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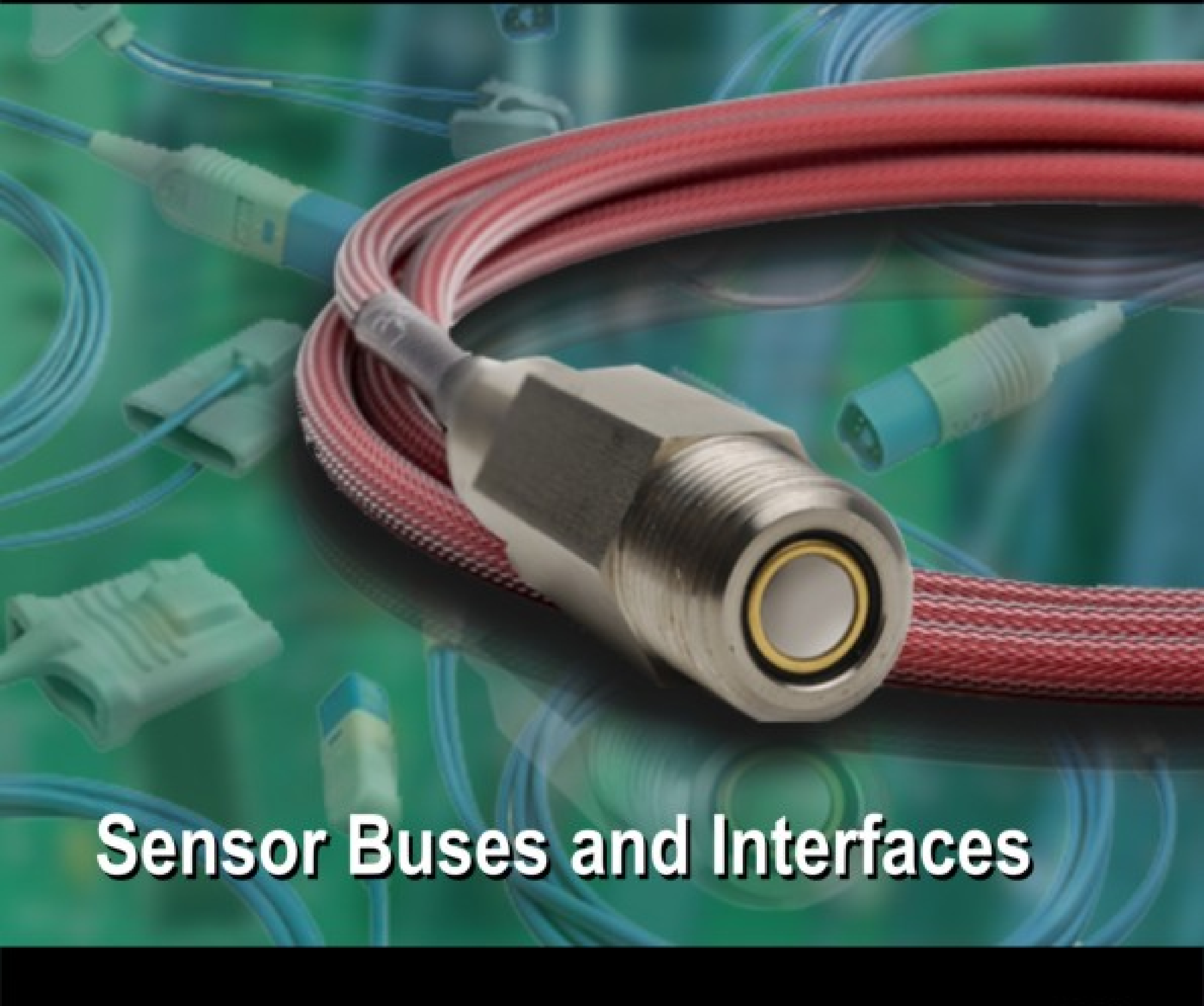

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A Single Rod Multi-Modality Multi-Interface Level Sensor Using an AC Current Source

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Abstract: Crude oil separation is an important process in the oil industry. To make efficient use of the separators, it is important to know their internal behaviour, and to measure the levels of multi-interfaces between different materials, such as gas-foam, foam-oil, oil-emulsion, emulsion-water and water-solids. A single-rod multi-modality multi-interface level sensor is presented, which has a current source, and electromagnetic modalities. Some key issues have been addressed, including the effect of salt content and temperature i.e. conductivity on the measurement. *Copyright © 2008 IFSA.*

Keywords: Oil separator, Multi-interface level, Capacitance sensor, Electromagnetic sensor, Salinity, AC current source

1. Introduction

Usually, crude oil from oil wells is sent to large separators (typically 1 - 3 meters in diameter and 3 -15 meters in length) to separate gas, oil, water and other material such as sand, aiming to extract oil. Most crude oil separators rely on gravity separation and the separation process takes a long time, depending on the size of the vessel, and type and quantity of the oil. To make efficient use of the separators, it is important to know what is happening inside of the separators, i.e. it is important to monitor the separation process and to measure the levels of multi-interfaces between different materials, such as gas-foam, foam–oil, oil–emulsion, emulsion–water and water–sand (Yang 2006).

This is particularly important for offshore oil companies. Crude oil from undersea contains significant amount of water, which is ideally separated on offshore oil platform rather than transported to the seashore, because the transportation process is very expensive and eventually water has to be separated from oil. Because the space on the platforms is limited and expensive, effective monitoring and control of the crude oil separation process on the platforms will result in huge saving to the oil companies. Therefore, it is necessary to have a reliable instrument to measure multi-interfaces for the benefit of oil companies. Accurate measurement of levels and fluid components will also benefit the environment by reducing pollution.

Although some sensors have been developed, such as the multi-modality multi-interface level sensor with segmented capacitance and electromagnetic sensing elements (Hwili 2007), Tracerco Profiler (Tracerco 2005), an ultrasonic detector from Christian Michelsen Research (CMR) (2005), capacitance sensors by Yang *et al*. (1994), Isaksen *et al*. (1994) and Jaworski *et al*. (1999, 2005) and a magnetic sensor by ABB (2001), all of them have some problems. A detailed review was given by Yang (2006). This paper presents a single-rod multi-modality multi-interface level sensor with a current source, aiming to overcome the problems.

2. Existing Instruments

Currently, few instruments can be used to measure multi-interface levels in crude oil separators. $\gamma-\text{ray}$ based measurement systems may be regarded as the most reliable for measuring multi-interfaces in crude oil separators. However, it has several drawbacks:

- It uses a radiation source, which causes safety concerns and potential health problems;
- It is expensive to purchase and expensive to maintain;
- In many countries, e.g. in EU countries, radiation-based instruments are not allowed to use in open space.

The Tracerco system is an example based on measuring the attenuation of γ radiation to detect the density profile in an oil separator (Tracerco 2005).

Ultrasonic transducers have been used for single-interface measurement. They are good at determining a single-interface between gas-liquid or gas-solids. CMR in Norway has developed ultrasonic systems for the multi-interface level measurement, in particular for the use in oil separators. The system consists of a clamp-on ultrasonic sensor, sensing electronics for the hazardous zone, a zone interface with ex-barriers, a power supply and a processing unit with a monitor. The clamp-on ultrasonic sensor is mounted with direct contact to the outside wall at the bottom of a separator, transmitting and receiving ultrasonic pulses along the vertical axis. The operation is based on pulse-echo and interface levels are estimated by time-of-flight (TOF) of echoes from the interfaces with consideration of the speed of sound in the propagation media (CMR 2005).The features of this ultrasonic system are non-invasive and non-intrusive. It can work with water.

Ultrasonic systems have several drawbacks:

- The ultrasonic signal is significantly attenuated by the first interface and hence the echoes from the second and further interfaces would be too small to detect.
- To deal with attenuation of signal due to the vessel wall, sufficient signal power must be applied. However, there is a limit to the energy applied by intrinsic safety. If the ultrasonic transducer is instead mounted inside of a separator, it becomes intrusive and again it causes intrinsic safety concern.
- Foam may completely absorb ultrasonic energy and thus a layer of foam will result in false reading.

Most capacitance-based transducers are designed to measure a single interface and based on a single rod with a single electrode, with the vessel wall as another electrode. This type of transducer is not accurate because capacitance is a function of temperature. That means any change in temperature can affect capacitance measurement significantly and give an inaccurate location of the interface between two different materials (Jaworski 1999).

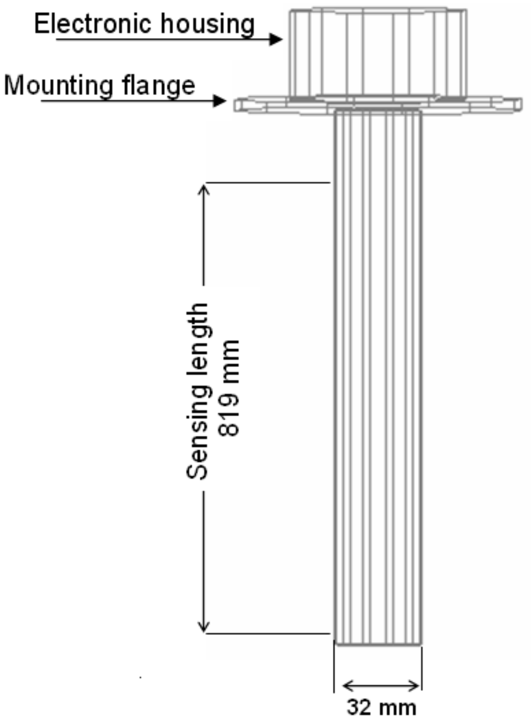
Recently, Sentech AS in Norway developed a single-rod capacitance probe called SeCaP for measuring multi-interface levels in oil separator (Sentech AS 2008). The sensor rod consists of several individual measurement probes. The distance between the probes is typically 10-40 mm depending on the accuracy needed. Each probe is electrically insulated from the surrounding substance as well as from the other probes. The electronic circuitry for each individual probe is integrated and mounted inside the rod in its entire length and are linked to each separate probe. A possible problem is that it relies on capacitance measurement only.

The ABB electromagnetic sensor is simply a rod with multiple sensing coils to detect the eddy current induced in medium. The advantage of this system is that it can measure the interface level between oil and water. The limitation is that it cannot measure the interface level between oil and gas.

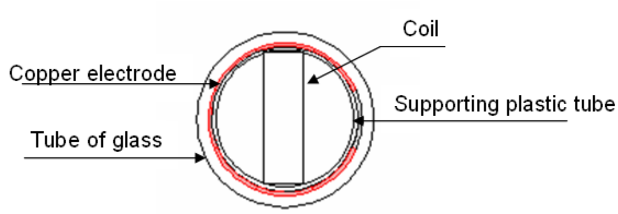
3. Single Rod Multi-Modality Sensor

The new sensor consists of a single rod (see Fig.1 (a)), which is selected to reduce the abstraction resistance to the liquid flow and to avoid the fouling problem. As a prototype, the length of the rod is 1 m long, and comprises the following items: a Perspex tube, 20 coils, 20 copper electrodes and a supporting plastic tube, as shown in Fig. 1 (b). Fig. 1 (c) shows two arrays of copper electrodes and inductance coils in the fabricated sensor.

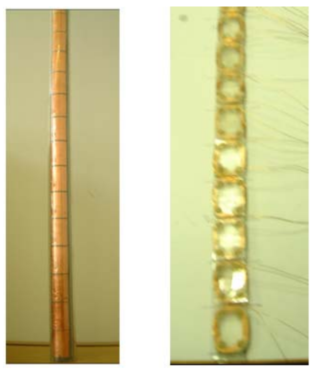
The operation of the copper electrodes and the induction coils are controlled by a microcontroller (PIC18F452) as shown in Fig. 2 (a) and (b).



(a) Geometry of new sensor.

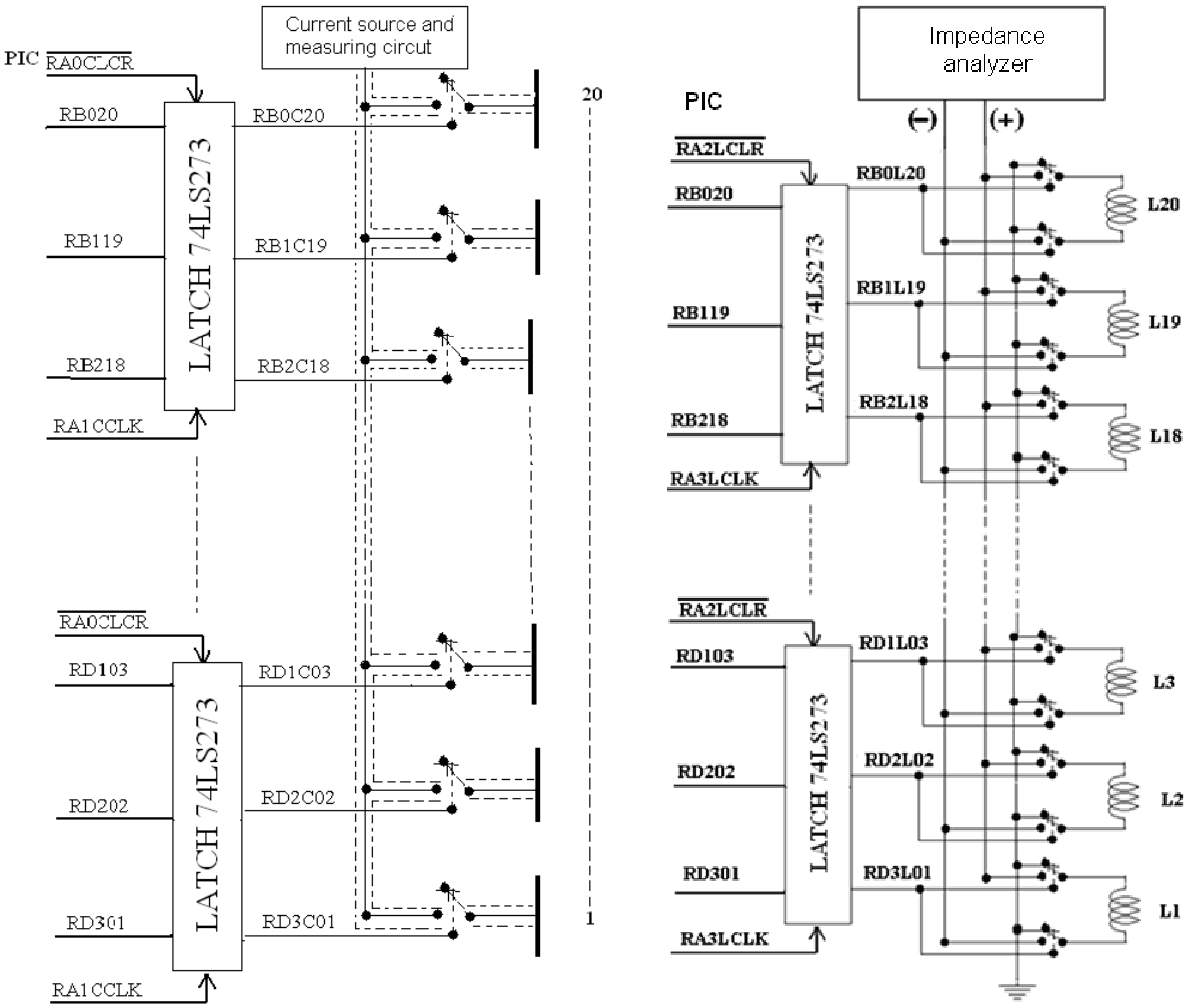


(b) Cross section of the sensor rods.



(c) Arrays of capacitance electrodes and coils.

Fig. 1. Single-rod multi-modality sensor.



(a) Capacitance electrode circuit.

(b) Induction coil circuit.

Fig. 2. Sensing element circuits.

3.1. Measuring Circuit

The block diagram of the measuring circuit using an AC current source is shown in Fig. 3, which is based on a modified version of the Howland voltage-controlled current source (Steel 1992), the AC current is to injected electrode. The output voltage of low-pass filter is dependent on the material surrounding the electrode. A full functional description of the current source can be found in (Nerino 1997).

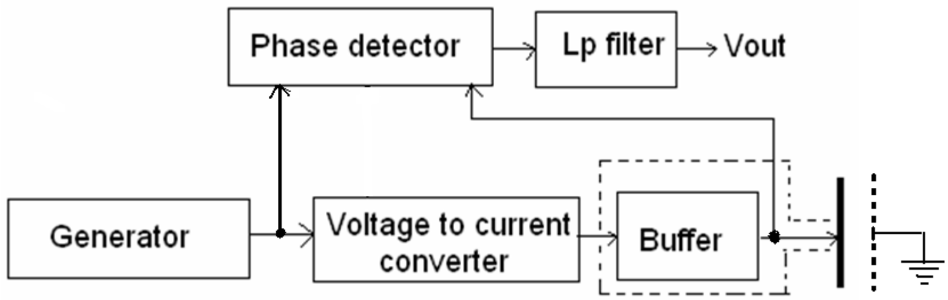


Fig. 3. Measuring circuit.

4. Experiments

To test the performance of the sensor preliminary experiments are conducted using a Pc an impedance analyzer an oscilloscope and a current source.

4.1. Experimental Results

A single electrode of the sensor was tested with different frequency of the AC current source and different materials. The output of the phase-sensitive detection circuit (PSD) is shown in Fig. 4.

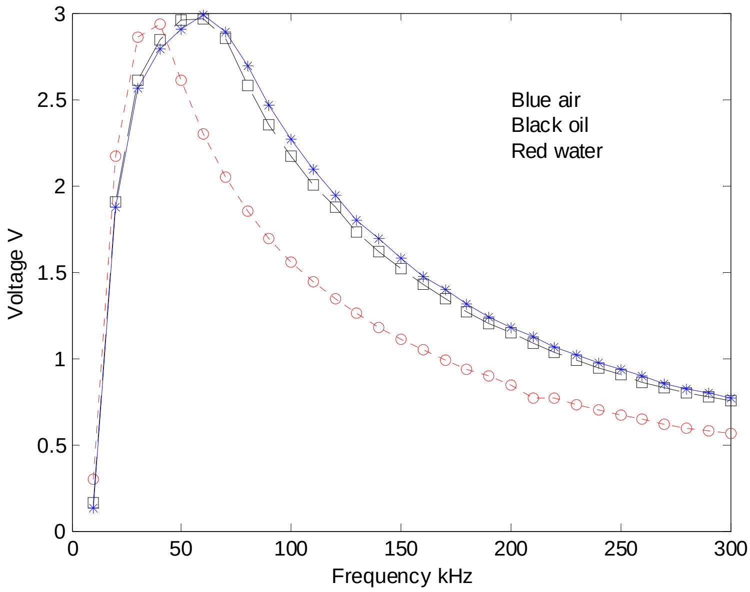


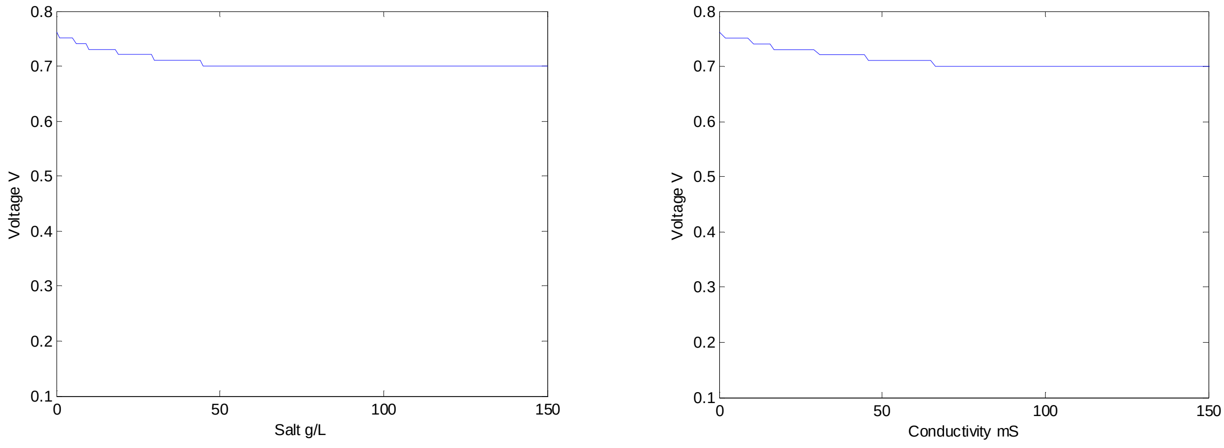
Fig. 4. PSD output with different frequencies.

The effects of salt, conductivity and temperature on the measurement were also tested and the results are shown in Figs. 5-6.

The sensor was tested when it was (i) empty, (ii) full of water and (iii) full of oil in a frequency range from 1 kHz to 4 MHz. Fig. 7 (a) shows the measured voltage of the PSD at a current source frequency of 150 kHz, when electrodes 1-7 were immersed in water, 8-12 in oil and 13-20 in air. There was no foam or emulsion in this experiment. Fig. 7 (b) shows the impedance measurement at 1 MHz, when coils 1-7 were immersed in water, 8-12 in oil and 13-20 in air.

4.2. Salinity Measurement

In an oil separation process the salinity is concentrated at the bottom of the separator, because salt is easily dissolved in water and it doesn't in oil. It is assumed that it is water continues phase with oil in it. In this case an oil-in-water model in equation (1) is used to estimate the conductivity (Jaworski 2005).



(a) Effect of salt. **(b)** Effect conductivity.

Fig. 5. Effect of salt and conductivity on PSD output.

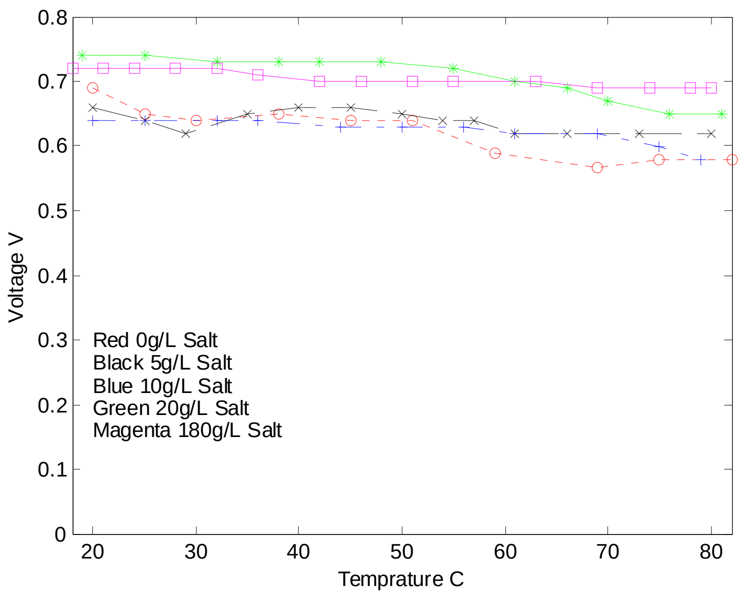
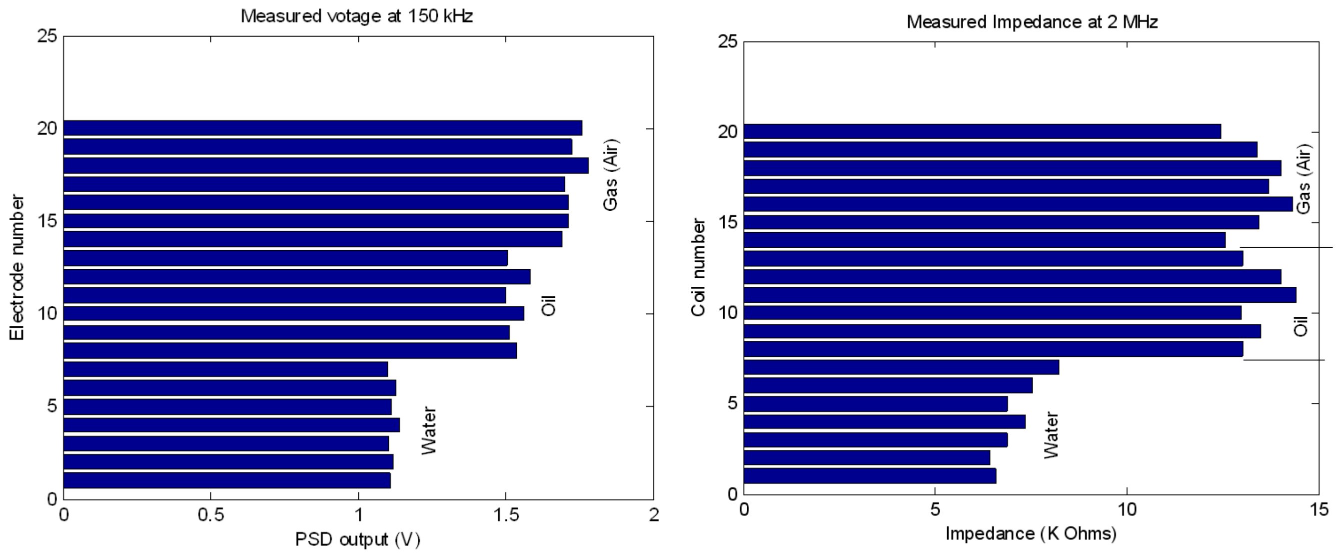


Fig. 6. Effect of temperature on PSD output.

$$\sigma_{est} = \sigma_{water} \frac{2\beta}{3-\beta}, \qquad (1)$$

where β is the water fraction at the bottom of the separator.

A simulation was conducted using COMSOL. Fig. 8 shows the relationship between percent of water and conductivity (COMSOL 2004). The relationship between the conductivity and magnetic field is linear as shown in Fig. 8. From this relationship the conductivity of the water can be calculated.



(a) PSD output profile. **(b)** Measured impedance profile.

Fig. 7. Measurement profiles.

The salinity of the water is also calculated based on the conductivity water (Perkin 1980).

$$S = \sum_{j}^{5} a_j R_T^{j/2} + \frac{(T-15)}{1+k(T-15)} \sum_{j}^{5} b_j R_T^{j/2}, \tag{2}$$

where R_T is the conductivity ratio:

$$R_T = \sigma(S,T,P)/\sigma(35,15,0), \tag{3}$$

where $\sigma(S,T,P)$ is the conductivity of the water with practical salinity S at temperature T and pressure P and $\sigma(35,15,0)$ is the conductivity of standard seawater with practical salinity 35 at 15^oC and atmospheric pressure.

$$\begin{array}{lll} a_0 = 0.0080 & b_0 = 0.0005 & k = 0.0162 \\ a_1 = -0.1692 & b_1 = -0.0056 & -2^oC \le T \le 35^oC \\ a_2 = 25.3851 & b_2 = -0.0066 & \\ a_3 = 14.0941 & b_3 = -0.0375 & \\ a_4 = -7.0261 & b_4 = 0.0636 & \\ a_5 = 2.7081 & b_5 = -0.0144, & \end{array} \tag{4}$$

In the simulation, the temperature is 20^oC and pressure is the atmospheric pressure.

5. Discussion and Conclusion

The experimental result in Fig. 4 shows that it is difficult to discriminate between the materials at low frequency. The best discrimination frequencies are between 100 kHz to 200 kHz. The effect of salt on the measurements was tested as shown in Fig. 5. There is small deviation in measurements at low salinity water and stable at high salinity water. The same conclusion can be drawn for the effect of the conductivity and temperature from Figs. 5b and 6. Figs. 4 and 7a shows that single electrode measurement method can detect also interface between water and oil clearly. The interface between oil and gas are too close to each other to be discriminated.

The existing systems for the multi-interface level measurement have problems. The capacitance type has problems with high conductive water, temperature and fouling. The electromagnetic type has problems with measuring gas and oil and cannot detect the foam layer. The ultrasonic sensors has problem with signal attenuation. This paper combines single electrode capacitance measurement method and electromagnetic sensors, to overcome the above problems.

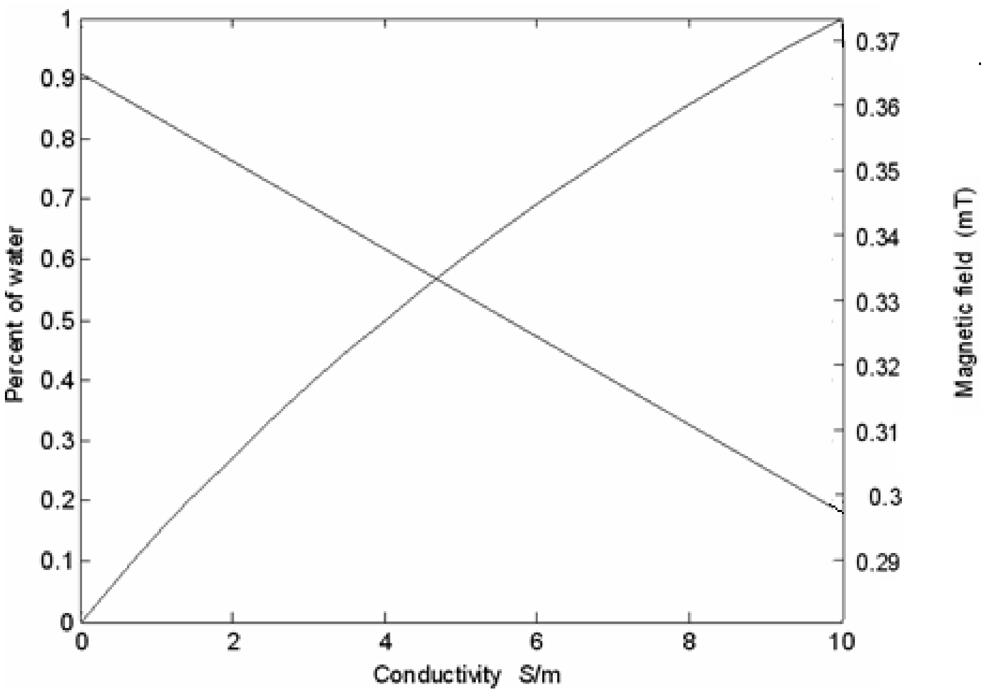


Fig. 8. Relationship between conductivity and percent of water and magnetic field.

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Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Sensor instrumentation;
- Virtual instruments;
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