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# ON-LINE CONDITION MONITORING OF HYDRAULIC OILS – UNDERSTANDING THE RESULTS

**Vito TIČ[1,*], Darko LOVREC[1]**

[1]University of Maribor, Faculty of mechanical engineering, Maribor, Slovenia

*Corresponding author: vito.tic@um.si

***Abstract:*** *On-line condition monitoring of hydraulic oils and other lubricants can not only protect the machine from sudden breakdowns, but can also be used as a tool for predictive maintenance of the machine. In order to monitor and track changes in hydraulic oil on-line the user should have good knowledge in complete hydraulic and monitoring system, such as sensors being used, operation of the hydraulic system, location and mounting of condition monitoring system, lubricant being used...*

*In the first part the paper presents several sensors and quantities that are most commonly used to on-line measure the properties of hydraulic oils, such as temperature, viscosity, relative humidity, electrical conductivity, relative permeability and cleanliness class. Besides presenting the quantities paper also discusses potential miss-readings and inaccuracies of the sensors.*

*In the second part the paper presents and discusses several real case studies from on-line condition monitoring systems of hydraulic oils from industry. The study shows that some changes, such as increase of water content in hydraulic oil, can be detected on-line very reliable, whereas some other changes, such as increase or decrease of viscosity cannot be detected so easily and trustworthy.*

***Keywords:*** *lubricants, hydraulic oil, on-line condition monitoring, maintenance.*

## 1. INTRODUCTION

Latest trends in industrial applications are to increase machine's productivity and reliability and to minimize operating-costs and down-time of the machine. One of the ways to achieve these goals is the use of the predictive maintenance which is based on planned maintenance intervals and condition-based servicing. Due to a widespread availability of robust and cost-effective on-line sensors for measuring various fluid properties, latest developments deal with on-line oil condition monitoring to determine the condition of hydraulic system and fluid. This allows for maintenance work to be carried out based on the detected system condition.

However, measurement of the oil condition is much more complex then measurement of e.g. pressure or temperature. The oil condition cannot be determined with only one single parameter. Several parameters must be observed at the same time. For the best understanding and interpretation of the results we also have to track trends of these parameters.

## 2. ON-LINE MEASURED OIL PARAMETERS

Some of the most important physical and chemical changes in hydraulic oil, which can be detected using on-line sensors, are presented below.

## 2.1 Temperature

Temperature is certainly one of the basic and most important physical quantities, which requires continuous monitoring. Known fact is that the hydraulic fluids age much faster at high operating temperatures because of the accelerated rate of oxidation. It is believed that life expectancy of hydraulic mineral oil is halved for every 10 °C above 60 °C. Moreover, most of the other physical and chemical parameters of hydraulic fluid are highly dependent on the temperature. The temperature also influences viscosity, relative humidity, dielectric constant and electrical conductivity of the hydraulic fluid.

## 2.2 Viscosity

Also, the viscosity is very important physical property of mineral hydraulic oils because it affects the lubrication film and thus the friction and wear. The viscosity value is typically specified in a narrow band for a certain type of oil. However from oil to oil the viscosity might differ. From system and component view certain upper and lower threshold values for the operating viscosity are specified. Changes of the viscosity throughout the operation might result from oil deterioration and contamination with other oils respectively fluids. Thermal oxidation very often leads to an increase of the viscosity, whereas shearstress especially of long chain VI-improver-oils leads to a decrease of viscosity.

Viscosity measurement can be made by placing the quartz crystal wave resonator in contact with liquid. As the acoustic wave resonator supports a standing wave through its thickness the wave pattern interacts with electrodes on the lower surface (hermetically sealed from the liquid) and interacts with the fluid on the upper surface. Described measurement principle is very sensitive to surface contamination and formation of deposits, which is a common problem of most modern on-line sensors.

Hydraulic oil viscosity varies with pressure and temperature. Since the measurements take place at relatively low and constant pressure, the effect of pressure can be neglected. However, we should not ignore the impact of temperature. With increasing temperature the viscosity is sharply declining. In order to accurately determine the change of viscosity of hydraulic oil through its lifetime is therefore appropriate to take a baseline - the calibration curve, which shows the relationship between temperature and viscosity.

## 2.3 Relative humidity

Water is in practice one of the greatest threats to the hydraulic and lubricating oil. Lubricant film reduces the load and act as a catalyst in the processes of aging and degradation of oil. Water may be present in dissolved, emulsified or free form.

Capacitive sensors detect changes in relative humidity and show the percentage of saturation of the hydraulic oil. Oil is 100 % saturated if it contains the maximum amount of bound water at a certain temperature and pressure. In addition to a function of temperature and pressure, water solubility also depends on the chemical compatibility of the water and oil. Consequently, the level of saturation can significantly vary depending on the different base oils and various packages of additives [1].

For hydraulic systems is important to know the relative humidity, because it allows us to monitor the point of condensation from the moist when oil starts separating water droplets. This leads to the formation of mild emulsion, and, consequently, accelerated corrosion of components.

## 2.4 Electrical conductivity

The conductivity of a solution is a measure of its ability to conduct electricity. The electrical conductivity of a solution of an electrolyte is measured by determining the resistance of the solution between two flat or cylindrical electrodes separated by a fixed distance. An alternating voltage is used in order to avoid electrolysis. Typical frequencies used are in the range 1 to 3 kHz. The dependence on the frequency is usually small.

Specific fresh oil has its own characteristic conductivity, which is typically lower value. Because conductivity is oil specific it is a criterion for differentiating oils. Also the entry of foreign substances (solid/liquid) can be detected if such entry causes a change in conductivity. Thus oil changes, oil mixtures, and contamination can be detected.

In addition conductivity changes due to aging processes so that the course of aging can also be tracked based on conductivity.

## 2.5 Relative permittivity

The relative permittivity of the fluid is a measure of its polarity. Basic oils and additive packages with different chemistry and from different manufacturers can differ in polarity. Thus polarity of the fluid is a quality factor through which oil changes, oil mixtures and refreshing can be detected. Moreover, oils change their polarity during the aging process. It is also possible to monitor the trend of aging.

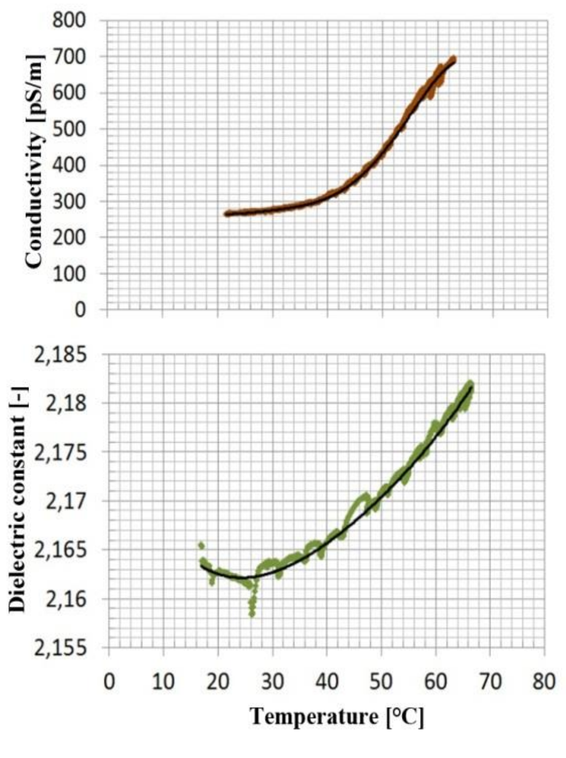


**Figure 1.** Temperature dependency of electrical conductivity and dielectric constant oil

Measurement of relative permittivity is based on a capacitive measurement transformer moistened with oil and is usually given as relative static permittivity or dielectric constant. Dielectric constant of the media is high, if its molecules are polar or highly polarized.

Figure 1 presents temperature dependency of electrical conductivity and dielectric constant for mineral hydraulic oil. Data shown on the figure were obtained experimentally and are further used to normalize temperature dependency of electrical conductivity and dielectric constant.

Like viscosity, the electrical conductivity and dielectric constant are also monitored at 40 °C to neglect the temperature effect on these two parameters. Since they cannot be always measured at 40 °C, they are normalized to 40 °C with post-calculation.

## 2.6 Cleanliness class

On-line measurement of particle contamination levels provides easy analysis of a machine's condition. Detecting failure mechanisms such as early detection of oil contaminants allows maintenance personnel to increase machine life and reliability.

The most widely deployed method today for determining fluid cleanliness is to use an automatic optical particle counter. There are a variety of instruments commercially available to optically count particles; from low-cost online optical particle counters, portable units for onsite use, to large, sophisticated lab-based instruments. However, all instruments, whether they be a hand-held unit or a full lab instrument use one of two methods, either a white light source, or more commonly today, a laser.

A sample of oil may contain a multitude of problems, which may interfere with the goal of accurately counting and sizing the solid particles. The most common problem is entrained air bubbles and water droplets, which scatter and block light, and are erroneously counted as particles by the optical automated particle counters. Without special sample preparation, an optical particle counter does not work well with fluid that is dark or fluids that are heavily contaminated with silt or soot. These conditions can produce so-called coincidence error, or in extreme cases may completely prevent the transmission of light.

## 3. REAL CASE STUDIES

A distinct advantage of on-line condition monitoring systems (Figure 2) is the continuous monitoring of individual fluids' parameters, thus knowing the oil condition at any time.

**Figure 2.** Industrial on-line oil condition monitoring system

In addition, any sudden changes are also detected (even an automatic SMS or E-mail alert can be triggered), whilst with off-line methods it cannot be. Figure 3 shows an example of on-line user interface of such on-line condition monitoring system.

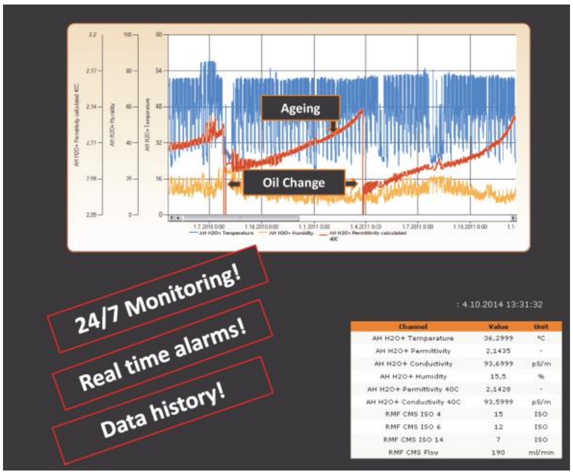


**Figure 3.** User interface of on-line condition monitoring system

Figure 4 presents detection of solid oil contamination. Our practical experiences show that there are many false alarms of oil contamination especially if the flow condition through the particle counter are unstable (i.e. bad installation of particle counter or at machine start-up phase). We have also noticed that larger water ingress can cause worse oil cleanliness class reading since water in free form (small droplets in oil) is detected as small particles. Thus, we should always monitor the relative humidity also.

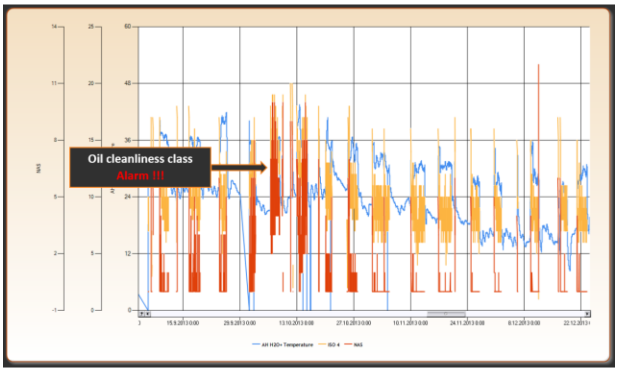


**Figure 4.** Detection of solid oil contamination (red)

Figure 5 presents detection of increased relative humidity (red) of oil because of water ingress due to damaged cylinder sealing. From our practical experiences the detection of increased relative humidity is often very reliable and even the smallest water ingress will increase relative humidity of oil. Humidity usually increases to 100 % very quickly, even at very small amounts of water. Since water ingress also increases electrical conductivity (yellow) and dielectric constant, we can use these two parameters to track water levels above 100 % relative humidity in oil.

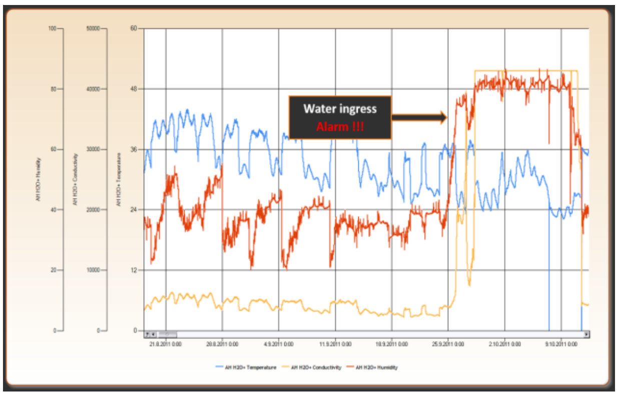


**Figure 5.** Detection of water ingress (red)

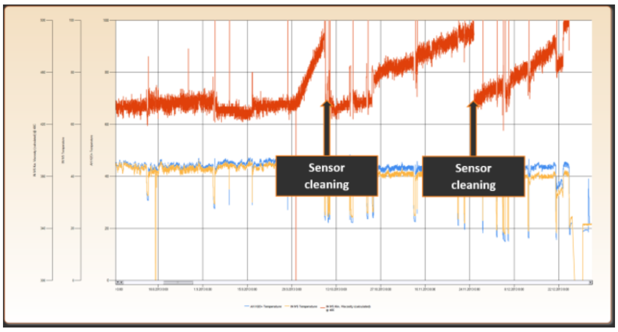


**Figure 6.** Miss-readings of viscosity (red)

Figure 6 presents miss-readings of viscosity measurements (red) of oil because of deposits of oil sediments on the sensor head. Since the vibrating piezo-electrical surface of the sensor head is contaminated with these sediments, the natural frequency of the measuring head is changed and thus, the viscosity is not measured correctly. The figure also presents two occurrences of sensor head cleaning which help maintain correct operation of the sensor. These miss-readings usually occur after 1 month or even earlier.

## 4. CONCLUSION

The use of on-line oil condition sensors together with appropriate knowledge of physicochemical changes in oil allows user to have constant overview of the oil quality and its properties. This information can sometimes be crucial to prevent damage and ensure reliable operation of the system.

Today's modern hydraulic systems often have a particle counter installed. However, since on-line particle counters cannot indicate all important fluid conditions (for example viscosity, water level, etc.), the proper on-line condition monitoring system should also include other sensors for evaluation of physical and chemical properties of hydraulic fluid and its condition. And it is also important to point out, that the most on-line sensors for condition monitoring of hydraulic fluids are basically only indicators for early detection of impending system damage. In order to obtain the most detailed, accurate and reliable information on hydraulic fluid state the on-line measurements should be updated with the periodical laboratory testing of the proper fluid sample.

## REFERENCES

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