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Enhanced lubricant management to reduce costs and minimise environmental impact

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ABSTRACT

One of the important factors when selecting the more appropriate hydraulic fluid for use in applications is definitely its long service-life. By using hydraulic fluid with long service-life, together with enhanced condition monitoring of the fluid, we can significantly reduce costs and minimise environmental impact due to less lubricant production, logistics, and disposal.

This paper describes a novel method for testing the durabilities of different hydraulic oils, followed later by addressing the condition-monitoring of hydraulic oils throughout their life-cycles. Particular emphasis is placed on quantitatively assessing, in detail, one mineral oil's condition and its remaining useful lifetime.

This paper proposes a hybrid mathematical model based on gathered data from previously conducted oil-ageing tests. The presented model is able to successfully and accurately assess the oil's condition and its remaining useful lifetime after the oil has only reached one third of its lifetime.

1. Introduction

The fact that mineral oils are present in almost all energy systems (production and use of the energy in industrial systems) is often overlooked. The quantities of oil used may be very high, e.g. hydraulic system of an extrusion machine can contain up to 10,000 L of mineral oil, a chain of hydro-electric power plants on the same river can take even 350,000 L of turbine oil or more. In such systems there is an urgent need to increase the operation reliability and to minimise oil consumption. Thus, it is extremely important to know the oil condition and its remaining useful lifetime at every moment.

The reasons why lubricants age and need to be replaced periodically are well-known [1–7]. However, rather less-known is the fact that there are great differences in the durabilities of hydraulic fluids when exposed to machine operating conditions.

As the world is coming to face a shortage of crude oil [8], a rising trend of fossil fuels' cost and environmental issues imply that lubricants should be utilized efficiently [9]. The extensions in service-lives of hydraulic and lubricant fluids can deliver both cost savings and environmental benefits such as reduced pollution and CO_2 emissions, without sacrificing the equipment's life. Major economic benefits associated with extended fluid service-life include reduced fluid costs, as well as reductions in serviced fluids' disposal costs. Secondary benefits include reduced maintenance costs and machine downtimes that, in many applications, can result in significant economic savings. The extensions in the service-lives of hydraulic fluids can also contribute to the minimisation of environmental impacts across the whole range of manufacturing, transport, and serviced fluid disposal [10].

The service-life of a hydraulic fluid can be extended in two ways: by carefully selecting the most appropriate modern high-quality lubricant with high oxidation stability, and by introducing modern condition monitoring techniques that ensure oil changes at just the right times.

In order to evaluate the service life of hydraulic oil, this paper proposes a novel method for testing the durabilities and oxidation stabilities of different hydraulic oils. Based on this test an advanced method is presented for assessing its current oil condition and its remaining useful lifetime, which can be used to optimise oil consumption, reduce costs and minimise environmental impact. The presented method and its precision in reporting oil conditions and RUL was tested for many years on various system at various operating conditions (automotive industry presses, extruder press that

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operates in one of the leading manufacturers of aluminium profiles for automotive and aerospace industry, steel industry and hydro-electric power plants).

2. Oil service-life and condition monitoring techniques

Hydraulic systems are widely used within industrial automation systems and therefore their reliable and smooth operation is crucial for continuous uninterrupted production. One of the more important components of hydraulic systems is without doubt the hydraulic fluid, as it directly affects the proper functioning of the whole system. The hydraulic fluid transmits forces and motion, lubricates all tribological components, cools hydraulic components and prevents corrosion [11]. Therefore, in addition to proper maintenance of the hydraulic system itself, the maintenance of the hydraulic fluid is also crucial. In order to satisfy the above requirements, the different physical and chemical properties of the fluid must remain within certain limits. Unfortunately, throughout its life-cycle hydraulic fluid is subjected to many physical and chemical operational effects [7], e.g. high pressures and temperatures, oxidation, mechanical and/or fluid contamination, and others, as shown in Fig. 1. Consequently, over time hydraulic fluid loses the ability to perform its key functions and therefore must be changed.

2.1. Oil service-life

The key property of hydraulic oil that determines its service life is its oxidation stability [12]. Oils oxidise at operating temperatures by a chemical reaction with oxygen that, over time, results in the formation of sludge and acids, increases viscosity, reduces the ability to handle contaminants, and decreases in filterability [1–7]. In other words, the lubricating oil has lost its ability to perform key functions and should be changed.

As presented in Fig. 1, a number of factors speed up ageing and oxidation processes: water, metals such as iron and copper, other contaminants and elevated aeration. However the most critical factor is the temperature. Elevated temperatures accelerate the oxidation process and the Arrhenius Rate rule states that for every 10 °C increase the rate of oxidation doubles [7].

2.2. Condition monitoring of hydraulic fluids

A vast amount of oil is wasted each year due to premature and unnecessary oil changes. In order to optimise and extend the oil drain interval, without sacrificing the equipment's life, the oil condition must be known at any time [13–18].

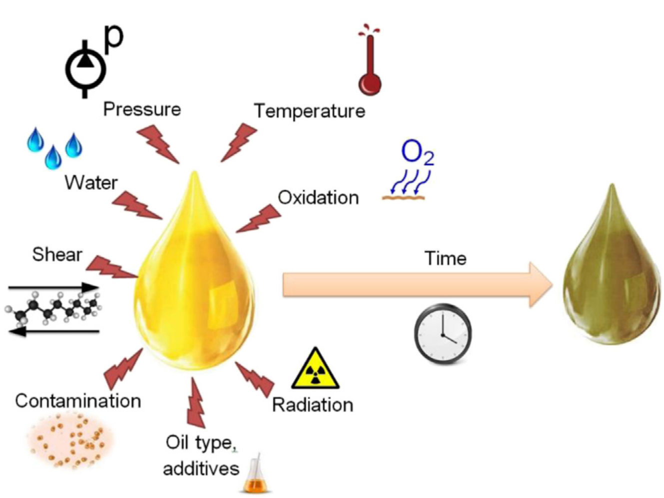

Fig. 1. The key factors that influence hydraulic oil ageing.

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 [7]. In most cases these are empirically estimated time intervals with a certain degree of safety factor. The actual quality of a fluid is not taken into account and nor are 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. On the other hand, when the machine is overloaded and the quality of the hydraulic fluid is rapidly decreasing, the deteriorations of the physical and chemical properties remain undetected for too long or are not detected at all.

2.2.1. Laboratory analysis

The actual quality (condition) of a hydraulic fluid is still more commonly determined by taking a sample of the fluid and analysing it in an appropriate laboratory. By eliminating the problems identified by the analysis failure rates, repair costs and production downtimes can be minimised. These "off-line" methods have become well-established on larger systems and systems that are crucial for uninterrupted production [7], where a fluid is periodically checked in a laboratory. Such a method allows for the changing or adjusting of a fluid's change intervals according to its actual condition [7]. Its reliability mostly depends on sampling intervals, the representation of the sample (location, time, and method of sampling, cleanliness of the sample container, elapsed time from sampling to analysis) and properly chosen monitoring parameters. Utilising periodic laboratory analyses ensures greater safety for the user but fails in the cases of sudden changes, e.g. penetration of water into the hydraulic system as a result of a cooling system's defect.

2.2.2. On-line condition monitoring

The highest reliability regarding hydraulic equipment's operation is achieved by using real-time continuous monitoring of the hydraulic fluid, which can detect impending breakdowns as soon as the abnormalities arise and before they lead to major damage. Due to increasingly efficient and cost-effective sensor technology, interest has increased in the on-line condition monitoring of hydraulic fluids.

These on-line condition monitoring methods are based on the applications of special sensors that are installed within a hydraulic system for measuring the physical properties of hydraulic fluid, e.g. temperature, viscosity, dielectric constant, electrical conductivity, relative humidity, and the cleanliness level. A distinct advantage of on-line methods is the continuous monitoring of individual fluids' parameters, thus knowing the oil condition at any time. In addition, any sudden changes are also detected (even an automatic SMS or E-mail alert can be triggered), whilst with off-line methods this cannot be [19].

2.3. Limitations that inspired our work

All of the above presented methods for hydraulic fluid monitoring suffer from one great common weakness. They lack practicality and usefulness when implemented within industrial environments. The results of either off-line or on-line analyses are much too complex for just anybody to understand and interpret the condition of the oil. Generally the user or maintenance personnel are only interested in two pieces of straight forward data: "what is the condition of the oil" and "when do I need to change it"?

The presented weaknesses inspired us to focus on the development of a universal, robust, and autonomous system for the