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Abstract:

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High-Resolution Non-Contact Microwave Sensor for Water-Cut Measurements

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ABSTRACT

A novel, real-time, non-contact, non-invasive and high-sensitivity planar microwave sensor is developed for water cut measurements of crude oil samples. This sensor demonstrates the capability of measuring water cut of bitumen in real-time, which is of low-cost and eliminates the hurdles of current measurement techniques, prevents loss of production, and paves the way for oil field automation. The platform of the proposed sensor is based on a passive split ring resonator-based sensor with a defected ground gap coupled transmission line as the reader. The performance of the microwave sensor has been verified with varying water concentration in oil samples. The non-contact nature and high-resolution of the proposed structure enables monitoring of water cut in the full range.

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INTRODUCTION

The oil-water two-phase flow is commonly found in the petroleum exploration, production and development of oil fields. Monitoring the composition of the fluid, especially the water cut is vital [1]. Precise measurement of water content can improve the production surveillance [1] and optimize production processes [2]. The accurate measurement can aid in the quality control of the oilfields production operations, monitor the condition of oil wells, minimize energy consumption, and automate the oil fields [3]. The classical offline methods such as distillation, Karl-Fischer titration and centrifuge require the samples to be taken offline to laboratories for analysis which lengthens the measurement cycle and can potentially delay crucial operational recommendations to be made regarding certain processes in the petroleum industry [4]. With the advancement in technology, online water cut meters have gradually been developed over decades which are commonly based on capacitance measurement, gamma ray attenuation, density difference or infrared spectroscopy [2]. Amongst these methods, microwave technology has gained the attention of various researchers in academia as well as in the industry. This technique is robust and precise with full-range water cut measurement despite drift in the instrument [2].

Recently, planar microwave sensors have gained considerable attention as potential candidates because of the several compelling advantages that they offer, such as a simple and unique fabrication process, easy integration into the circuit, [5] low-cost, high-quality factor, [6] non-contact and real-time sensing capability [5]. These sensors are versatile and have been employed in a wide variety of applications ranging from oil and gas industries, optical sensing, pH sensing, gas concentration monitoring and chemical detection to volatile organic compound sensing [5-7].

Here, we propose a fast and reliable approach using planar microwave sensors to measure the water cut of the oil-water emulsions due to the numerous advantages that they offer. The principle of operation in the microwave sensor is based on the variation in the dielectric properties of the sample under the test, which is impacted by the water content in the mixture. A coupled reader-tag pair sensing approach is proposed, which enables sensing and monitoring in harsh environments. The tag is the main sensing element and can tolerate high temperatures and this property is immensely useful in harsh environments. The design of the ground engineered gap coupled transmission line as the reader is such that it can be placed at an arbitrary distance from the tag sensor and monitor the variation of water content in the sample around the tag while protecting the sensor from high temperature environment. The tag is chipless, battery-less, passive split-ring resonator sensor, which was fabricated on a flexible substrate of 0.254 mm thickness. The tag can be mounted on a container while the reader is fabricated on a more rigid substrate of thickness 1.575 mm purchased from Rogers Corporation.

EXPERIMENTAL SECTION

Two emulsion samples, including water/pentane and water/bitumen were used for water cut measurements. Pentane employed in the experiment was purchased from VWR

Chemicals Ltd with a purity of ≥ 99%. For the water/bitumen case, 170 g of Mackay River bitumen was mixed with 30g of toluene (17 wt.%) to allow the formation of workable oil/water emulsion at room temperature. The toluene is used as the carrier phase for bitumen, and its volume was subtracted from the oil phase in water cut measurements. The setup consisted of the sensor, a mixer for homogenizing the solvent mixture at a constant RPM, a beaker containing the mixture of oil & water and a Vector Network Analyzer (VNA), which records the data and shows the variation of the sample that is changing around the tag.

The core principle of operation of this sensor can be explained using equation (1).

$$f_r \approx \frac{c}{2l\sqrt{\varepsilon_{eff}}} \tag{1}$$

where c is the speed of light (m/s), l is the tag's length and ε_{eff} is the overall effective permittivity of the tag sensor. According to the above equation, increasing the effective permittivity of the material under test decreases the resonance frequency of the tag relatively. The variation in the effective permittivity will cause the resonance frequency to shift upward/downwards depending on the sample under test. As the mixture inside the tube changes from pure water (ε_{eff} = 80) to samples with more oil (Bitumen/Pentane: ε_{eff} = 2.6/1.84) concentration, the effective permittivity around the tag thereby increases.

In this experiment, three concentrations of pentane/water emulsion samples were prepared and examined by varying the concentration of pentane in water, and four different samples were prepared for the bitumen-water mixture. The beaker containing the mixture was stirred under the mixer for an average of two minutes to create a perfectly homogenized mixture. The tag was mounted on the container, and the sensor's frequency response for the mixture was observed and recorded in the VNA. Increasing the concentration of the different samples affects the effective permittivity of the mixture during the test. This change in permittivity is brought about by the tag, which senses the variation of the material around it and wirelessly communicates it to the reader in the circuit. The reader receives the signals, and the VNA then records the shift in frequency response of the sensor. The concentration of pentane was determined up to 90% in water which clearly establishes the robustness of this planar sensor, and the concentration of water was varied up to 28.57% in the bitumen sample by gradually adding 20 g of water in each step.

Figure 1 depicts the variation in the resonance profile of pentane/water emulsion under test in v/v%. Figure 2 shows the variation of water concentration in the bitumen sample in w/w%. Based on the reference material and the increasing concentration of pentane sample, the effective permittivity reduces, and we observe an upshift in the frequency response as expected. Based on equation (1), for the bitumen-water emulsion, the addition of more water increases the overall effective permittivity, and we observed a downshift in the resonance frequency.

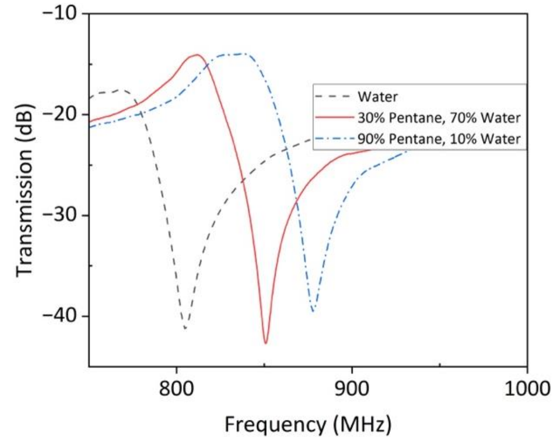

Figure 1. Resonant frequency profile for 3 different effective permittivities of Pentane-water mixture.

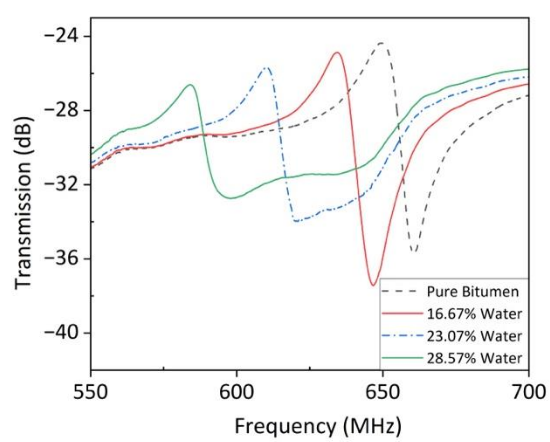

Figure 2. Transmission response of the sensor to varying concentration of water in bitumen sample.

The proposed sensor is a promising candidate for real-time monitoring, and label-free sensing of hydrocarbons for water cut measurement in the petroleum industry. The versatility of this sensor clearly demonstrates its potential for detecting other hydrocarbons for solvent detection and water cut measurements.

CONCLUSION

This work presents a novel technique for detecting solvents and water concentration in the petroleum industry using a non-contact high-resolution microwave sensor measuring in real-time. The experimental results confirm the potential of this sensor for its high sensitivity and quality-factor for detection by varying concentration of hydrocarbons in water. The resonance frequency was the main variable considered for studying the sensor's response to changes in the concentration of the hydrocarbons. This technique produced promising results and is a low-cost microwave sensor with a sensing capability that could be extended for the detection of other hydrocarbons in water as well.

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