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Applicability of Thermal Conductivity Sensing for Condition Monitoring

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In a vast number of applications the monitoring of liquids is of primary importance. A prominent example is the condition monitoring of oil-based liquids such as lubrication and insulating oils. In both cases the water contamination of the oil often cannot be avoided, which seriously influences its performance if certain levels are exceeded. In the case of lubrication oil excessive water content leads to insufficient lubrication and subsequently to abrasive wear and corrosion. In case of insulation oils increased water content results in a considerable reduction of the breakdown voltage. Thus, the detection of water content in the oil is decisive. Comparing the thermal transport properties of mineral oil and water it turns out, that the latter features a five times higher thermal conductivity. This indicates that thermal conductivity is a potential parameter for the detection of water content in mineral oils.

In recent years miniaturized sensing elements for thermal conductivity and diffusivity have gained increasing importance in the field of liquid analysis. Due to distinctive features associated with micro-technology such as small thermal masses of micromachined membranes, high sensitivities can be achieved at a comparably small heating power. In consequence, unwanted effects such as natural convection and other disturbing mechanisms associated with high excess temperatures can be significantly reduced. In this contribution the performance of two micro sensors differing in both, measuring principle and physical dimension is explored by investigating the thermal transport properties of water-in-oil (W/O) emulsions.

The first sensor considered in our presentation is a "bulk" hot film micro sensor. The device consists of a glass substrate with a resistive loop made of molybdenum simultaneously serving as both, heater and sensing element. By applying a transient electrical current, the wire and the surrounding medium under investigation start heating up. Recording the corresponding temperature response of the wire enables the determination of the thermal conductivity and diffusivity of the surrounding fluid.

The thermal mass of a "bulk" hot film sensor is predominantly defined by the substrate used. To reduce the thermal mass and to restrict the lateral heat conduction the resistive structure is often placed on a thin membrane. Thus, the second sensing element considered in this contribution, a "membrane" hot film sensor, is based on a novel micromachined chip, which has also been utilized as a thermal flow sensor. It consists of a thin silicon nitride membrane supported by a silicon frame. On this membrane two vapour-deposited, highly sensitive amorphous germanium thermistors are located symmetrically to a central platinum heater. By applying a sinusoidal heater current, a diffusive heat wave propagates from the heater into the surrounding liquid. The steady state amplitude and the phase of the AC-component of the thermistor temperature on the membrane are determined by the thermal conductivity and diffusivity of the liquid.

To evaluate the applicability of these devices, the above mentioned application of monitoring water contamination in oils has been considered. The measurement results show that W/O emulsions feature increased thermal conductivities compared to the base oils, which indicates that monitoring the thermal conductivity could be utilized in online oil condition monitoring systems. Furthermore it turns out that the "bulk" hot film micro sensor exhibits a lower sensitivity compared to the "membrane" hot film sensor which can be lead back to the significantly higher thermal mass and the associated measurement principle. Thus, in terms of applicability of micro-machined thermal conductivity sensors in harsh industrial environments, a trade-off has to be found between sensitivity and mechanical robustness.