

## Research Article

### Study of Liquid Mixtures Electrical Properties as a Function of Electrical Conductivity using Capacitive Sensor

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**Abstract:** In this study design and operation of a capacitive cell sensor for liquid mixture monitoring is reported. Operation of the capacitance measurement module for such probe is based on the charge and discharge method. The capacitive effect of small drop of different liquids in tap water was studied using this capacitive sensor. A small percentage of contaminating agents such as oil in tap water is determined with a good sensitivity. Comparison of the measured resistances for different liquid mixtures shows a decrease by increasing Total Dissolved Solids (TDS). In another study the electrical capacitance of different solutions, mixture of ethanol and water, mixture of methanol and water, mixture of petroleum and water and other liquid mixtures were studied. It must be pointed out that the measuring capacitance of the sensor is different from that of the liquid capacitance, but the samples electrical characteristics can be compared relatively with each other. The effects of the electrical conductivity on the permittivity and conductance of different liquid mixtures are also investigated. The experimental results are promising concerning water liquids and verify the successful operation of such device as a liquid sensor and are a useful method for checking the electrical quality of the water mixture that is required for different applications.

**Keywords:** Capacitance measurement, electrical conductivity, electrical properties, liquid mixture, sensor

## INTRODUCTION

The concentration measurement of two-component fluids using capacitance sensing techniques is sometimes affected by conductivity variations of the components. Typical examples of this problem occur in measurement of water content of oil-water mixtures in the oil industry and of glass bead concentration in water slurries in the machining industry (Strizzolo and Cinverti, 1993). The conductivity problem has been of most concern in the area of dielectric measurement. There has been a great deal of interest in the development of precise capacitive sensors in recent years (Heidari and Azimi, 2011). Different reports on the design, characterization, operation and possible applications of such devices have been given by the authors (Golnabi, 1997; Golnabi and Azimi, 2008a) and others (Ahn *et al.*, 2005; Zadeh and Sawan, 2005; McIntosh *et al.*, 2006). Capacitive sensors have been used in many industrial applications to control the processes and in machine diagnostic tasks. However several problems including stray capacitance, baseline drift, stability and sensitivity have motivated the development of new transducers and measuring systems. To alleviate some of the problems in this field concerning a variety of the capacitive sensor systems have been developed and reported (Golnabi and Azimi, 2008b). In this respect, for example, the effects of a guard ring electrode on the operation of a capacitive

transducer have been investigated (Golnabi, 2000). Development of a three-dimensional capacitance imaging system for measuring the density of fluidized beds was reported (Fasching *et al.*, 1994). In another report the design and the operation of a capacitive sensor for water content monitoring in a production line was presented (Tsamis and Avaritsiotis, 2005).

On the other hand many researchers have focused on the development of the readout circuits. The goal of such research has been to introduce a readout circuit that can be used for a low-noise operation with the cancellation of the operational amplifier 1/f-noise and offset voltage. A new capacitive-to-phase conversion technique for measuring very small capacitance changes has been reported (Ashrafi and Golnabi, 1999). This method provided a powerful mean for recording very small capacitance changes. Much progress has been made over the last years in developing the capacitor transducers and complementing the measuring circuits. For the precision in instrumentation and measurements, the small capacitances to be measured are in the range of 0.01-10 pF with a required resolution of better than 0.01-10 fF. This requirement along with other considerations such as environmental effects, structural stability and standardization challenges the development of a much more sensitive and reliable capacitance sensor systems (Woodard and Taylor, 2007).

## ELECTRICAL CONDUCTION

A point charge at rest produces the electrostatic field and electric potential around it and moving charges constitute a current and thereby the charge that is transported is called conduction. The electric current is defined as the rate which, charge is transported past a defined point in a conducting system. In a metal, the current is carried by electrons, while the heavy positive ions are fixed at regular positions in the metallic crystal structure. It must be mentioned that only the valence atomic electrons are free to move and participate in the conduction process; while the other electrons are tightly bound to their ions. In general, an electric current arises in response to an applied electric field or an electric potential difference.

If an electric field is imposed on a conductor, it will cause a positive charge that carries to move in the direction of the field and a negative charge that carries in the direction opposite to the field; hence all currents produced in this process have the same direction as the electric field. The charge carries as falling into groups, each of which has a common motion called the drift motion (velocity) of the group. Such currents are known as conduction currents; however currents arising from mass transport (hydrodynamic motion) are called convection currents that may occur in liquids and gases. Convection currents are important to the subject of atmospheric electricity in the thunderstorm's process. In an electrolyte solution, when an external electric field is applied to the object the current is carried out by both positive and negative ions, although, because some ions move faster than others, conducting by one type of ions usually predominates. It is noted that positive and negative ions traveling in opposite directions in such a medium contribute to the unified current in the same direction.

A steady-state conduction problem can be solved in the same way as an electrostatic problem. Consider a homogeneous, isotropic medium characterized by conductivity  $g$  and permittivity  $\epsilon$ . Steady-state conduction problem may be solved in the same way as electrostatic Laplace's equation. Consider two separate metallic conductors in a homogeneous, isotropic and ohmic medium of moderate conductivity,  $g$ , like a salt solution. If the metallic conductors are maintained at the potentials  $U_1$  and  $U_2$ , then the current flow,  $I$ , between two electrodes is given by:

$$I = \frac{U_1 - U_2}{R} \quad (1)$$

where,  $R$  is the resistance of the medium. Such a current may be considered as the steady-state current in a medium without a source of electromotive force.

Now consider the produced electric current in the inhomogeneous medium. Let us consider a conduction

object composed of ohmic material, but which is not necessarily as before homogeneous, so that the conductivity  $g$  is independent of the local electric field but vary from point to point in the medium. For this case instead of a constant conductivity factor,  $g$ , we must consider  $g(x, y, z)$ . Suppose two points on the boundary of the conducting object are maintained at the potentials  $U_1$  and  $U_2$ , respectively. The current lines for such a medium from Ohm law follow those of the local electric field ( $\vec{J} = g\vec{E}$ ) and the equipotential surfaces intersecting the current lines at right angles are not necessarily parallel to each other in this medium. In this case actually we can consider a large resistance network constructed from many elemental resistors  $R_i$  in the shape of short wire segments. According to the resistance formula for a resistor we have:

$$R_i = \frac{l_i}{g_i A_i} \quad (2)$$

where,

$g(x, y, z)$  = The local conductivity

$A_i$  = The cross-sectional area of the segment

$l_i$  = The distance between the equipotential surfaces

In the limiting case where the number of the equipotential surfaces between  $U_1$  and  $U_2$  becomes very large and the number of elemental resistors becomes correspondingly large, the resistors  $R_i$  fill the entire space occupied by the conducting object. Thus such a network has an equivalent resistance  $R$  that can be considered in Eq. (1).

The generated electric current may be written in terms of the current density,  $J$ , in the medium such as:

$$I = \oint_S \vec{J} \cdot \hat{n} da \quad (3)$$

where,

$S$  = Any closed surface, which completely surrounds one of the conductors

$\hat{n}$  = The surface unit vector perpendicular to surface element

But we have ( $\vec{J} = g\vec{E}$ ) and by combining Eq. (1) and (3) one obtains:

$$\frac{U_1 - U_2}{R} = g \oint_S \vec{E} \cdot \hat{n} da \quad (4)$$

On the other hand, if the identical electric field were produced by an electrostatic charge,  $Q$ , on the two metallic conductors, then by Gauss law (assuming very long conductors) we can write:

$$\oint_s \vec{E} \cdot \vec{n} da = \frac{Q}{\epsilon} \quad (5)$$

where,  $\epsilon$  is the permittivity of the medium and in this condition two conductors form a capacitor with the charge value of:

$$Q = C(U_1 - U_2) \quad (6)$$

And by the insertion of Eq. (6) and (5) into (4) we can write:

$$RC = \frac{\epsilon}{g} \quad (7)$$

This is a relation between the equivalent resistance of the medium and the effective capacitance of the electrostatic problem.

Let us now consider the approach to an electrostatic equilibrium in a conductive object. The question is how we describe the effect of the extra charge on a conductor. It is shown that the excess charge on a conductor resides on its surface. This is of course shows the equilibrium situation and for a good metallic conductor the attainment of the equilibrium is extremely rapid. The poorer the conductor, the slower is the approach to an electrostatic equilibrium. In fact if the conductivity of the metal is extremely low, it may take years or even longer to reach the electrostatic equilibrium. As before consider a homogeneous, isotropic medium characterized by conductivity  $g$  and permittivity  $\epsilon$ , which, has a volume density of a free charge  $\rho(x, y, z)$ . If this conducting system is suddenly isolated from the source of emf and time-dependent electric field, it will tend toward the equilibrium situation where there is no excess charge in the interior of the system. According to the equation of the charge continuity:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \vec{J} = 0 \quad (8)$$

Which with the aid of Gauss' law can be written as the relation to the source of the field according to Maxwell equation and we have:

$$\frac{\partial \rho}{\partial t} + \frac{g}{\epsilon} \rho = 0 \quad (9)$$

And the solution of this partial differential equation is:

$$\rho(x, y, z) = \rho_0(x, y, z) \exp(-gt / \epsilon) \quad (10)$$

From Eq. (10) it is observed that the equilibrium state is approached exponentially. It is also evident that the quantity  $\epsilon/g$  has the time dimension and it is called

time constant or relaxation time,  $t_c$ , of the medium, so one can write:

$$t_c = \frac{\epsilon}{g} = \epsilon \eta \quad (11)$$

where,  $\eta$  is defined as resistivity of the medium (ohm-m). Time constant is a measure of how fast the conducting medium approaches the electrostatic equilibrium; precisely, it is the time required for the charge in a specific region to decrease to 1/e of its original value.

A material will reach its equilibrium charge distribution in a specific application when its time constant is much shorter than the characteristic time required to make the pertinent measurement. For some applications a time constant of less than 0.1s is sufficient to ensure conductor like behavior; since more permittivities fall into the range  $\epsilon_0$  to  $10 \epsilon_0$ , this requires a material with resistivity  $\eta$  less than  $10^9$  or  $10^{10}$  ohm-m. For high-frequency applications a shorter time constant and a correspondingly smaller resistivity, are required for the true conductor like behavior. In fact:

$$t_c \ll \frac{1}{f} \quad (12)$$

The Eq. (12) must be satisfied in which  $f$  the highest frequency is involved in the experiment.

In general the complex permittivity of a medium can be written as:

$$\epsilon = \epsilon' + j\epsilon'' = \epsilon' + j \frac{g}{\omega} \quad (13)$$

where,

$\epsilon'$  = The real

$\epsilon''$  = The imaginary part of the permittivity

$\omega$  =  $2\pi f$

The condition for a good conductor medium is that the imaginary part to be much larger than the real part, i.e.:

$$\left( \frac{g}{\epsilon' \omega} \right)^2 \gg 1 \quad (14)$$

where,  $g$  is the conductivity. For a good dielectric medium the given ratio must be much less than unity. For the metallic conductive materials the conductivity is high (for copper  $5.88 \times 10^7$  mho/m or S/m) while for the good dielectric medium the permittivity is high.

## EXPERIMENT

The experimental setup, measurement method, materials and sample preparations are described in this section.

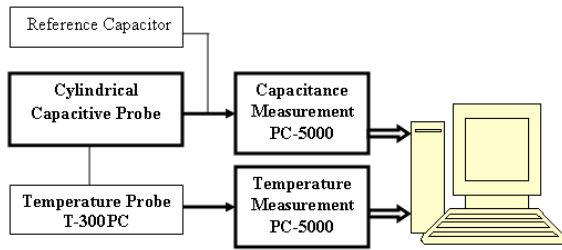


Fig. 1: Block diagram of the experimental arrangement for capacitance measurements

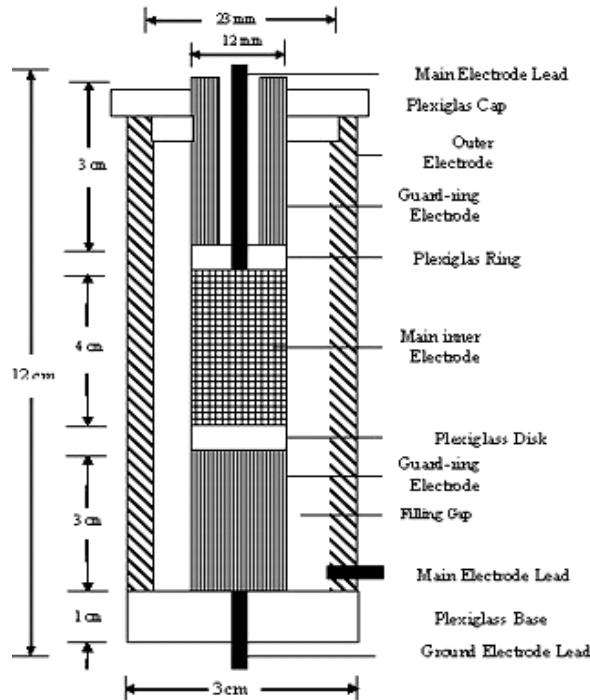


Fig. 2: Diagram of the designed cylindrical capacitive sensor

**Setup:** Capacitance measurement system in general includes a sensing probe and a measuring module. Our experimental setup is a simple one, which uses the capacitive sensing probe and the measuring module as shown in Fig. 1. The experimental arrangement includes the cylindrical capacitive sensor, two Digital Multi-meter (DMM) modules (SANWA, PC 5000), a reference capacitor and a PC. As shown in Fig. 1, one of the digital multi-meters is used for the capacitance measurement and a similar one together with a temperature probe (T-300PC) is used for the temperature measurements. The DMM has features such as the real time graphic display with a scale grid, real-time display of MAX&MIN values with time stamp and current measuring window (Sanwa Electric Instrument Co.).

It provides more functions with optional accessories such as temperature probe that is used in this experiment. The software (PC Link plus) allows one to

log measuring data into PC through RS232 port with digital multi-meter PC series. The operation of this software is possible by using any operational system such as the windows 98, NT4.0/2000/ME/XP/VISTA/7 versions. It provides a function for capacitance measurements using the charge/discharge method and capacitance in the range of 0.01 nF to 9.99 mF, which can be measured with the best nominal accuracy of  $\pm (0.8\% \text{ rdg} + 3)$  and a resolution of about 0.01nF. The temperature probe consists of a platonic thin thermo-resistor ( $1000 \Omega$  at  $0^\circ\text{C}$ ) with a temperature measurement range of  $-50$  to  $300^\circ\text{C}$ . The response time of this probe is about 7 sec and offers an accuracy of about  $\pm 0.1^\circ\text{C}$  in temperature recording.

The proposed capacitive probe shown in Fig. 2 consists of a three-part coaxial capacitive sensor in which the middle one is acting as the main sensing probe and the other two capacitors considered as the guard rings in order to reduce the stray capacitance effect and the source of errors in measurements (it must be mentioned that such design is more useful for the case of small capacitance change measurements). As shown in Fig. 2, in this experiment a cylindrical geometry is chosen and aluminum materials are used as the capacitor tube electrodes. The diameter of the inner electrode is about 12 mm and the inner diameter of the outer electrode is about 23 mm and has a thickness wall diameter of about 3.5 mm. The overall height of the probe is about 12 cm while the active probe has a length of about 4 cm. The radial gap between the two tube electrodes is about 5.5 mm and the overall diameter of the probe is about 3 cm. The length of the employed wire connection to the inner active electrode is about 5 cm. As shown in Fig. 2, the middle active part of the probe has a length of 4 cm and outer guard electrodes have a length of about 3 cm. Using Gauss's law the capacity of a long cylindrical capacitor can be obtained from:

$$C = \frac{2\pi\epsilon L}{\ln \frac{b}{a}} \quad (15)$$

where,  $\epsilon$  is the permittivity of the gap dielectric medium. Here  $a$  is the inner electrode radius,  $b$  outer electrode radius and  $L$  is the capacitor length. However Eq. (15) is only valid when  $L \gg a, b$ . Several problems such as edge effect can cause deviation in the actual capacity from the given formula in Eq. (15). For this reason, various attempts have been made to reduce errors due to limited size effects. One simple remedy has been the use of a Kelvin guard-ring (Golnabi, 2000) in which the main inner electrode is shielded by a grounded guard-ring electrode.

**Measurement method:** Depending on the capacitance electrode configuration of the sensor the equivalent circuit can be considered for the case of invasive (direct

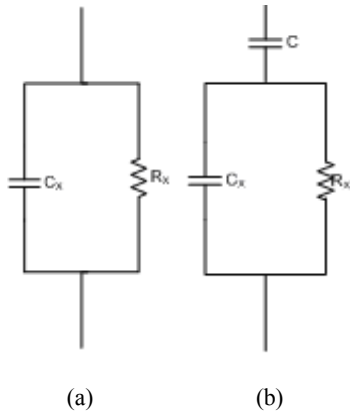


Fig. 3: Equivalent circuits for the invasive (a) and non-invasive (b) electrode arrangements

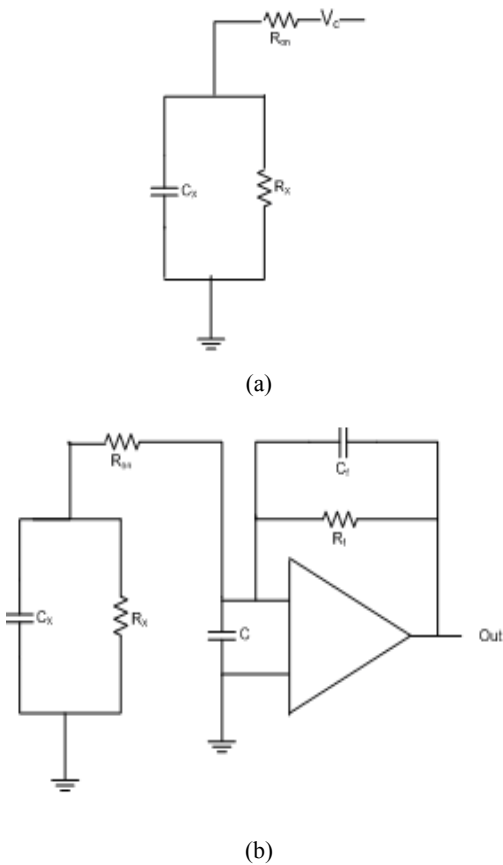


Fig. 4: Schematics of the capacitance charge (a) and discharge (b) processes

contact between the metal electrode and liquid) and non-invasive (no contact between the metal electrode and liquid) sensors. In a simple form if we consider a uniform liquid with the given permittivity and conductivity, the equivalent circuits for the case of non-invasive and invasive sensors can be considered.

It must be mentioned that the given capacitance value is the measured value by the charge transfer

reading circuit and fluid capacitance must be deduced from the measured values. Also noted that the capacitance sensing is affected by the conductivity variations of the components. This conductivity problem has been the main concern in the field of dielectric measurements and several attempts have been made to compensate for such variations and for a simple case the effect of conductivity is presented by a resistive element in parallel with the sensor capacitance. However, for sensors using non-invasive electrodes and those measuring two-component fluids, the sensor system must be represented by more complex equivalent circuit models. As a result an investigation into the effects of component conductivity should be done for precise measurements.

Equivalent circuits for the invasive and non-invasive cases are shown in Fig. 3a and b, respectively. In the invasive situation when there is a contact between the metal and the liquid it is equivalent to a circuit consisting of a capacitor  $C_x$  in parallel with a resistor  $R_x$ . In this analysis  $R_x$  representing the resistance of the fluid due to its conductivity effect and  $C_x$  shows its capacitance as a result of its permittivity. For the non-invasive case as shown in Fig. 3b an extra capacitor  $C$  is considered in series with  $R_x$  and  $C_x$ , which are acting in parallel. As can be seen, measured capacitance element is depending on both  $C_x$  and  $R_x$  of the fluid under measurement.

In general a variety of techniques have been employed for measuring the absolute and relative capacitance changes. Oscillation, Resonance, charge/discharge, AC Bridge and capacitive-to-phase conversion are the most common methods for such capacitance measurements. Since the measurement module uses the Charge/Discharge (C/DC) circuit, therefore, this method is described here. The charge/discharge operation is based on the charging of an unknown capacitance under study  $C_x$  to a voltage  $V_c$  via a CMOS switch with resistance  $R_{on}$  (Fig. 4a) and then discharging this capacitor into a charge detector via a second switch (Fig. 4b).

A DMM with the given specification based on the charge discharge operation is used here for the capacitance measurements. This capacitance measuring module is capable of measuring precisely the capacitance values in the range of 0.01 nF to 50 mF.

The capacitance measurements for the cylindrical capacitive probe shown in Fig. 1 depend on the permittivity,  $\epsilon$ , of the liquid and its resistance factor that depends only on the conductivity,  $g$ , of the liquid. Thus one can write:

$$C_x = f_1(\epsilon) \tag{16}$$

$$R_x = f_2(g) \tag{17}$$

The capacitive element  $C$  is obtained only by the insulation of the electrodes and reducing the conductivity effect. As described, in general there are

invasive and non-invasive electrode arrangements. For the case of non-invasive sensors, in measuring the capacitance of a liquid, the effect of resistive component is usually very small because of the dielectric insulator. For the invasive sensors the effect of  $R_x$  on the measurement of  $C_x$  cannot be neglected and the effect of conductivity of the liquid must be considered in our analysis. However, the effect of  $R_x$  can be negligible if the on-resistance of the charge switch  $R_{on}$  is small compared with  $R_x$  and if the discharge time, which is determined by the switching-on time of the resistance of the discharging switch, is short compared with the time constant given by  $R_x C_x$ .

To analyze the electrical conduction of the tested liquid mixtures, additional measurements were made on the Electrical Conductivity (EC) and the Total Dissolved Solid (TDS) density of the samples used in this experiment. In conductivity meters usually measurements are made by placing a cell (probe) in a solution. The cell consists of two electrodes of specific sizes, separated at a specific distance that defines the cell K factor. The conductivity of a liquid is determined from the ratio of the current to the voltage between the two electrodes.

For measurements a conductivity meter (Hach Company, 2001) is used, which is useful for a variety of applications such as water quality, measuring salinity (a measure of dissolved salts in a given mass of solution), acids, bases and other qualities of aqueous samples. The meter features a digital LCD display that simultaneously displays the temperature and other measurement results. The specifications of this meter are as follows: Conductivity range of 0-199.9 mS/cm and resolution of 0.01  $\mu$ S/cm to 0.1 mS/cm, respectively, for the selected measurement ranges. The ranges for TDS are: 0-50 g/L with a resolution of 0.1 mg/L to 0.1 g/L for different ranges. Measurement range for salinity is 0-42 ppt with a resolution of  $\pm 0.1$  ppt and an accuracy of  $\pm 0.1$  ppt. The measuring temperature range is from -10 to 105°C. The accuracy for conductivity is  $\pm 0.5\%$  of range, for TDS is  $\pm 0.5\%$  of full scale and for temperature is  $\pm 0.3^\circ\text{C}$  for 0-70°C and  $\pm 1.0^\circ\text{C}$  for 70-105°C.

**Samples and procedures:** Fortunately this experiment does not require many reagents and complicated chemical procedures for sample preparation. In this experiment one type of samples was used including the Two-phase solutions. The Two-phase solution includes the mixture of antifreeze and water, mixture of ethanol and water, mixture of methanol and water, mixture of petroleum and water, mixture of oil and water and mixture of consumed oil and water samples. All other agents and liquids were at regular grade purchased from the related suppliers.

## RESULTS

Since the minimum reliable limit of DMM is about 0.01 nF, therefore the results for air reading were not so

reliable and as mentioned a parallel reference capacitor is used as indicated in Fig. 1. However, when the gap is filled with a liquid, since the dielectric constant of the fluid is larger than that of the air, then the measured capacitance value is increased and the reference capacitance is not necessary. As described, our measuring apparatus is operating under the charge/discharge technique.

In order to test the precision of the capacitance measuring module, in the first experiment the capacitance of a known reference capacitor is measured. For a capacitor with the nominal value of 470 nF the average measured capacitance for this reference is about 494.2 nF. The extra value of the capacitance is most likely due to the lead probe capacitance, which is added to the capacitance of the reference capacitor. As mentioned the best accuracy of the DMM for capacitance measurement is about  $\pm (0.8\% \text{ rdg} + 3 \text{ dgt})$  which are  $\pm 3.4$  nF for 50 nF,  $\pm 7.0$  nF for 500 nF and  $\pm 4$   $\mu$ F for 50  $\mu$ F range.

As described the averaged measured capacitance for the reference capacitor is found to be 492.5 nF and after this investigation the air gap capacitance of the sensor was investigated. The averaged air gap capacitance of the probe when it is parallel with the reference capacitor is around 497.5 nF. By subtracting the value of the reference capacitance, thus the air gap capacitance for the designed probe is about 5 nF. However, as described this value is different from the calculated value of 3.6 nF from Eq. (15). It must be pointed out that Eq. (15) is obtained with the assumption that the length of the probe is much higher than its gap, which is not satisfactory for our probe; therefore the observed difference looks reasonable.

In the next study to see the capacitance variations of the different water solutions a series of measurements are performed and results are shown in Fig. 5. As can be seen in Fig. 5, the mixture of methanol and water shows the lowest measured value and the mixture of antifreeze and water shows the highest (24.6  $\mu$ F) value among the tested liquids. As described conductivity of the liquid material has an important role in the capacitance measurements and as a result in sensor operation. From Fig. 5 two major points can be concluded. First, the measured capacitance value recorded by the module is not only the liquid capacitance but also the capacitance due to the liquid conductance. Thus the present probe provides a sensitive cell for the investigation of the conductance effect in such measurements. Among the tested water liquids the mixture of antifreeze and water shows the highest measured capacitance value of 24.6  $\mu$ F while the mixture of methanol and water shows the lowest measured value of 13.8  $\mu$ F. Considering a notable difference (10.8  $\mu$ F) in capacitance values for the different water liquids, which is indicative of the high sensitivity of the reported sensor.

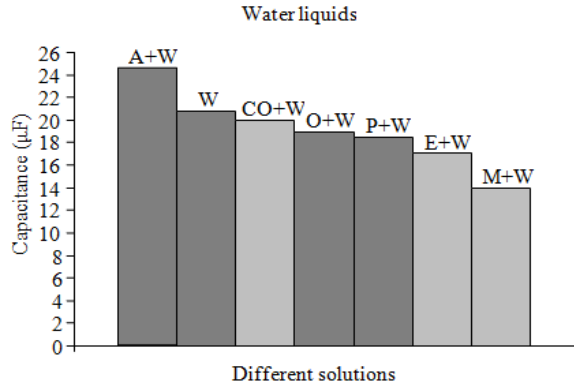


Fig. 5: Comparison of the electrical capacitance values for solutions

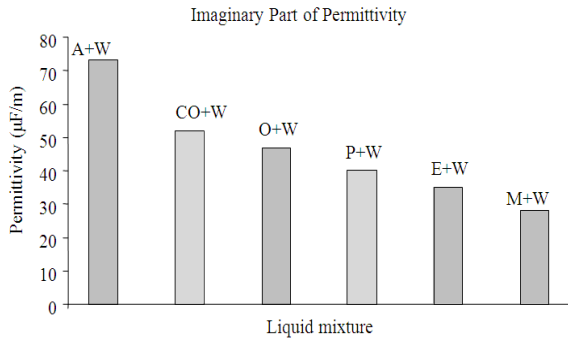


Fig. 6: Comparison of the imaginary part of the permittivity values for different liquid mixtures

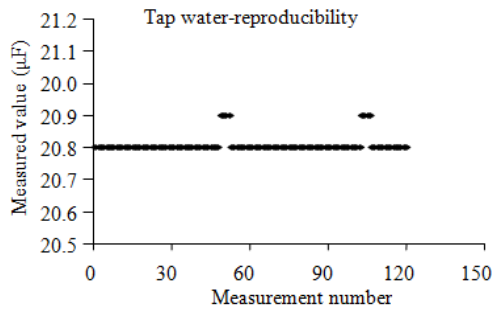


Fig. 7: Reproducibility of the results for the sensor

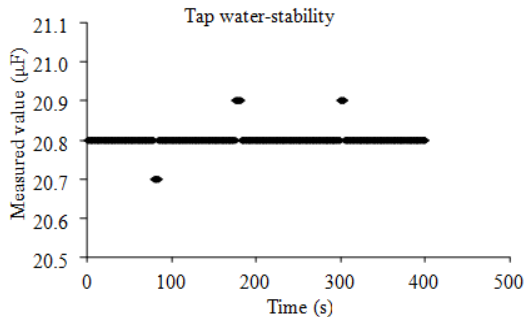


Fig. 8: Time stability of the reported sensor system

Table 1: Comparison of the electrical properties for different water liquids

Sample	EC (µs/cm)	TDS (mg/L)	C (µF)	VPA (%)	T (°C)
A+W	1491.3	780.1	24.8	33.00	25.0
CO+W	521.2	312.8	20.1	33.00	24.8
O+W	471.1	248.6	19.2	33.00	24.9
P+W	442.0	212.6	18.0	33.00	24.9
E+W	378.9	194.2	16.8	33.00	25.1
M+W	182.5	178.5	14.2	33.00	25.0
W	620.3	272.3	20.8	33.00	25.1

To understand the importance of the permittivity variation as a result of different solutions, in Fig. 6 we consider the measured values for different liquid mixtures. As indicated in Fig. 6 the average permittivity values given for different samples are 72.85, 51.23, 46.13, 39.20, 34.17, 27.33 µF/m, for the mixture of antifreeze and water, mixture of consumed oil and water, mixture of oil and water, mixture of petroleum and water, mixture of ethanol and water and mixture of methanol and water.

In Fig. 7 the repeatability of the results for the reported capacitive cell sensor is shown. Such parameter indicates the ability of the sensor to reproduce output reading when operating under the same ambient condition. To provide such a condition a number of 150 measurements were made consequently for a series of readings. Such measurements are performed for all the samples and for the case of tap water-gap are shown in Fig. 7. The reproducibility of the measured values for such consequent measurements is estimated to be about 1% of the full scale value.

The stability of a sensor is another important parameter, which is described in this section. Such factor shows the Stability of the sensor to maintain its performance characteristics for a certain period of time. In this experiment the capacitance values for liquid-gap (tap water) is measured for a period of 400 sec in 10 sec increment. The result of such study is shown in Fig. 8. As can be seen measured values show a good stability for this period of time, which is about 1.3% of the full scale. Since the response time of the sensor is in the order of a few seconds, therefore, the output fluctuation is negligible for such a short period of time. To look at the source of instability, it is noted that the major source of such fluctuations could be as a result of the ambient condition variation and the fluctuation of the stray capacitances.

A comparison of the results for different liquid mixtures at given temperature is listed in Table 1. The Electrical Conductivity (EC), Total Dissolved Solid (TDS), Capacitance (C), Volume Percentage Additive (VPA) and Temperature (T) are listed in Table 1. As can be seen in Table 1. For the samples, the EC factor is increased as well as the TDS in the given order for the tested liquid mixtures. Considering the capacitance value with the EC values confirms our argument about the effect of the electrical conductance on the capacitance measurements. It is noted that there is a relation between the increase of the electrical

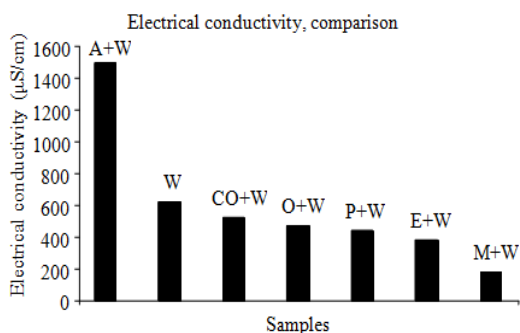


Fig. 9: Comparison of the electrical conductivity values for different samples

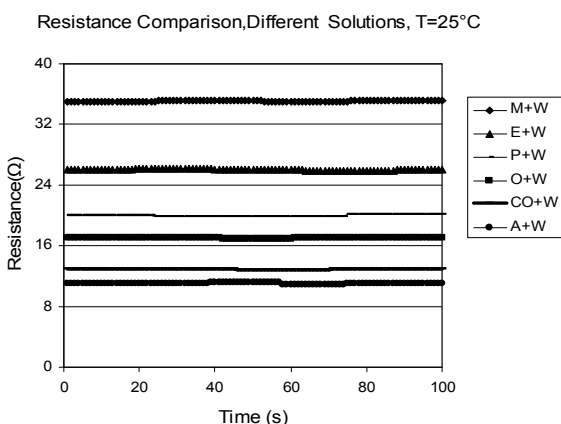


Fig. 10: Comparison of the resistance values for different solutions as a function of time.

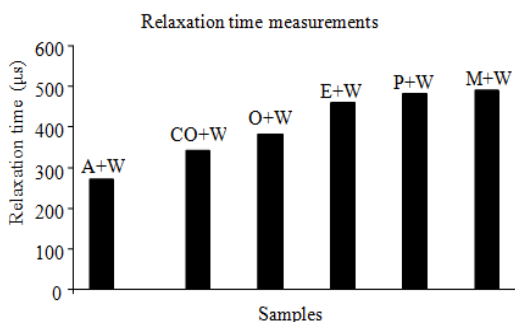


Fig. 11: Time constant values for different liquid mixture samples

conductivity of the liquids and the increase of the measured capacitance. Looking at Fig. 9, it is noted that the mixture of antifreeze and water poses the highest EC value of 1493  $\mu\text{S}/\text{cm}$  while the mixture of methanol and water shows the least EC value of 180  $\mu\text{S}/\text{cm}$  at the same temperature.

In the next study, to see the resistance variation of the different water mixtures containing foreign agents, a series of measurements are performed. In Fig. 10 a comparison of the measured resistance values for the

liquid mixtures is presented. All measurements for the mixtures are for the base solution of tap water at a temperature of 23°C. The measured value for the mixture of methanol and water is 34.35  $\Omega$  while all the mixtures except the tap water as can be seen in Fig. 10 show lower values. Among all the mixtures antifreeze + water shows the lower value of 10.8  $\Omega$  while for the mixtures methanol + water it is about 34.35  $\Omega$ . The measured value for the mixtures oil + water sample is about 17.4  $\Omega$ . One interesting point is in this study is a comparison of the water containing the fresh oil and water mixture with the same type of consumed oil after the usage. The results displayed in Fig. 10 indicate that the cell sensor can be used to recognize different mixtures by comparing the results with that of a known standard water sample.

By measuring the resistance and capacitance values simultaneously the relaxation time for different liquid mixtures are measured experimentally. From Eq. (7) it was shown that the ratio of permittivity to conductivity is equal to the product of the RC value. In this experiment using specific module both C and R measured and such products for the cell probe are shown in Fig. 11 as described such relation time the measure of the conduction relaxation and for a good conductor such time is very short. as can be in Fig. 11, the relaxation time for the mixture of methanol and water is about 488.36  $\mu\text{s}$ , for the mixture of ethanol and water 458.56  $\mu\text{s}$ , for the mixture of petroleum and water 481.25  $\mu\text{s}$ , for the mixture of oil and water 379.22  $\mu\text{s}$ , for the mixture of consumed oil and water 341.68  $\mu\text{s}$  and finally for the mixture of antifreeze and water 270.25  $\mu\text{s}$ . From the obtained results it is noted that for the mixture of antifreeze and water takes a very short time of about 270  $\mu\text{s}$  to establish a stabilized conductor-like behavior while for the mixture of methanol and water longer time of about 490  $\mu\text{s}$  is required to reach such a condition. As expected the results clearly show the conductance effect of the tested liquid samples.

## CONCLUSION

The goal here was to introduce a capacitance sensor for liquid mixture monitoring and to study the role of a foreign agent in the capacitance and conductivity measurements. The invasive sensor such as the one reported here provided a useful mean to study the conductance effect of the reactance capacitance and its role in capacitance measurements. For the case of a gap material with low conductivity the charge/discharge method was used with the proposed cylindrical probe to measure the capacitance. This was a useful method for the checking of the quality of the water mixtures, which is required for different applications. The next objective was to recognize different water mixture liquids as a result of such capacitance measurements.



Although the results reported here were for the liquid mixtures, but the reported sensor could be effectively implemented for the study of other conducting liquids such as industrial oils and liquid mixtures, which have wide applications as lubricator, electric insulator and cooling agents with a notable conductance contribution. Arrangements described also can be used for liquid mixture checking and also to see effect of impurities in the water solution.

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