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A DEVICE AND METHOD FOR THE EVALUATION OF HYDRAULIC OILS PERFORMANCE USING IMPEDANCE PARAMETERS MEASUREMENT

Key word

Hydraulic oils, dielectric parameters, oil quality.

Abstract

The global trend to reduce operating costs of machinery and equipment, while improving their reliability without harming the environment, makes it necessary to monitor the quality potential of industrial oils. This generates the need for inexpensive and fast methods for oil testing in working conditions that would greatly limit or replace the current labour-intensive and time-consuming laboratory assessment. This article presents a method and a device for diagnostic assessment of the performance of industrial oils by measuring the impedance parameters of a serial replacement system or a parallel inductive measuring capacitor with oil as its dielectric. The object of this study was used hydraulic oil subjected to the process of monitoring. The physicochemical properties were studied that reflect the ageing of the oil and its electrical properties. The correlations between the impedance parameters of inductive measuring capacitor and selected parameters describing the physical and chemical characteristics of oils are presented. The study confirmed the usefulness of the method and the diagnostic device for monitoring changes in hydraulic oils during their service lives.

Introduction

The fundamental direction of a pro-ecological economy is minimizing the amount of produced waste [1–3]. This also applies to industrial oils and lubricants. In respect to such products, this means, e.g. the maximum use of performance potential and lengthening service life [4, 5]. The quality status of oil determines the proper functioning of the machinery and equipment. It reflects not only the level of performance properties of the oil, but also the degree of the wear of machinery and equipment, in which it functions. Continuous and strictly specified in time and scope, control of the properties makes it possible to monitor the predefined oil performance in lubrication systems. It makes it possible to apply appropriate treatment to re-create the qualitative potential of the oil or to replace it at the most optimal moment. It also makes it possible to diagnose the condition of machinery [6–8].

Monitoring the quality of the oils includes a number of individual indicators, usually measured in laboratory conditions [6, 7] and often by time-consuming, expensive methods, requiring a considerable amount of research samples and specialised equipment. Such a situation is not conducive to frequent oil testing. Thus, solutions are sought to find a means for fast, inexpensive, and comprehensive assessment of oil quality, preferably at the place of operation. The indicators of oil quality that can be measured in all conditions are dielectric parameters [9, 10]. This article presents a method and a diagnostic device for the assessment of the performance of industrial oils by measuring the impedance parameters of an inductive measuring capacitor with oil as its dielectric.

1. Diagnostic device for the evaluation of working oils

The device is used for the examination of the changes in the quality of industrial oils in service. The measured impedance parameters reflect the content of polar components, which are diagnostic for chemical aging, among others, for chemical ageing products, water, and metallic wear products from friction elements. The device is shown in Fig. 1.

The set consists of a volume measuring microprocessor and a measuring capacitor (volume sensor) submerged in the sample oil, combined with a measurement using a specialized measuring cable (Fig. 1). The meter measures the impedance parameters of the measuring capacitor with the tested oil as is its dielectric. The parameters are the following: capacity, loss of resistance, and loss coefficient D, or a goodness coefficient (Q) for both parallel and serial equivalent circuit capacitor. The assessment of the degree in the performance change of the oil is made by comparing the results of the measurements of impedance parameters for used oil and fresh oil. The meter can be used with a computer and with the dedicated software, and the measurements can be recorded in the text files.

a)  b) 

Fig. 1. The evaluation device for changes in industrial oils (a), and measuring capacitor (b)

Technical specifications of the device:

Measuring capacitor:

- A double-sided printed circuit board with the electrodes in ridge arrangement are in the casing with a socket for plugging it to the volume sensor. The dimensions of the active part of the sensor are 25 × 30 × 1.6 mm.
- Impedance parameters of the capacitor in the air are set for a frequency of fp = 10 kHz.
- For serial the equivalent capacitor system, the specifications are as follows: serial capacity Cs = 100.70 pF, serial resistance Rs = 2.27 kΩ, and goodness coefficient Qs = 70.
- For the parallel equivalent capacitor system the specifications are as follows: parallel capacity Cs = 100.6 pF, parallel resistance Rr = 11 MΩ, and goodness coefficient Qs = 70.

Volume meter: Type APPA 703 – technical specifications as per instruction manual of the meter.

2. Method of the evaluation of the quality of hydraulic oil using a diagnostic device

The method of quality evaluation of hydraulic oils uses the measurement of the dielectric properties of the oils, which are the following: leakage conductance q, and resistance r in parallel, and serial measuring system. Because the dielectric properties of themselves are not included in the requirements of the norms for hydraulic oils, and they are a reflection of the presence of polar particles in oil (mostly the thermo-oxidising ageing products, water, and functional additives), their changes have been correlated with the changes in the normative parameters, showing the relationship of such products as acid number and water content. According to the guidelines of the manufacturers and companies involved in the oil economy, the value criterion of the acid number change in oil during operation is 20–30%, and the maximum water content can reach the level of 0.2% [2, 7, 11].

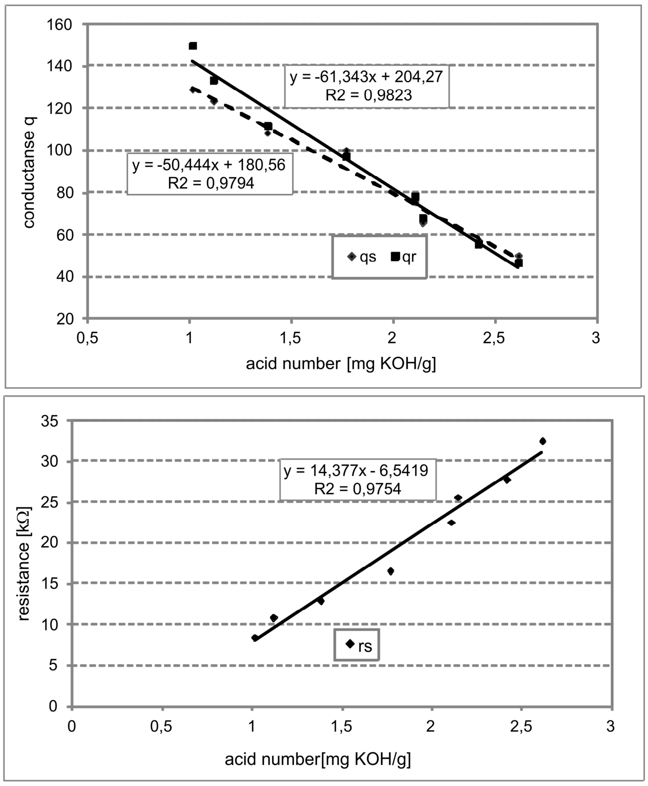
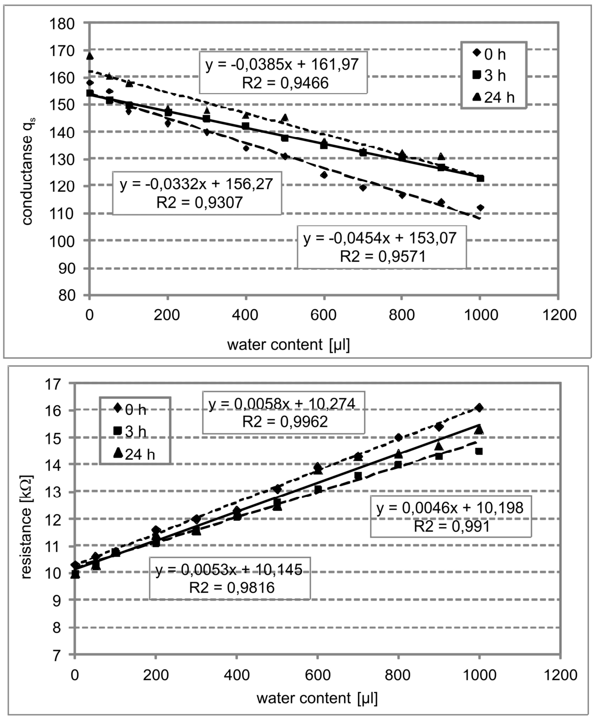


Fig. 2. The correlation of the leakage conductance (a), resistance, (b) and the acid number in aged hydraulic oil LHL 46

Figure 2 presents the relationship between selected dielectric parameters on the selected acid number of the LHL hydraulic oil aged under laboratory conditions, while Figure 3 presents the relationship between the same parameters and water content in hydraulic oil. The acid number was determined according to the PN-ISO No.6618: 2011, while the water content was determined according to PN ISO 3733:2008, and dielectric parameter values were obtained through the diagnostic device.

Changes in the value of leakage conductance determined for parallel (qr) and serial (qs) equivalent system showed a directly proportional dependence, while in the resistance is measured in the rs serial system, and the changes had an inversely proportional dependence in relation to the acid number of the oil (Fig. 2). The correlation between the changes in the dielectric parameters and the acid number was high. The R^2 coefficient of the determination of the obtained lines was very high (greater than 0.9). Therefore, the measurement of dielectric properties can indicate chemical ageing of hydraulic oils.

The designated trend lines between the leakage conductance, the resistance, and the water content in hydraulic oil LHL 46 showed the parameters to be highly correlated (Fig. 3).



a)

b)

Fig. 3. The relationship between leakage conductance (a), resistance (b), and the water content in hydraulic oil LHL 46

Because water suspended in oil has a tendency to sink, testing for leakage conductance and resistance in water-contaminated oil were carried out at intervals of 3 h and 24 h. For each series of tests, resulting curves were linear in shape. The coefficient of determination was within the 0.93–0.99 range, which indicated a high correlation between variables. With the increase in water content, the value of leakage conductance decreased and oil resistance values increased.

The determined correlations between the selected dielectric parameters and the acid number or water content in hydraulic oils have a linear form, and the values of the coefficients of determination were very high. It was found that the dielectric properties can be an indicator of chemical changes and water content changes occurring in oil. A survey of many different oils differing in their viscosity class, and in varying degrees of chemical ageing and water content, has enabled the determination of the criterial change values in the selected dielectric parameters exceeding the limit of acid number and water content (Tab. 1) [12]. They are key indicators of the test methods of the state of functioning using the described diagnostic device.

Table 1. Boundary values of changes in the dielectric parameters of oils for which the acid number increased by 20%, and the water content exceeded the value of 0.2% (measured at the frequency of 1 kHz)

	Leakage conductance q_s	Leakage conductance q_r	Resistance r_s
Acid number			
Boundary value of changes	7.5	6.5	1.0
Water content			
Boundary value of changes	6.0	5.5	1.0

Figure 4 is a diagram illustrating the method for the evaluation of the fitness for use of hydraulic oils using the diagnostic equipment.

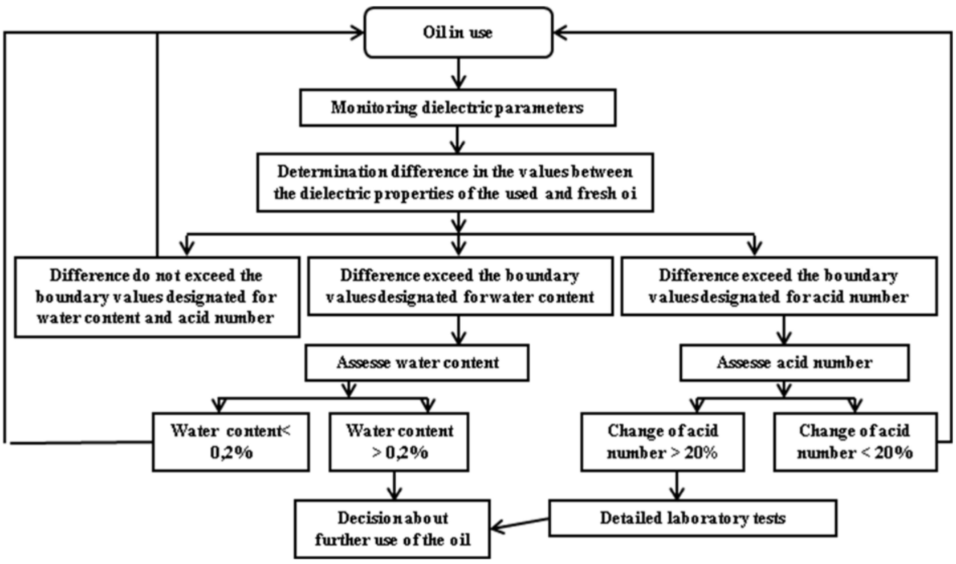


Fig. 4. A diagram of the method for assessing the fitness for use of hydraulic oils using diagnostic device

The method involves monitoring the following changes in the dielectric properties of oil: leakage conductance in serial and parallel systems and circuit resistance in a serial system. The measurements are carried out at an electrical frequency of 1 kHz, at the same temperature for fresh oil and used oil. The measured differences in the values between the properties of the used and fresh oil determine further steps in regards to the used oil. When one of the boundary values designated for water content or the acid number is exceeded, the value of these parameters is assessed. If the water content is less than 0.2% and an increase in the number of acid number is less than 20%, the monitoring of the dielectric properties of oil is continued. However, if the water content or the increase in the acid number exceeds the boundary values, the oil is subjected to detailed laboratory tests. Depending on the values of the evaluated parameters, a decision is made concerning further use of the oil.

3. An example of a practical application of the method

A study was conducted on dielectric and physicochemical properties (correlated with the indicator) of the hydraulic oil used in various pieces of equipment in the same enterprise. The time of active operation was different for in different pieces of equipment. Direct values of the parameters were measured and the differences in reference to fresh oil were calculated. Table 2 presents the results.

Table 2. Dielectric and physicochemical properties of the tested hydraulic oils

	Fresh oil	Oil 1	Oil 2	Oil 3	Oil 4	Oil 5
qs	78.60	73.50	71.10	71.10	69.80	69.50
Change qs	–	4.90	7.50	7.50	8.80	9.10
qr	77.60	73.30	70.30	70.6	71.10	70.30
Change qr	–	4.30	7.30	7.00	6.50	7.30
rs [kΩ]	23.60	24.10	24.80	24.7	24.70	24.90
Change rs [kΩ]	–	0.50	1.20	1.10	1.10	1.30
Acid number [mg KOH/g]	0.46	0.55	0.86	0.88	0.90	0.94
Acid number change [%]	–	19.60	86.90	91.30	95.60	104.30
Water content [%]	0.003	0.007	0.011	0.009	0.009	0.009

The water content in the tested oils did not exceed the limit value of 0.2%; however, oils 2–5 were characterised by an acid number of more than 20% in relation to the fresh oil. Moreover, the values of the selected dielectric parameters were greater than the criterial values. For Oil 1, the dielectric properties did not exceed these values.

Summary

The products of chemical ageing and water content that have a very negative impact on the functional properties of hydraulic oil have a polar character. Having a dipole moment of these particles makes it possible to determine their concentration by examining the dielectric properties. This study has shown a highly linear correlation of the measured dielectric properties with the acid number, indicating the degree of chemical ageing of oils and the water content. The high indicator of determination among the obtained results indicates the possibility to test the status of oil in use by evaluating the dielectric properties using the diagnostic device. The method described is intended for hydraulic oils; however, it may also be used to assess the quality of any other type of industrial oils. However, due to the different performance requirements and very different chemical composition, it is required that separate criterial values are set for the changes in the dielectric properties of these oils.

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12. Raporty cząstkowe z realizacji zadania badawczego pt. Zaawansowane metody oceny jakości i czystości olejów przemysłowych w ramach Programu Strategicznego POIG pn. „Innowacyjne systemy wspomagania technicznego zrównoważonego rozwoju gospodarki”.

Zestaw i metoda do oceny stanu eksploatacyjnego olejów hydraulicznych z wykorzystaniem pomiarów parametrów impedancyjnych

Słowa kluczowe

Oleje hydrauliczne, parametry dielektryczne, jakość olejów.

Streszczenie

Ogólnoświatowa tendencja do ograniczania kosztów eksploatacji maszyn i urządzeń, przy jednoczesnej poprawie ich niezawodności oraz bez szkody dla środowiska naturalnego, stwarza konieczność monitorowania potencjału jakościowego olejów przemysłowych. Generuje to potrzebę stosowania tanich i szybkich metod badania olejów możliwych do stosowania w warunkach eksploatacji, które znacznie ograniczają lub zastępują stosowaną obecnie praco- i czasochłonną ocenę laboratoryjną. W artykule przedstawiono metodę oraz urządzenie diagnostyczne do oceny stanu eksploatacyjnego olejów przemysłowych poprzez pomiar parametrów impedancyjnych zastępczego układu szeregowego lub równoległego kondensatora pomiarowego, którego dielektrykiem jest olej. Przedmiotem badań były oleje hydrauliczne pochodzące z eksploatacji poddane procesowi monitorowania. Badano właściwości fizykochemiczne odzwierciedlające stopień chemicznego zestarzenia olejów oraz właściwości elektryczne. Przedstawiono korelację parametrów impedancyjnych kondensatora pomiarowego ze zmianami wybranych parametrów opisujących właściwości fizykochemiczne olejów. Stwierdzono przydatność zastosowanej metody i urządzenia do diagnostyki zmian stanu olejów hydraulicznych w trakcie ich eksploatacji.