innovative
Sensor
Technology

physical · chemical · biological

MOISTURE IN OIL

WHITEPAPER

Oil is the lifeblood of many industrial plants and machines. It is used for cooling, lubrication, insulation, and power transmission.

To operate a gearbox, a transformer or an industrial plant safely and stable over a long period of time, monitoring the condition of the lubricants with the support of process sensor technology is recommendable.

Every oil changes with chemical and physical aging, as additives degrade and impurities accumulate. The oil's ability to absorb water can suffer and its lubrication ability and insulation strength are reduced. Unchecked, operating machines with unsuitable oil condition with a too high water content may lead to machine downtime and expensive repairs.

Continuous monitoring of moisture in oil is key to running preventive maintenance economically and / or to trigger automated counter-measures within the monitored system.

Contents

1.0 Motivation

2.0 Technology

3.0 Measurement Results

4.0 Outlook

1.0 Motivation

Continuous monitoring is a crucial first step towards extended equipment lifespan. E.g. transformers need to operate safely and reliably under extreme weather conditions. Offshore infrastructure like wind turbines, oil rigs and cargo ships are prominent examples of machines with high installation and maintenance costs.
Also, heavy duty vehicles are subject to high reliability standards for hydraulic and power transmission systems.

Thermal management of battery packs with oil immersion cooling is another emerging application example.

Prime oil condition is essential for these complex machines to operate smoothly. Sporadic laboratory checks can be upgraded to continuous process monitoring. Coupled with built-in or mobile filtration and de-humidifcation they ensure maximum efficiency.

Maintenance can be scheduled before any malfunction or efficiency loss occur and keeps services costs economical.

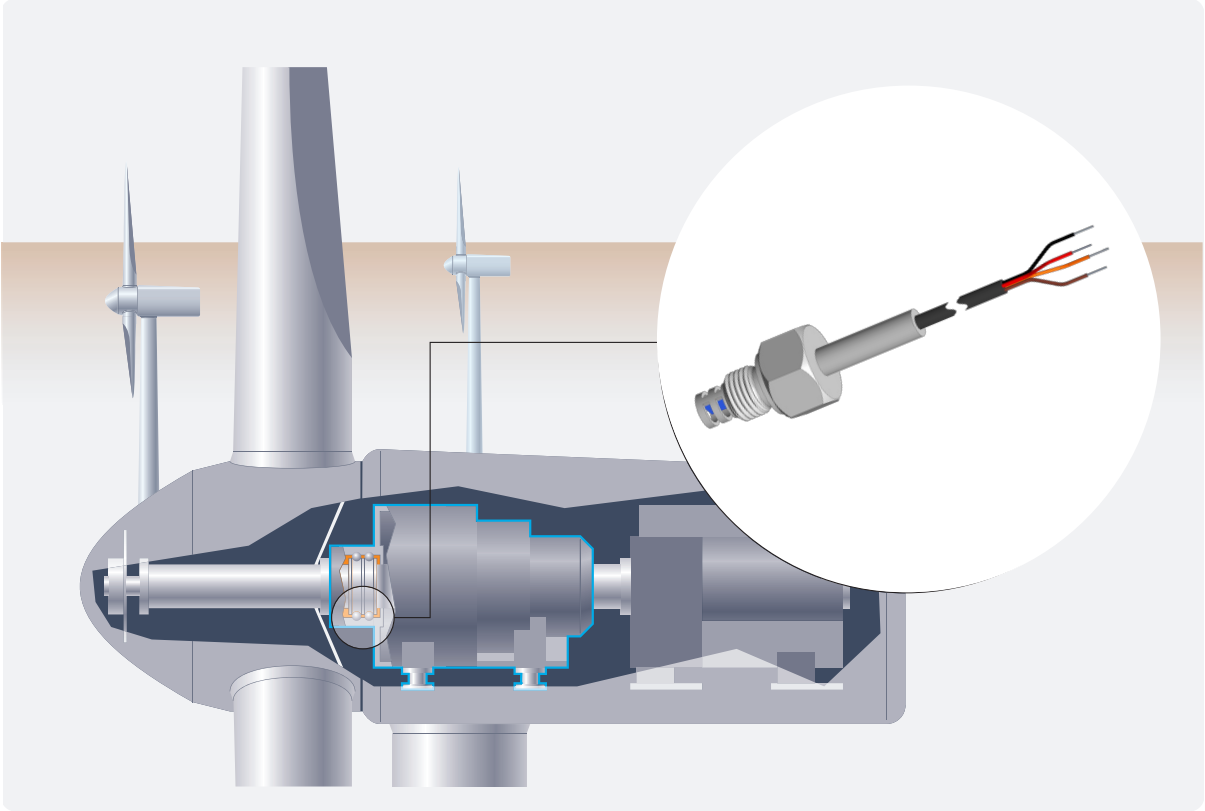
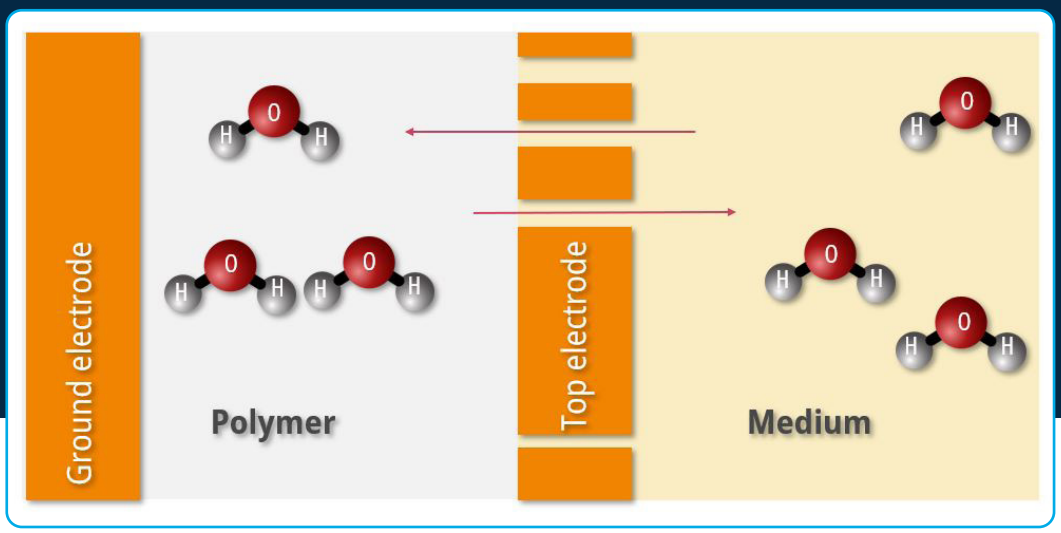


Figure 1: Application example with wind turbine and detail of humidity sensor to be implemented in a gear box. (Source: © IST AG, 2024)

Figure 2:
Measuring principle of a capacitive humidity sensor element:
A concentration gradient driven diffusion of water molecules in and out of the polymer layer effects the capacitance of the sensor



2.0 Technology

Capacitive humidity sensors are common in air monitoring systems. The polymer layer of the sensor is in contact with the surrounding air through the porous top electrode. Water can diffuse through the pores of the electrode from the surrounding air into the polymer layer and vice versa until an equilibrium state is established (see figure 2).
The amount of polymer-bound water influences the capacitance of the sensor which is the measured variable.
The measuring principle remains the same in oil. Humidity diffuses from the oil into the polymer layer and back. In oil, the operational conditions are harsher due to high temperatures and the risk of interaction with potentially aggressive chemicals.

iST`s MK33 sensor element is uniquely suited for moisture in oil monitoring. Due to undeclared additives in commercial oil products, it is strongly recommended to evaluate the compatibility of the moisture sensor with a particular oil.

Linearization and translation of the sensor‘s capacitive raw signal requires precise calibration against relative humidity and temperature.
iST`s calibration procedures for the HYT modules are application-specific and achieve best accuracy under operational conditions critical for process control. For applications in oil this often involves elevated temperatures and high relative humidity levels.

Moisture in oil is traditionally monitored offline applying laboratory analysis. Karl-Fischer titration is considered as reference analytical method. During Karl-Fischer titration, the absolute water content in the sample is determined. The underlying chemical reaction is as follows:

$$2\,H_2O + SO_2 + I_2 \rightarrow H_2SO_4 + 2\,HI$$

The total water content consists of free, reversibly bound and dissolved water.

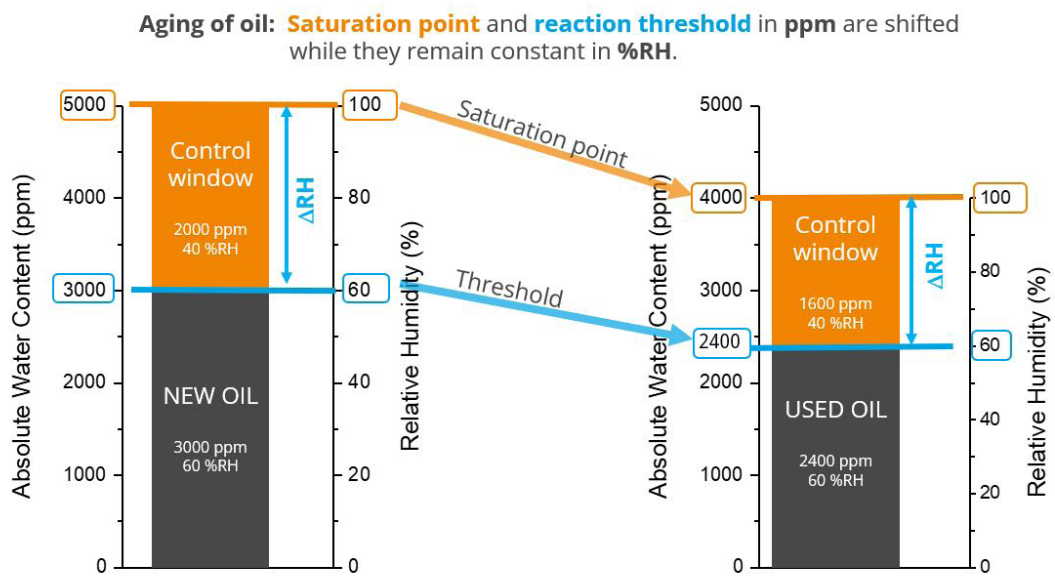


Figure 3:
Control window for process control expressed in %RH (corresponding to water activity a_w)

Note: The displayed reaction threshold and absolute water content values are randomly selected for illustrative purposes only

The results obtained by Karl-Fischer titration disregard any changes in water solubility due to oil aging and additive depletion as it gives the absolute water content in ppm. Laboratory analysis also disregards the operational conditions. Especially temperature has a strong influence on the solubility of water in oil. The interpretation of laboratory results relies on detailed knowledge of a particular oil sample. Determining the absolute water content in ppm, as Karl-Fischer titration does, has several disadvantages compared to determining the relative humidity in %RH which corresponds with the saturation level of moisture in oil.
On one hand, the moisture saturation level in oil varies with changing temperatures (e.g. day-night cycles). This occurs even with constant ppm total water content. There is a potential for a mismatch between threshold and actual saturation level and free water. On the other hand, as the oil ages, the ability to dissolve water changes and the threshold in ppm needs to be adapted to avoid free water (see figure 3).

In this example, a water content of 60 %RH corresponds to 3000 ppm in new oil. The oil ages over time and the saturation point shifts from 5000 ppm to 4000 ppm. The relative humidity (%RH) considers this change in solubility while the absolute humidity (ppm) does not. For the aged oil the threshold of 60 %RH corresponds to only 2400 ppm.
If the system is operated with a threshold of 60 %RH, the operator will be warned before critical amounts of water are present, as the current condition of the oil is considered. If a threshold of 3000 ppm were used, the aging would decrease the safety margin for oil reconditioning.

Material datasheets for oils contain maximum water activity (a_w) upon shipment. This value corresponds to dissolved water content expressed as ratio of saturation level. Relative humidity as measured by a capacitive humidity sensor relates the same information in percentual format.

A capacitive humidity sensor giving the moisture content in %RH presents an attractive alternative to titration for process control purposes with the following advantages:

- Continuous in-process measurement
- Easy and immediate interpretation, respecting the actual condition of the oil
- All measurement points are coupled with temperature and allow to evaluate changes in solubility, e.g. with day-night cycles

3.0 Measurement Results

It takes time to reach physical equilibrium with dissolved water evenly spread throughout a certain volume of liquid oil (see figure 4).
The dissolving process of water in oil is sped up at higher temperature and with effective high-speed mixing. Sample homogenity remains the limiting factor for a reliable data read-out. The response time of the humidity sensor to its immediate surroundings is significantly faster.

A deliberate sensor positioning to utilize flow dynamics has major implications for an effective process control setup.

Long-term measurements show the stability of our sensors in an ester and a mineral oil sample (see figures 5 and 6).
The measurements were performed at room temperature, open to ambient air, without mechanical strain. Effects of ambient humidity and temperature fluctuations were observed. Air exchange in transformers, aka breathing, has a similar effects on moisture in oil cycles.

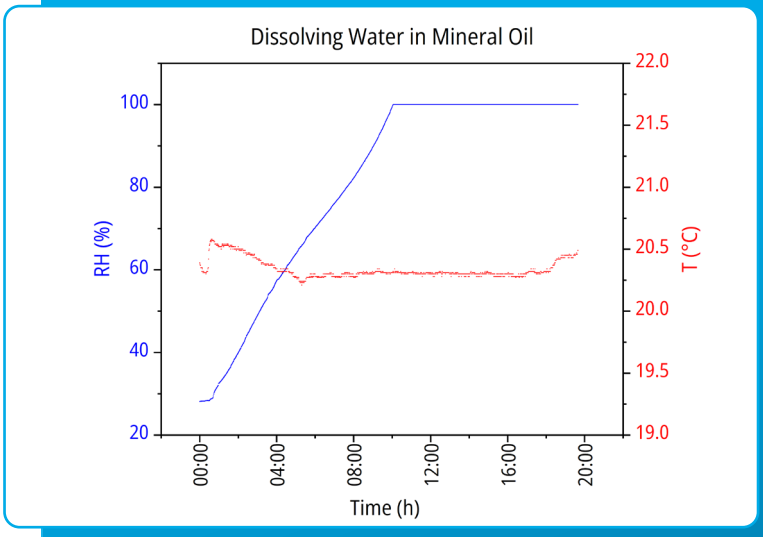


Figure 4: The slow dissolving process of water in oil is demonstrated by monitoring moisture in oil after the addition of sufficient water to saturate the oil sample. Water was added in a single step to a sample of mineral oil with initially 30 %RH under costant stirring (300 rpm)

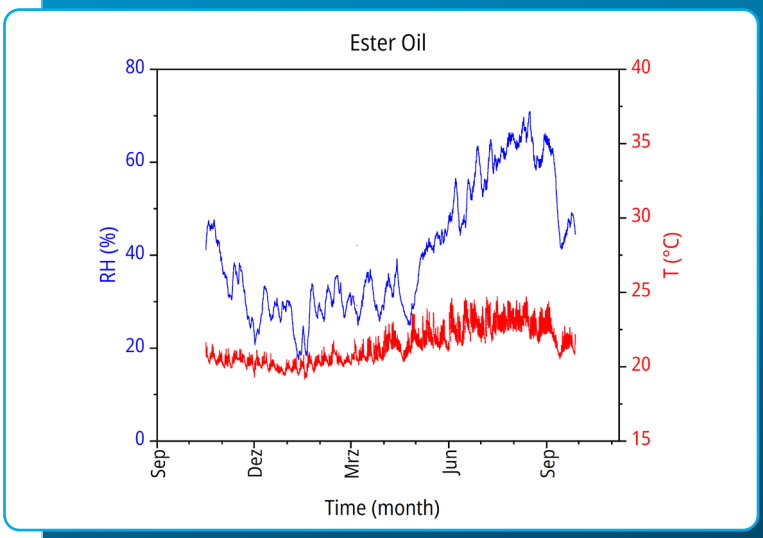


Figure 5: Long-term measurement in ester oil. The fluctuations in humidity and temperature are caused by the changing ambient conditions in the laboratory.

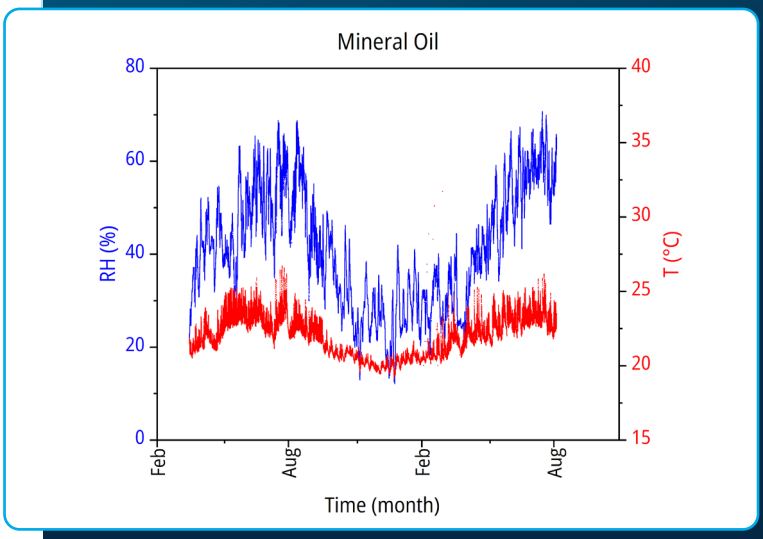


Figure 6: Long-term measurement in mineral oil. The fluctuations in humidity and temperature are caused by the changing ambient conditions in the laboratory.

Innovative Sensor Technology IST AG

Your partner and manufacturer for physical, chemical and biological sensors

With more than 30 years of experience Innovative Sensor Technology IST AG is one of the world's leading manufacturers of physical, chemical and biological sensors.

We specialize in the development and manufacturing of temperature sensors, thermal mass flow sensors and modules, humidity sensors and modules, conductivity sensors and biosensors. In addition to our standard products, we offer sensor adaptions to individual, customer-specific application needs – right up to the joint development of new technologies. iST-sensors are characterized by their accuracy and consistency in various measurement conditions. They are used in measuring and monitoring instruments for numerous applications across all industries.

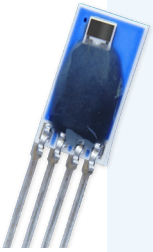
Out of our state-of-the-art-facilities we manufacture varying quantities from small order numbers to fully automated high-volume manufacturing.

iST is a company of the Endress+Hauser Group, headquartered in Reinach, Switzerland.
Endress+Hauser is among the global leaders in measuring instruments, services and solutions for industrial process engineering.

The products

Product code 150138

MK33-W mini
For measurement in oil and extreme environment



Product code 153382

HYT 271 Module
RH/T module for harsh conditions, factory calibrated with digital I²C interface

Product code 155958

Moisture in oil sensor
155958
Ready-to-use insert probe

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