IOP Conf. Series: Materials Science and Engineering **724** (2020) 012035 doi:10.1088/1757-899X/724/1/012035

Lubricants condition monitoring by using a global performance passport

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Abstract. Lubricants degradation processes are characterized by the physical and chemical indicators changes for oils composition, caused by internal and external factors and the operating conditions severity. Lubricants condition monitoring involves experimental methods to study their behaviour, for developing a lubricants life cycle assessment methodology. The paper proposes the lubricants behaviour complete characterization by using a global performance passport, to study the rheological, tribological and microscopic properties, for various wear stages. The global rheological lubricant feature is expressed by the maximum film pressure, by using the original rheological experimental module. The reference rheological lubricant feature is obtained by using the viscometer validation module, based on the variation of viscosity by the temperature. The tribological lubricant feature is given by the tribological experimental module, based on friction coefficient variation according to the normal pressing force and sliding speed. The structural microscopic lubricant feature is shown by the wear particles analysis module, analysing the solid particles type identified in the fresh and worn lubricant. The global performance lubricants passport assess the lifetime reserve, function the specific use conditions, to reduce operating costs. To do the initial investment for the preliminary experimental tests conduct it is recommended to determine the economic profitability threshold for the user investment.

1. Introduction

The lubricants degradation is a quantified process, by using physical characteristics and chemical composition oils changes; these are caused by internal and external factors and by the severity of operating conditions. The degradation of lubricants during time is due to the mechanical loads, to the operating temperature and contamination; the result is the lubrication deterioration and the worsening of other functions (providing cooling parts, their corrosion protection, etc.). The degradation process is progressive and it is more intense if the service conditions are more severe. There is a variety of external factors involved in determining of the lubricants degradation and their disuse [1-2]:

- the contamination with different impurities or chemical agents, during the usage, transport or storage;
- the mechanical of thermal overstressing;
- the possibility of increased aeration and water penetration into the oil, in bigger quantity.

The consequence of reported changes is the shortened lubricant use, which is associated, in some cases, with endangering the safety of the equipment [3]. The problem of a long use of industrial lubricants is transposed over the existence of a life cycle, which is economically satisfactory.

The lubricants choice has effects the longer use of the production equipment and life cycle costs.

By choosing a lubricant for the existing equipment of a factory it is necessary to take into account several factors, [4]:

- The lubrication frequency: the power generating equipment may require frequent re-lubrication, a special lubricants use and it is possible to have an impact over the production and the costs, during time.
- The extreme production environments: high temperatures and concentrated chemicals can cause lubricant breakdown, compromising performance and leading ultimately to an additional maintenance effort.
- The safety and the environmental interests: some lubricants contain volatile organic chemical materials or chlorinated materials, which can be hazardous to the environment and employees. The frequent re-lubrication can increase employee exposure to hazardous areas, with high temperatures.

The useful time identification for the causes which reduce the lubricants durability is possible by a careful laboratory control and by the determinations of specific parameters due to the specialized personnel. For this purpose there are necessary typical tests on laboratory stands, using standardized methods. The interests of specialists regarding the assessment of the lubricating environment efficacy led to the development of laboratory methodologies to simulate real conditions, which are specific to machinery exploitation, [5].

2. Methods and results at international and national levels

Researches from Western Europe, SUA or Japan signed that the oil changing moment is based on the oilcans written instructions, with a minimal recommended covered distance. To discover the most important factors of the lubricants degradation it is important to do the periodically physical-chemical oil analyses, in order to analyse the oxidation and the contamination oils. The damage of oil is pointed when its characteristics had touched some limit values, which are established for each type of engine.

The contamination level and the "lifetime" of used oil depend on the exploitation conditions, the oil quality, the construction and the technical state of engine. At international level the main directions are orientate to the preventive maintainability domain, for applying into any closed lubrication system.

Some examples from industrial domain are the MAN firm from Germany, which uses the basicity analysis method for Mobil class oils, for the oil lifetime determination for engines trucks, the firm Mercedes from Germany, which uses insoluble impurity in oil, with microscopic tests for class Shell oils. BOGE Compressors Ltd. From United Kingdom can yield up to 5% energy savings by using its special lubricants (S46 Screw Lube mineral oil, SYPREM 8000 S), which extend maintenance life to 40.000 hours. The importance of using the adequate lubricant and the oil changing moment at the proper mileage can improve engine reliability and has the potential to reduce nationwide waste and recycled oil by 325 million gallons annually, [6-7].

The problem was analysed also at national level, by making used oil changing moment evaluations at ROMAN firm on Lubrifin Romanian oils, by applying the oil spot method, which is based on the aspect of the spot made on a filter paper. Another method applied in ROMAN firm on Lubrifin oils is represented by the photoelectric method, which allows the establishment of used oil changing moment, according to the quantity of oil impurities.

At educational level there were made researches by the "POLITEHNICA" University from Bucharest and "GHEORGHE ASACHI" Technical University from Iaşi, for the determination of the rheological properties of the mixture of oil with polymers, that was emphasized their non-Newtonian thixotropic character. "TRANSILVANIA" University from Braşov made interesting results in management direction of solid residues from lubricants, by using the ferografic analysis of used oils.

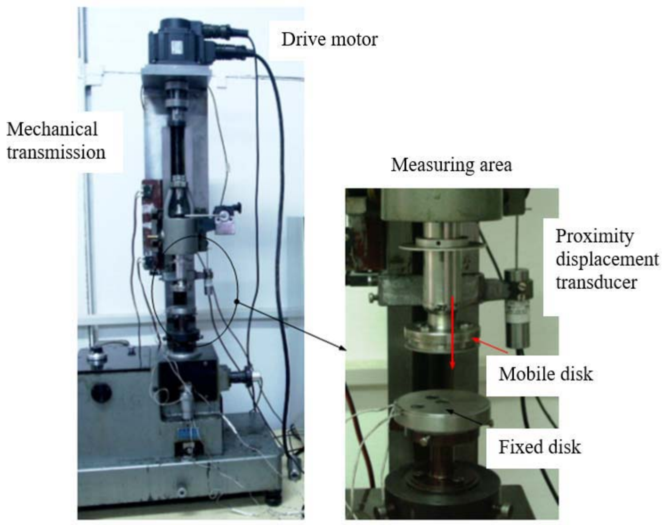
Lubricants properties and durability were made in Romanian manufacturing bearing firms: RULMENTUL Braşov, TIMKEN Ploieşti or Koyo Alexandria. The industrial laboratories offered the opportunity to make physical-chemical standard tests and tribological ones (Timken stand, Amsler stand, etc). The information obtained by analysing these methods give important data from performing laboratories, at high technical level, but it involves special attention from the technical staff, a good practice experience and high level practitioners, [8].

3. Basic principles concerning the global performance lubricants passport

Experimental methods for determining the wear degree and lubricants durability, which are analysed in other works, led to the development of a global methodology for the assessment and quantification of lubricants life cycle and the achievement of a complex, service life, monitoring tool.

There are presented the basic steps required to implement the global methodology for life cycle lubricants monitoring, during their lifetime. The applied methodology consisted in following steps:

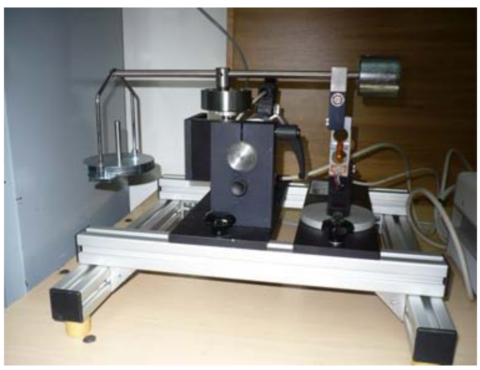
1. The acquisition of two types of industrial lubricants: one oil from internal combustion engines and one hydraulic power transmission oil;
2. The defining of two specific users for these lubricants types: one cross-country car and a construction equipment. These users will be monitored during all life cycle of the used lubricants;
3. The testing of the studied lubricants during the working operation, for all users, with regular removal of oil samples, at varying wear degrees;
4. The complex analysis of fresh and worn oil samples and the determining of the rheological, tribological and structural characteristics, by using the four basic modules of the complex monitoring instrument (Figure 1);



a) Original experimental rheological modulus

b) Wear particles analysing modulus

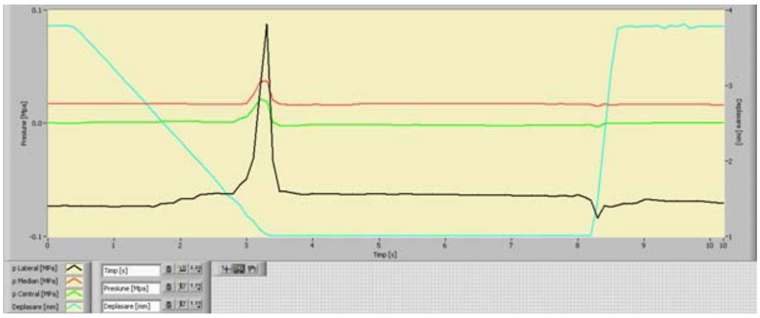
c) Viscometric validation modulus



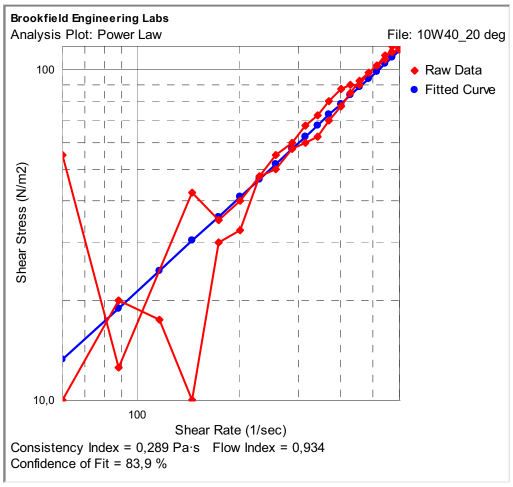
d) Experimental tribological modulus

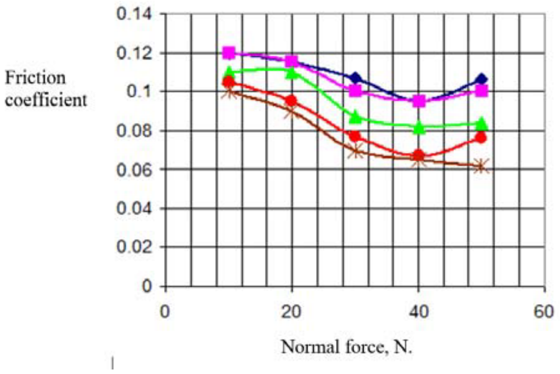
Figure 1. The Complex monitoring instrument

The obtaining of the performance lubricants global passport, which represents a complete characterization of the lubricants behaviour during their lifetime (Figure 2).

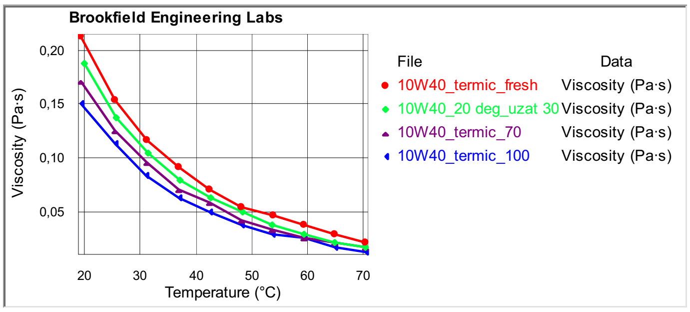


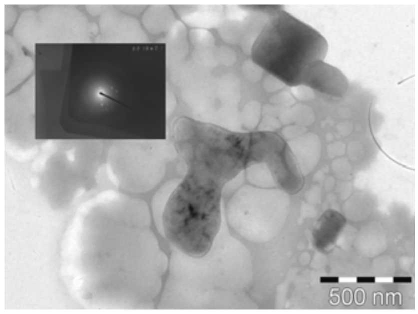
a) Characteristic squeeze film curve





b) Oil reference rheogram c) Variation of the friction coefficient with the velocity and load





d) Variation of the viscosity by the temperature e) Wear particles identified in oil

Figure 2. Global performance passport

The core of this global methodology for the industrial lubricants monitoring is done by the complex monitoring tool, which is composed from four experimental modules: the rheological one, the viscometer one, the tribological one and the structural analysis. Briefly, the four experimental modules of the monitoring complex instrument are:

- the original rheological experimental module, which has a measuring device mounted on a Weissenberg rheogoniometer and a data acquisition and processing system. By using for the diagnose a small amount of lubricant, it is recorded the temporal variation of lubricant film thickness, by using a proximity sensor, while the oil film is expulsed with constant speed. It is recorded the squeeze-film curve, which is the "fingerprint" of the worn-out lubricant (Figure 2 a).
- the viscometer validation module, which is based on a Brookfield viscometer type. Its role is to validate the experimental results provided by the rheological experimental module and to establish the necessary correlations (Figure 2 b, d).
- the tribological experimental module consists in a friction torque pin – disk tribometer, made by Guntt company. It is possible to determine the friction coefficient variation due to contact pressure and sliding speed, for lubricants having varying wear degrees, in terms of the same friction torque use (Figure 2 c).
- the wear particles analysis module, which is based on the transmission electronic microscopy, in order to obtain information on the wear particles, which are identified in worn lubricants samples. Working element is represented by the JEOL Japan - JEM - 200 CX transmission electron microscope. By comparing two microscopically structures of the same lubricant, in various decay stages, it may be revealed the wear particles, their shape and their concentration (Figure 2 e).

Global methodology for assessing and quantifying the industrial lubricants life cycle aims, finally, the achievement of a global lubricants performance passport. This is a complete characterization of the lubricants behaviour, which are studied during their life cycle, in terms of rheological, tribological and microscopically point of view.

4. Experimental investigations

The experimental research were monitored for the lubricants, during their working time, till their complete degradation. Rheological, tribological and structural tests were conducted, over their entire service time; finally there was obtained a global performance passport, for each lubricant. This will include:

- the global rheological lubricant feature, which is expressed by the maximum pressure of fresh and worn lubricating film;
- the reference rheological lubricant feature, which is expressed by the variation of viscosity with the temperature, according to various lubricant wear stages;
- the lubricant wear feature, which is given by the viscosity variation, function the wear degree;
- The tribological lubricant feature, which is expressed by the friction coefficient variation according to the normal pressing force and the sliding speed, both for fresh and worn lubricant;
- the structural (microscopic) lubricant feature, which is done by the solid particles type which are identified in the fresh and worn lubricant.

Tables 1 and 2 show two examples of the global performance passport for two lubricants types, one for the internal combustion engine (10W40 oil – Table 1) and the other, for the hydraulic power transmission (H46 oil – Table 2).

5. Conclusions

Analysing the results presented in the previous paragraphs it is obvious the necessity of a global performance lubricants passport, which represents a complete characterization of the studied lubricants behaviour, during their life time. Each lubricant has a specific rheological, tribological and structural behaviour, which requires continuous monitoring of these properties, all the use period, from fresh stage till its complete depletion.

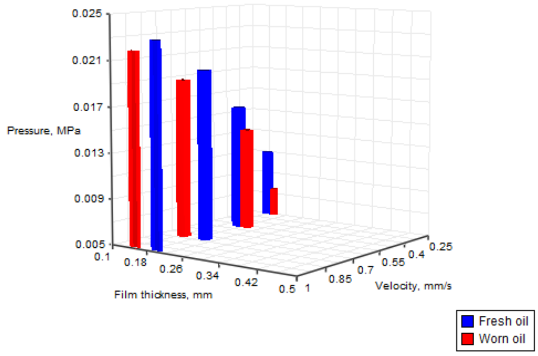
The developed global performance lubricant passport may be used to assess the lifetime reserve, function specific use conditions (load, speed, temperature, etc.). Its advantages are the reducing of operation costs, but it requires an initial investment for the preliminary experimental tests conduct. In conclusion, the achievement of a global performance lubricant passport should be correlated with the determination of economic profitability threshold for the investment made by a potential user.

Companies with mechanical maintenance needs might be familiar with used oil testing for their equipment, but many have not fully grasped the relevance of and the value incurred from implementing an oil testing program.

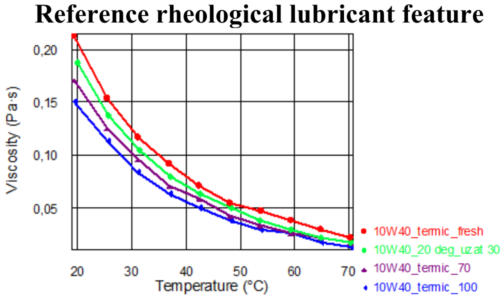
This paper provides an overview of the practice of a lubricant global performance passport and clarifies how testing and lubricant behaviour analysis imply companies benefits, with no operating equipment investments. Using passport model, it will minimize equipment downtime, permitting more efficient maintenance scheduling, protect warranty claims and increase equipment resale value.

Table 1. The global performance passport for the internal combustion engine 10W40 oil.

Global rheological lubricant feature



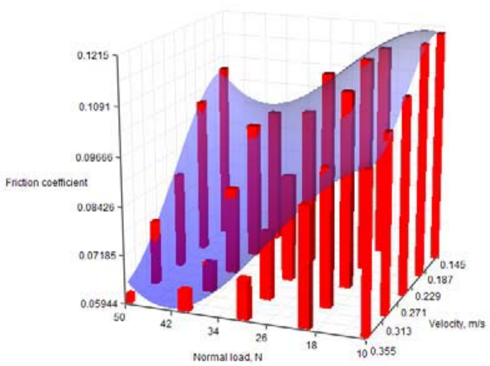
Reference rheological lubricant feature



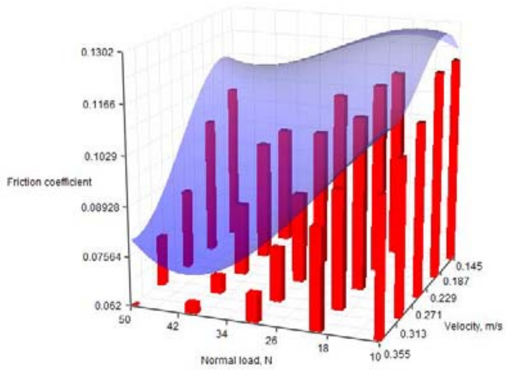
Wear lubricant feature

$\eta = \eta_0 e^{-Kd}$, where η_0 = 0,2141 Pa.s and K = 4,3243·10^{-5} km^{-1}

Tribological lubricant feature



Fresh oil



Worn oil

Structural lubricant feature

- ZnO hexagonal (ASTM 80-0075)
- $ZnSO_4$ cubical (ASTM 70-1255)
- $Ca_3(PO_4)_2$ (ASTM 02-0786)
- Amorphous phase

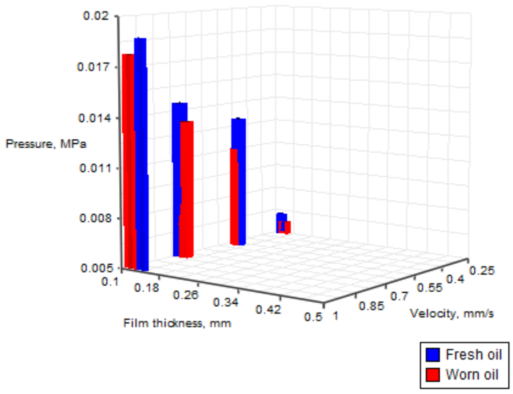
Fresh oil

- Cr_2O_5 unidentified cristalization type X (ASTM 28-0370)
- AlNi cubical (A) (ASTM20-0019) + V_2O_3 rhombohedral (B) (ASTM 84-0319)
- $Mn_{0,9}V_{0,1}P$ orthorombic (ASTM 78-0802)
- Amorphous phase

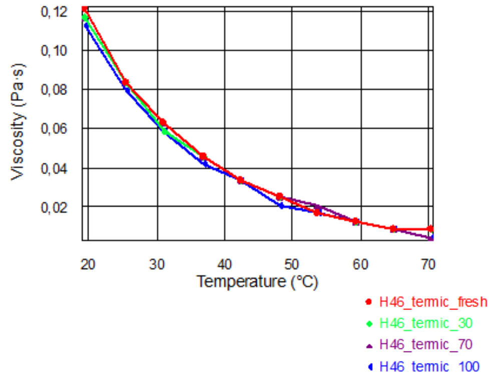
Worn oil

Table 2. The global performance passport for the hydraulic power transmission H46 oil.

Global rheological lubricant feature



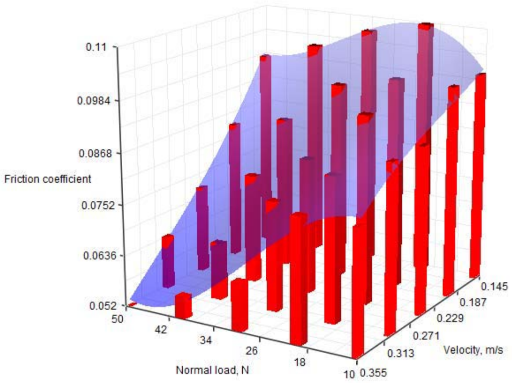
Reference rheological lubricant feature



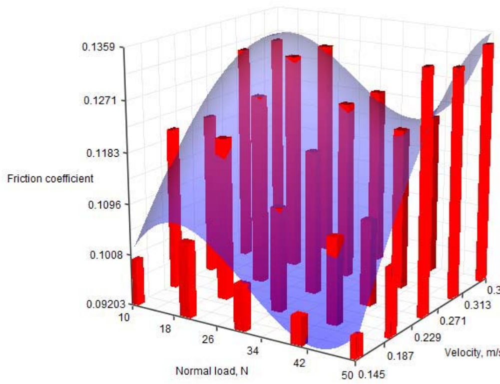
Wear lubricant feature

$\eta = \eta_0 e^{-Kd}$, where $\eta_0 = 0{,}1206$ Pa.s and $K = 1{,}4073 \cdot 10^{-5}$ hours^{-1}

Tribological lubricant feature



Fresh oil



Worn oil

Structural lubricant feature

- $ZnSO_4$ cubical phase (ASTM 70- 1255)
- Mo_2S_3 (X) (ASTM 12-0692)
- Unidentified cristalization phase

Fresh oil

- C (diamond) cubical (ASTM 6-0675) + SiC (ASTM 02-7463)
- γ FeOOH orthorombical (Wustit) (ASTM 8-98)
- Al_4Si cubical (ASTM 24-0035)
- C cubical (ASTM 6 -0675) + $FeCO_3$ rhombohedral traces (ASTM: 29-0696)
- Amorphous phase

Worn oil

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