numerous construction equipment, the first phase of the study involved selection of the critical machine type amongst them. To assist in selecting the critical machines, several factors among others were considered and evaluated: (1) does machine consider adequate replacement, (2) does machine have high complexity level, (3) does machine service implies high costs and (4), does machine failure significantly affects the productivity of the company. After the consideration all the aforementioned factors, one of the critical machines for the company business was selected – the Asphalt Paving Machine whose image is found in Figure 2.

Figure 2. Asphalt paving machine.

3.2. Lubricant parameters selection

According to the company standard, oil filling of the hydraulic system is changing every two years, no matter what the condition of hydraulic oil is. Hydraulic oil condition check, was not a part of the company's practice and oil change is mostly based on equipment manufacturers recommendations or on their own judgement. Since the company has never controlled the condition of oil filling so far, it has been agreed to monitor certain oil parameters during the exploitation to determine the appropriate interval for oil change.

After consultation and discussions, four lubricant properties deemed important in the hydraulic fluid operation under this case context were selected. They included viscosity at 40^{o}C, water content, solid particles content and TAN (Total Acid Number). The study mission period was set for two years in which sampling and testing of the lubricant was done every four months during this period. For the parameters being tested and measured, standards given in the following Table 1, were used.

Table 1. Standards used for testing oil parameters.

Parameter	Standard
Viscosity	ASTM D 7042
Water content	ISO 12937
Solid particle content	ISO 4406
TAN	ASTM D 664

3.3. UOA data analysis

This section shows the data analysis by trending on the four lubricant parameters as per Table 1 in Section 3.2.

3.3.1. Viscosity monitoring

The lubricant viscosity measurement is a standard test since it represents the basic physical property of the lubricant. Viscosity is the single most vital lubricant parameter, for instance viscosity affects lubrication oil film thickness, intensity of mechanical friction, internal or external oil leakage, heat generation, etc. Conventionally used alarm limits for industrial lubricants are given in Table 2.

During the monitoring period of the asphalt paving machine hydraulic oil, viscosity did not significantly change its value (Figure 3). The largest deviation of the oil viscosity values compared to the new oil was +1.6%.

Table 2. Recommended alarm limits for viscosity change.

Limit	Percentage deviation
Upper critical	+ 10 %
Upper cautionary	+ 5 %
Lower cautionary	- 5 %
Lower critical	- 10 %

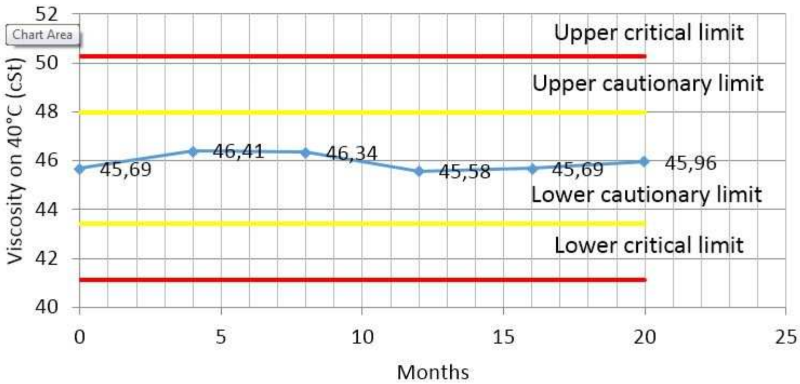

Figure 3. Trend of viscosity values change.

Any change in viscosity, higher than cautionary limit, should be investigated and rectified because the consequences can be very costly. These changes can be attributed to a change of chemical characteristics of oil (thermal cracking of oil molecules, oxidation, polymerization, formation of insoluble, evaporation, etc.), or due to contaminant ingression (water, air, wrong oil, fuel, etc.) that affect the serviceability of the lubricant and reliability of the equipment. The increase in viscosity leads to high internal friction which inherently would raise the lubricant temperature and eventually cause oxidation of the lubricant. Contrary, decline in viscosity offers less lubricity and low film thickness that propagates high wear on the lubricated parts.

3.3.2. Water content monitoring

The second test is the absolute water content in the lubricant. It is an essential test because water has extremely negative influence on the performances of the lubricant during machine operation. For example, the presence of water affects lubricant film thickness and load-carrying ability, power transfer characteristics (compressibility), oil additive depletion, cavitation, corrosion, etc. Tolerated water content depend on the used base oil, additive packages and the application of the hydraulic system. In a mineral hydraulic oil, according to [3], absolute water content limit is up to 0.05%, while some types of oils (such as fire-resistant fluids) can have limit up to 0.4% and higher [4]. Analysed samples of hydraulic oil, which belongs to HM group of hydraulic fluids (and comply with the requirements of ISO 11158), had a much lower water content than the tolerated value, see Figure 4.

It is imperative for maintenance managers to acknowledge that there is no acceptable level of water in any lubricated system, including hydraulic systems, but also hydraulic fluid cannot be totally free of water, since there is always some portion of water in oil. Even the smallest portion of water will impact the chemical properties of the lubricant and oil wetted metal surfaces. The severity of damage to the oil and the machine depends upon how much water is present and for how long. If water level exceeds the limit, it must be removed using some methods like a water-absorbing filters, vacuum dehydrator, centrifuge or some other form of dehydrating separators. Maintenance team should perform root cause analysis (RCA) to determine the nature and source of the water ingression and make appropriate changes necessary to avoid recurrence. Conventional sources of water in oil include

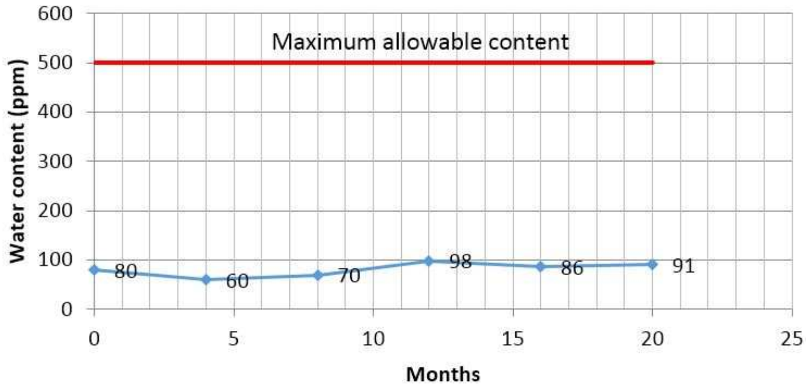

Figure 4. Trend of water content values change.

faulty or ineffective breathers, lubricant top-ups, leaky oil coolers, poorly sealed hatch covers, inadequate lubricant storage practices, aggressive wash-down practices, etc.

3.3.3. Solid particles content monitoring

Considering that approximately 70% of hydraulic system failures are associated with solid particles oil contamination [5,6], test of particle content is another test that was made within this study tests. Depending on the working conditions and hydraulic system application, there are sensitive and very sensitive components on solid particles contamination. According to [7], solid particles in hydraulic system can generate three types of mechanical failures: structural failures (fracture and distortion failures), wear failures (surface degradation failures), motion or jam failure (motion impediment failures). The influence of the solid particles is more critical if proportional or servo-hydraulic components are installed in the system which is the case here. The machine such as asphalt paving machine, have a lot of these components which controls the machine actuators.

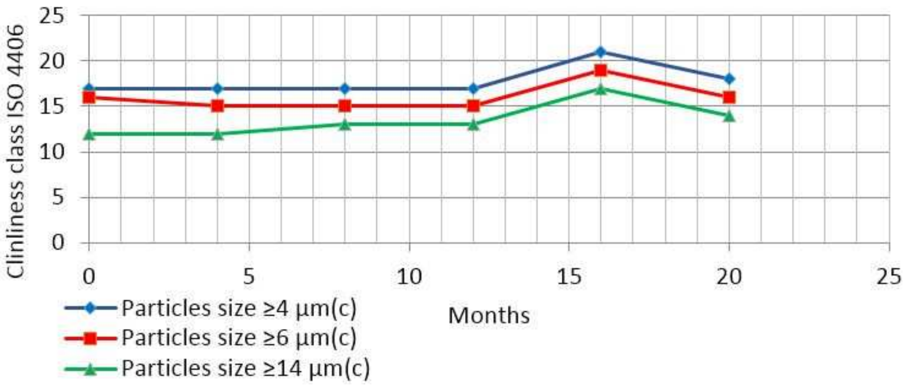

Figure 5. Trend of solid particles content values change.

During the experiments, the solid particle content of the oil filling was mostly constant within the permitted limits for the type of hydraulic system on this machine. However, in the fifth sample, a significant increase in the content of solid particles in oil is observed as depicted in figure 5. After obtaining information on this sudden spike of solid particles, in order to avoid a possible mechanical failures of hydraulic components, it was suggested to check the installed filters and give consideration to the application of the secondary filtration system, which would surely reduce the level of contamination within the permitted limits for the most critical component in hydraulic system [8,9]. According to [8] there are four primary sources for solid particle contamination: contaminated new oil, built-in contamination, contamination ingression and internally generated contamination.

3.3.4. TAN monitoring

The basic set of tests for experiment purposes, along with the aforementioned, is rounded up with a TAN test. This parameter serves to determine the amount of potassium hydroxide (KOH) solution necessary to neutralize the acidic compounds (concentrated and weak acids) in the oil, which are formed as products of oil aging, or its chemical degradation.

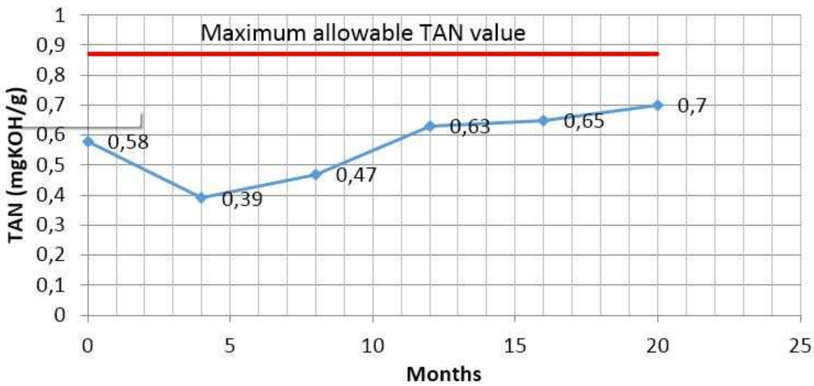

Figure 6. Trend of TAN values change.

During the experimental period, TAN value moved within the recommended tolerances (Figure 6). For hydraulic oils, permitted increase of this parameter is 50% in relation to its value for new oil. A gradual increase in TAN values attends a common phenomenon, because in the process of operation, compounds that increase acidity are produced. If sudden rise of TAN value is viewed, the oil must be tested in detail. As mentioned before, most of the acids in lubricating oils are products of oil oxidation process (aging).

The oxidation process implies a self-propagating chemical chain reactions. Oxidation results includes formation of carboxylic acids and eventually high-molecular weight polymeric compounds. These compounds often are insoluble, and as such they settling as sludges and resins causing problems such as filter blockage, nozzels blockage, obliteration, erratic movement of valve parts etc. Formed acids aggressively impact the seals and oil wetted metal surfaces (corrosion).

3.5. Maintenance decision making support

In addition to the equipment manufacturer's recommendations, maintenance managers now also acquire information about the oil’s condition, thus enabling the determination of the most appropriate interval of oil change. Laboratory oil analysis and trend analysis results, after a period of 20 months, gives to managers much clearer picture about the condition of the hydraulic oil in use.

The examined hydraulic oil complies with the basic requirements, and there was no need to replace it. In this way, oil can be used until the parameters of its condition point to a potential problem. Consequently, one should continue to monitor oil condition during the future machine operation. Depending on which parameter has attained a critical value, appropriate actions must be taken (such as secondary filtration, water separation) which will extend the useful life of oil and machinery. For example, significant increase of the TAN value point on extreme additive depletion, which means that there is present intensive thermal oxidation process which is impossible to eliminate or reverse. A unique solution to this is to change the oil together with system filters. On the other hand, when water level in oil reached a critical value, the sugestion is to use one of the dehydration techniques in order to extend the oil life. In any case, if there is a drastic change in one or more of the monitored parameters, more extensive studies should be conducted of how and why such disturbances have occured.

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4. Conclusion

The paper describes the application of oil condition monitoring to assist in determining the appropriate interval for the replacement of hydraulic oil. Four basic oil condition parameters were observed, over a period of 20 months. In the case of asphalt paving machine, sample analysis and analysis of the trends of change in each of the parameters indicate that oil filling can continue to be used in exploitation for a quite some time. Also, this means that oil condition paremeters should be monitored, until the time comes to change the oil. In case when managers acquire adequate information on oil's condition, it is not obligatory to strictly adhere to the manufacturer's recommendation. This eliminates the cost of premature oil replacement, unnecessary service engagement, and other costs associated with the removal of waste oil and filters. Maintenance managers are more independent in reaching the decisions if they obtain qualitative information about the machines condition and state.

In addition to determining the most appropriate interval of oil replacement, using other condition monitoring techniques, early failures can be identified, timely prepare the material and required workforce and more precisely determine the optimal replacement intervals for the component which has failed.

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