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Reliably measuring the condition of mineral-based transfer fluids using a permittivity sensor – practical application to thermal fluid heat transfer

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ABSTRACT

This article describes a series of experiments to assess the performance and suitability of a permittivity sensor in the area of heat transfer. The permittivity sensor measures condition index and temperature of a fluid. A series of 5 experiments was conducted. They assessed the reproducibility of the sensor using both clean and dirty fluid samples, and showed the sensor had good reproducibility based on calculations of coefficients of variation. The sensor also detected water contamination, assessed from construction of a stimulus-response curve to step-wise increases in water and from real-life samples where water content was reported to be out of specification. Further experiments tested the association between condition index and both water content and fluid cleanliness in a real-life setting. Results demonstrated the sensor that condition index reflected changes in fluid water and cleanliness and was therefore a measure of fluid condition. The implication of these findings is that the sensor can be used to make rapid and reliable assessments of fluid condition using only small samples (i.e., <50 ml). The sensor may be of benefit to customers that need to make a lot of regular samples over a large processing site, such as concentrated solar power plants.

1. Introduction

Understanding and predicting the thermal degradation of heat transfer fluid (HTF) is critical to any planned preventative maintenance program. The process of thermal is a complicated process [1] involving a number of factors including elevations in temperature above the HTFs bulk operating temperature, oxidative stress and contamination within the system (i.e., wear particles) and the build-up of foreign particles (i.e., water). The chemical composition of a HTF can be routinely conducted in a laboratory [2,3] and should be conducted according to International standards [4,5]. Water is routinely measured along with other functional parameters of HTF condition. These include carbon residue, acids, flash components and changes in kinematic viscosity. Manufacturers and insurers suggest that HTFs are sampled and analysed at least once per year when a HTF is operating close to its bulk temperature and biannually if it is more than 20 °C below its bulk temperature [6,7]. This allows the condition of a HTF to be monitored over time which can be communicated to the

Abbreviations: ; HTF, heat transfer fluid; ASTM, American society for testing and materials; CV, coefficient of variation
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manufacturer or insurer. Likewise, it is also important that HTF condition is monitored prior to any intervention, for example, prior to a system fill a HTF sample is taken to determine if water is present [8]. Indeed, water contamination can occur during storage and it is important that HTF drums are not stored outside as water will inevitably get into the drum and this is a potential entry point of water into a HTF system and a source of potential problems [9]. Moreover, contaminants work to accelerate the ageing of a HTF and can potentially shorten the working life of a HTF [1], so it is important to be able to accurately and reliably assess their appearance and also remove them to maintain the long-term efficiency and safety of the plant.

The presence of water can be detected visually as water and HTFs are immiscible and so water is seen as a clear and separate layer at the bottom of a HTF sample. Testing should be complimented by a standardised, quantitative test to provide accurate assessments and to draw sound scientific conclusions. Chemical testing routinely involves assessments performed in the laboratory, but this approach can be labour intensive if a wide range of parameters is being assessed. This can be frustrating to all involved, especially when water has been visually confirmed. Hence there is a need for fast, reliable and accurate assessments to be conducted onsite and once the HTF sample has been drawn. One possible approach might be to assess HTF condition using a permittivity sensor which may be a valuable addition to HTF condition based maintenance [10].

Permittivity sensors offer the potential to provide a measure of HTF condition and temperature. Our study was designed to test the reliability of measures performed with the Global Thermocare™ Sensor (GTS) which is a permittivity sensor. This sensor can be used to make assessments of a fluid's condition based on permittivity. The current study assessed the functionality of this sensor. This was done by assessing: (a) the reproducibility of measurements from assessments of intra- and inter-group coefficients of variation of both virgin and used HTF; (b) comparison of water contamination recorded using standard laboratory tests and the permittivity sensor; (c) the response of the sensor to water which was assessed in the laboratory by constructing a stimulus-response curve to increasing water content; and, (d) assessing the functionality of the sensor in a real-life setting during the flushing of a newly built HTF system [11]. The results of this study are presented herein and discussed in the context of current and possible future uses.

2. Experimental methods

2.1. Global Thermocare™ Sensor (GTS)

GTS is a dielectric sensor used to measure the capacitance of a HTF, which changes as the oil becomes damaged. The GTS works in a similar manner to a traditional dielectric sensor. It passes an alternating current electric across two electrodes. The change in current flow changes with the state of degradation. The GTS works in a similar fashion but measures permittivity, which is a combined measure of capacitance and conductance. Capacitance is the ability to store an electrical charge. Based on a parallel-plate capacitor, capacitance (C) $=\varepsilon_r \bullet \varepsilon_0 \bullet A/d$ where A is the area of overlap of the two plates; ε_r is the relative static permittivity or the dielectric constant of the material between the plates; ε_0 is the electric constant; and, d is the separation between the plates. Conductance is the ease with which an electric current passes through a conductor and is defined as current divided by voltage or 1 / resistance.

Permittivity is a reflection of a material's ability to transmit or 'permit' an electric field and is affected by humidity, temperature and other parameters.

Fig. 1. Screenshot of customised software used with the Global Thermocare™ Sensor.