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Investigation of Conductivity Effects on Capacitance Measurements of Water Liquids Using a Cylindrical Capacitive Sensor

¹G. Behzadi and ²H. Golnabi

¹Plasma Physics Research Center, Science and Research Branch,
Islamic Azad University, P.O. Box 14665-678, Tehran, Iran

²Institute of Water and Energy, Sharif University of Technology,
P.O. Box 11155-8639, Tehran, Iran

Abstract: In this study by using a Cylindrical Capacitive Sensor (CCS), the Electrical Conductivity (EC), effects on the capacitance measurements of the water liquids was investigated. Theoretical values of the capacitance measurements of water liquids with the cylindrical length in the range 0.5-5 cm are calculated. Our obtained results indicate that measured capacitance value by CCS depends on the liquid capacitance and reactance capacitance. Liquid capacitance value of the distilled water for permittivity of 80 is about 33.5 pF and reactance capacitance value is about 0.290 μ F, when the cylindrical length value is about 1.6 cm. The reactance capacitance for the mineral, tap and dilute salt water liquids are also investigated in this study. The reactance capacitance value of 22.80 μ F for the mineral water, 37.50 μ F for the tap water and 47.80 μ F for the dilute salt water obtained when the cylindrical length value is about 1.6 cm. A comparison of our obtained result indicated the liquid capacitance value in the capacitance measurement is negligible. A comparison of the theoretical and experimental values shows that theoretical values are smaller than the experimentally measured values that due to the stray capacitances. The minimum error is about 3.3% for distilled water and maximum error is about 12.9% for salt water. Hence, the reported CCS provides a high sensitivity to determine the reactance capacitance value for the different water liquids with low EC.

Key words: Electrical conductivity, cylindrical length, reactance capacitance, water, liquid capacitance

INTRODUCTION

Capacitive sensors can be used in different applications for measuring a variety of parameters (Golnabi, 1997; McIntosh *et al.*, 2006; Kasten *et al.*, 2000; Moe *et al.*, 2000; Ahn *et al.*, 2005). In a report capacitance sensors for measurement of phase volume fraction in two-phase pipelines are investigated (Strizzolo and Converti, 1993). The effect of phase distribution or flow pattern was considered for determination of the volume fraction in two phase pipe-line by using the capacitance measurements. They have shown that the capacitance measured depends not only on the volume fraction but also on the phase distribution and they have shown such effect by an example. Due to their inherent simplicity and low cost they also have found many industrial applications (Guo *et al.*, 2000; Shuangfeng *et al.*, 2008). Much emphasis has been placed on the works to construct a sensor with output capacitance, which varies linearly with the measured variable. Recently some researchers investigate on the EC and dielectric

permittivity effects on capacitance measurement of water using capacitive sensors. The conductivity effects on the capacitance measurements of two-component fluids using the charge transfer method for capacitance measurements has been reported by Huang *et al.* (1988). The goal of such research has been to introduce effects of conductive elements on the measurement of these models are analyzed theoretically and tested experimentally using a capacitance transducer based on the charge transfer method. In another report, the differential charge-transfer readout circuit for multiple output capacitive sensors has been reported by Rodjgard and Loof (2005). This study provides a true differential, low-noise readout scheme for multiple output capacitive sensors. It overcomes the restrictions with multiple sense capacitors connected to a common node that is common in micro machined gyroscopes and multiple axis accelerometers. The comparison of the use of internal and external electrodes for the measurement of the capacitance and conductance of fluid in pipes has been reported by Stott *et al.* (1985). The analysis of this study shows that for external

electrodes the measured capacitance is dependent on both the conductivity and the permittivity of the fluid and that even for liquids with low or zero conductivity that sensitivity of the measurement falls away as the permittivity rises. In another report the dielectric permittivity, conductivity and loss tangent of water were measured with capacitive sensor for different thicknesses of the sample and for various oscillator levels was given (Rusiniak, 2000). In a report estimating water content in soil from electrical conductivity measurements with short Time Domain Reflectometry (TDR) was given (Persson and Haridy, 2003). Applications of the capacitance type sensors for measurement of water content of different materials have been reported. For example design of a planar capacitive sensor for water monitoring in a production line was reported by Tsamis and Avaritsiotis (2005). The primary contribution of the present study is the investigation of EC effects on the capacitance measurement of water liquids by CCS.

MATERIALS AND METHODS

The reported experiment was conducted in Institute of Water and Energy as part of research program of the Sharif University of Technology for the period of 2007-2009. Design and performance of a CCS to monitor the electrical properties of liquids was introduced in a recent report and simultaneous measurements of the resistance and capacitance by using a cylindrical sensor system was reported by Golnabi and Azimi (2008a). In the following study monitoring temperature variation of reactance capacitance of water using a cylindrical Cell Probe was reported by Behzadi and Golnabi (2009). The proposed capacitive probe shown in Fig. 1 consists of a three-part coaxial capacitive sensor in which the middle one (A) 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 source of errors in measurements (C, D). As shown in Fig. 1, 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 (B) is about 22 mm and has a thickness wall diameter of about 4 mm. The overall height of the probe is about 100 mm while the active probe has a length of about 16 mm. The radial gap between the two tube electrodes is about 5.5 mm and the overall diameter of the probe is about 30 mm. The length of the employed wire connection to the inner active electrode is about 50 mm. As shown in Fig. 1, the middle active part of the probe has a length of 16 mm and outer guard electrodes have a length of about 37 mm. The

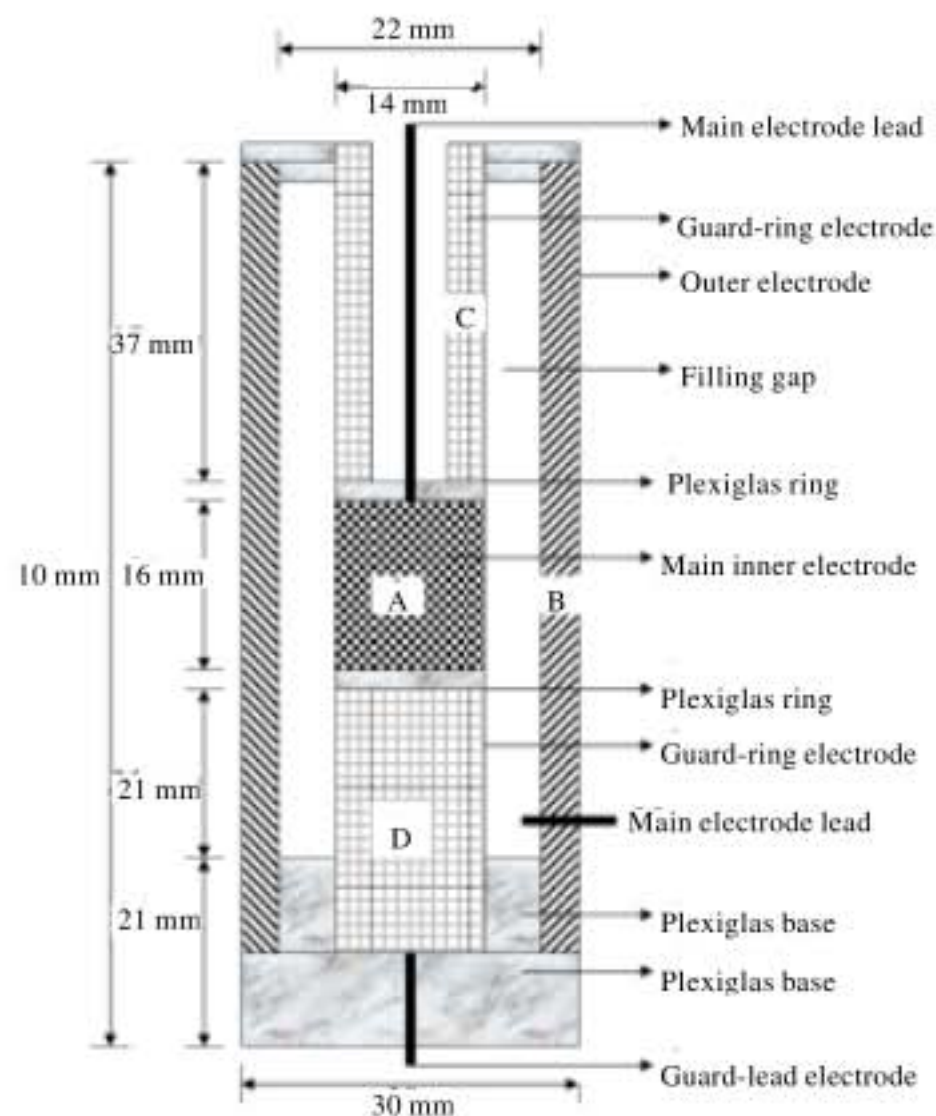


Fig. 1: Design of the cylindrical cell probe

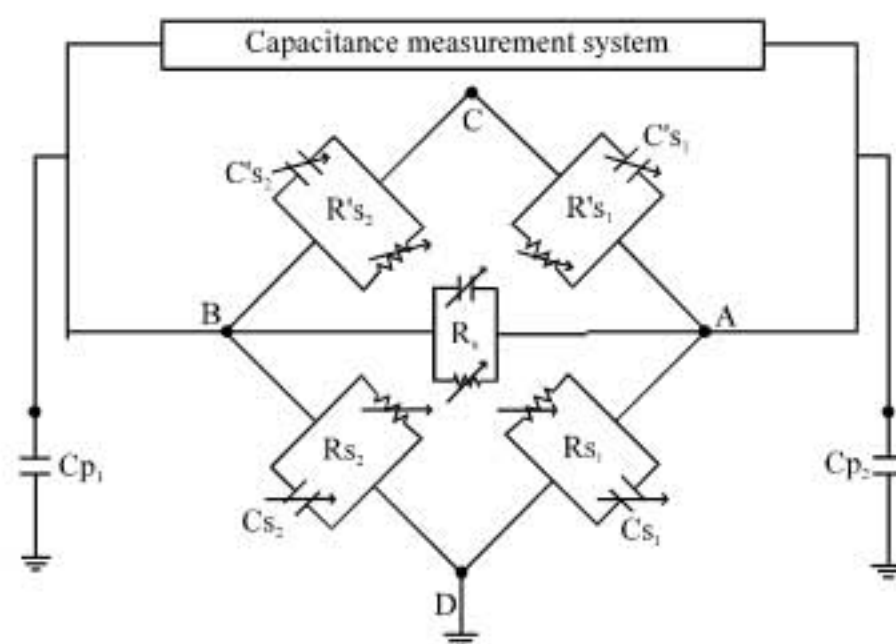


Fig. 2: Equivalent circuit of the cylindrical cell probe

equivalent circuit of cylindrical cell probe as shown in Fig. 2 consisting of a capacitor C_x in parallel with a resistor R_x . In this analysis, R_x represents the resistance of the fluid due to its conductivity effect and C_x shows its capacitance as a result of its permittivity. The stray capacitances between the electrodes are (C_{s1} , C_{s2} , C'_{s1} , C'_{s2}), that they are parallel with the resistors (R_{s1} , R_{s2} , R'_{s1} , R'_{s2}). The stray capacitances (C'_{sb} , C'_{s2}) due to connection the water liquids with the outer guard electrode (C) and (C_{s1} , C_{s2}) due to connection with the inner guard electrode (D). The measured values for the consequent

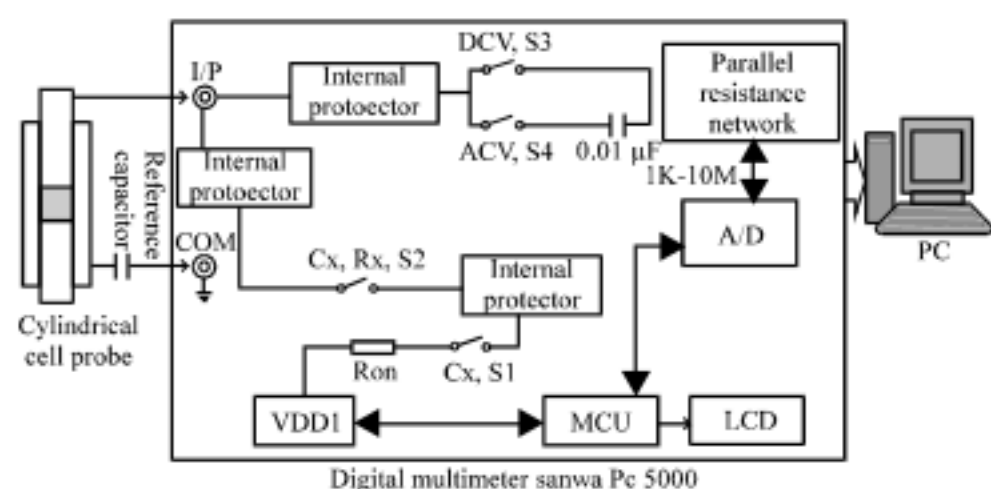


Fig. 3: Block diagram of the experimental setup for the capacitance measurements

measurements of the tap water of (C_{S1} , C_{S2}) is estimated to be about 8.5% and (C_{S1} , C_{S2}) is estimated to be about 1.67% of the full scale. Their values for different water liquids may not be constant and depends on EC of liquids. By increasing in the EC the stray capacitance is increased. For the dilute salt water with EC value about $831 \mu\text{S cm}^{-1}$ the stray capacitance of (C_{S1} , C_{S2}) is about 11.23% of the full scale and for the distilled water with EC value about $4.2 \mu\text{S cm}^{-1}$ the stray capacitance of (C_{S1} , C_{S2}) is about 1.63% of the full scale. Other strays may arise from the parasitic capacitances C_{P1} and C_{P2} of the capacitance measuring electronics connected to the sensor. The value of C_{P1} and C_{P2} usually ranges from a fraction to a few tens of pF. 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. 3. It includes the cylindrical cell probe, a reference capacitor and a digital multimeter (DMM) modules (SANWA, PC 5000), that can be interfaced to a PC. The software (PC Link plus) allows one to log measuring data into PC through RS232 port with digital multimeter PC series. The operation of this software is possible by using any operational system such as the windows 98, NT4.0/2000/ME/XP versions. It provides function for capacitance measurements using the charge/discharge method and capacitance in the range of 0.01 nF to 9.99 mF can be measured with a resolution of about 0.01 nF. The nominal input impedance of the DMM is about 10 M Ω and 30 pF. The specified accuracy of the DMM for 50.00-500.0 nF capacitance range is about $\pm(0.8\% \text{ rdg}+3\text{dgt})$ and $\pm(2\% \text{ rdg}+3\text{dgt})$ for the 50.00 μF range. A DMM with the given specification based on the charge discharge operation is use 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. Since, the reported reading module cannot measure precisely the capacitance values smaller than 10 pF, thus for such cases a reference

capacitor (470 nF) as shown in Fig. 3, is used in parallel with the sensor capacitance to assure the proper readings for the small capacitances. However, for high capacitance values such a reference capacitor is not required. Since, the measurement module uses the charge/discharge (C/DC) circuit, this method described here.

The charge/discharge operation is based on the charging of an unknown capacitance under study C_x to a voltage V_{DD1} via a CMOS switch (S_1), with a resistance, R_{on} that resistance is about 6.65 M Ω . The charge transfer through the C_x capacitor to the parallel resistances network from 1 to 10 M Ω by a (S_4) switch. In the resistances, network the charge transfer from 1 K Ω resistance when the C_x capacitance is about 9999 μF and for 999 μF , 99 μF , 999 nF and 99 nF capacitances, respectively, the charge transfer through 10, 100, 1.1 and 10 M Ω resistances. The resistances network connected to an Analog-to-Digital converter (A/D) and then connected to Micro Control Unit (MCU). Discharge is stopped when the charge transfer from MCU to V_{DD1} source.

RESULTS

The capacitance measurement for the cylindrical cell probe depends on the permittivity, ϵ (F/m), of the liquid and its resistance factor that depends only on the conductivity, σ (S/m), of the liquid.

$$C_x = f_1(\epsilon) \tag{1}$$

$$R_x = f_2(\sigma) \tag{2}$$

Precise formulation of electrical capacitance for a cylindrical capacitive sensor was reported (Ashrafi and Golnabi,1999). Using Coulomb law the capacitance of a CCS can be obtain from:

$$C_m = \frac{Q}{\phi_{ab}} = \epsilon^* 2\pi L \left[\int \ln \left(\frac{z - \frac{1}{2} + \sqrt{a^2 + \left(z - \frac{1}{2}\right)^2 - 2a^2 \cos \phi' + a^2}}{z + \frac{1}{2} + \sqrt{a^2 + \left(z + \frac{1}{2}\right)^2 - 2a^2 \cos \phi' + a^2}} \right) d\phi' - \int \ln \left(\frac{z - \frac{1}{2} + \sqrt{b^2 + \left(z - \frac{1}{2}\right)^2 - 2b^2 \cos \phi' + a^2}}{z + \frac{1}{2} + \sqrt{b^2 + \left(z + \frac{1}{2}\right)^2 - 2b^2 \cos \phi' + a^2}} \right) d\phi' \right]^{-1} \tag{3}$$

where, ϵ^* is the permittivity (in general complex) of the gap dielectric medium. Here a is the inner electrode radius, b outer electrode radius and L is the capacitor length. The complex permittivity is define by:

$$\epsilon^* = \epsilon - j(\sigma/\omega) \tag{4}$$

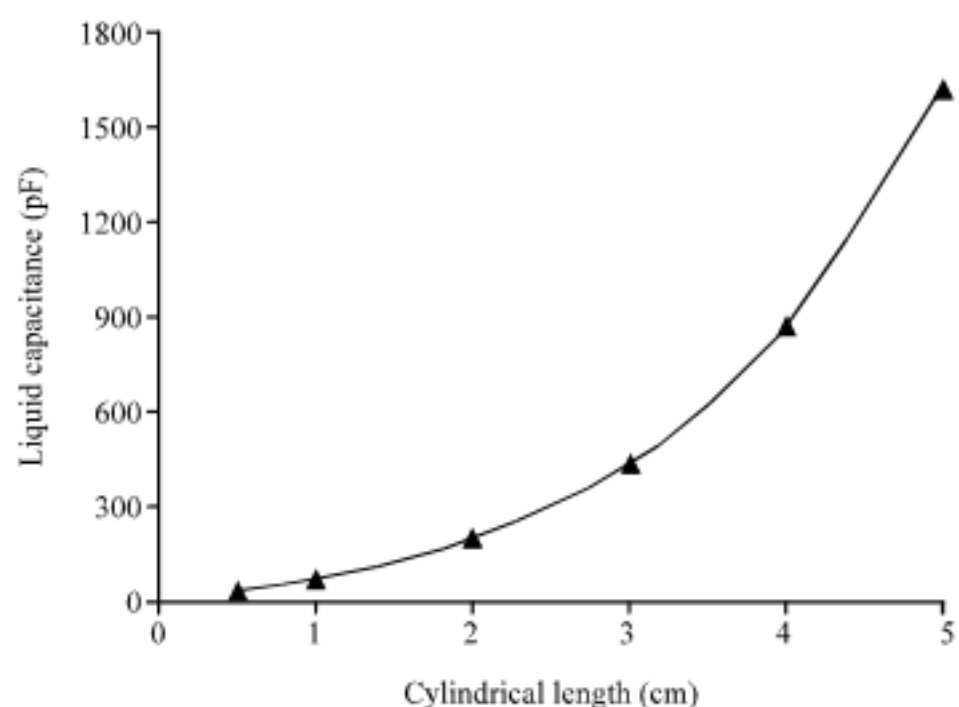


Fig. 4: Computational results of liquid capacitance for distilled water versus the cylindrical length

where, ϵ' is real part of dielectric permittivity and (σ/ω) is imaginary part of dielectric permittivity. $\omega = 2\pi f$ and f is the frequency of the readout measurements. With substitute Eq. 4 into Eq. 3, obtain:

$$C_m = C_x - j(G_x/\omega) \tag{5}$$

where, x denotes the sample filling the gap and parameter G_x shows the liquid conductance ($1/R_x$).

Figure 4 shows the results of our theoretical computation of the liquid capacitance of distilled water as a function of cylindrical length for water permittivity of 80. For the water the dielectric permittivity as stated in the handbook by Weast (1981) varies with any change in the medium temperature. This constant for the temperature of 25°C is found to be about 80. It is consider in Coulomb method by increasing the cylindrical length from 0.5-5 cm, the capacitance increasing from 28.9 to 1612 pF. The digital multimeter (DMM) module (SANWA, PC 5000) measured capacitance using an AC voltage, at 60 Hz frequency. When a DC voltage applied to the electrodes of a sensor, positive H^+ ions and negative OH^- ions move to the positive and negative electrodes of the sensor. The ions gain or lose electrons and are converted to hydrogen gas at the negative electrode and oxygen gas at the positive electrode. These gases effectively form an insulation barrier at the electrodes, increasing the apparent resistance that in turn decreases the apparent conductivity of the solution. Using an AC voltage and increasing the cross sectional area of the electrodes, virtually eliminates the effects associated with polarization. Using Eq. 3 the resistance of a solution in cylindrical cell probe can be obtain from:

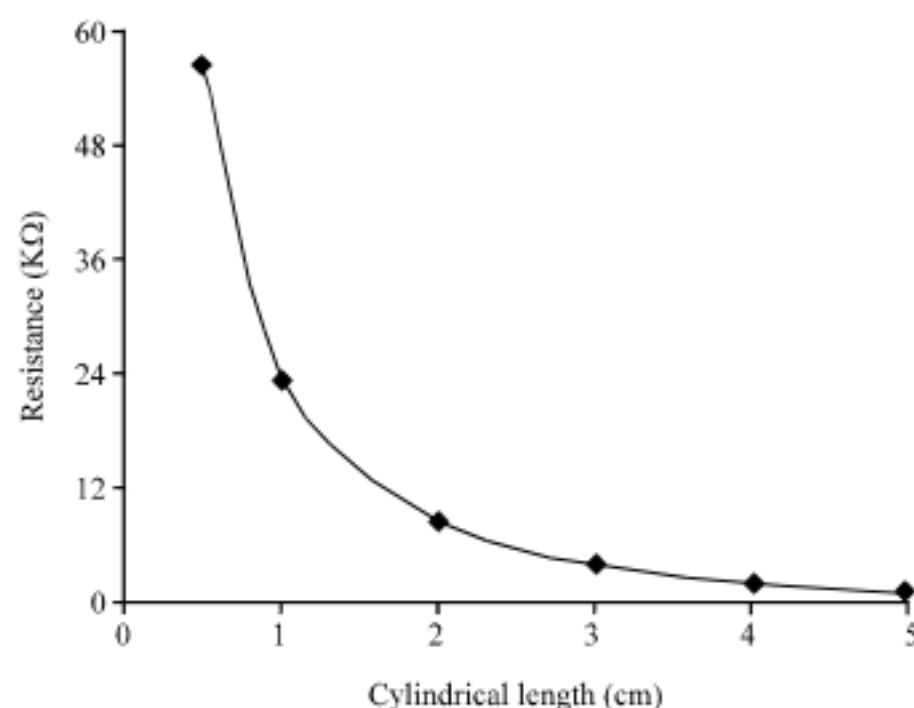


Fig. 5: Computational results of resistance variation for distilled water versus the cylindrical length

$$R_x = \frac{\rho}{2\pi L} \left[\int \ln \left(\frac{z - \frac{1}{2} + \sqrt{a^2 + \left(z - \frac{1}{2}\right)^2 - 2a^2 \cos \phi' + a^2}}{z + \frac{1}{2} + \sqrt{a^2 + \left(z + \frac{1}{2}\right)^2 - 2a^2 \cos \phi' + a^2}} \right) d\phi' - \int \ln \left(\frac{z - \frac{1}{2} + \sqrt{b^2 + \left(z - \frac{1}{2}\right)^2 - 2b^2 \cos \phi' + a^2}}{z + \frac{1}{2} + \sqrt{b^2 + \left(z - \frac{1}{2}\right)^2 - 2b^2 \cos \phi' + a^2}} \right) d\phi' \right] \tag{6}$$

where, ρ is the resistivity of the dielectric medium. Here a is the inner electrode radius, b outer electrode radius and L is the capacitor length. The resistivity of distilled water is about 0.24 MΩ cm.

Figure 5 shows the resistance for the distilled water. As can be seen in Fig. 5, variation with cylindrical length is show, which starts from 58.23 KΩ and decreases to about 1.05 KΩ. For distilled water, the reactance capacitance value shown in Fig. 6. It is consider that by increasing in the cylindrical length from 0.5-5 cm, the imaginary part of capacitance increasing from 0.456 to 2.534 μF. Initial measurement indicated that the measured capacitance values (C_m) are very sensitive to the conductance and geometrical configuration.

Figure 4 and 6 show that the real part of the measured capacitance is in the range of pF and imaginary part is in the range of μF. Therefore, the conductance effect is notable in measuring capacitance. There are practical limits to increasing the electrode surface area. Electrode size cannot become too large due to the physical constraints of sensor installation. To analyze the electrical condition of the tested water liquids, another device was used to measure the EC and the Total Dissolved Solid (TDS) density of the water samples in this experiment. The EC of different water liquids measured using conductive

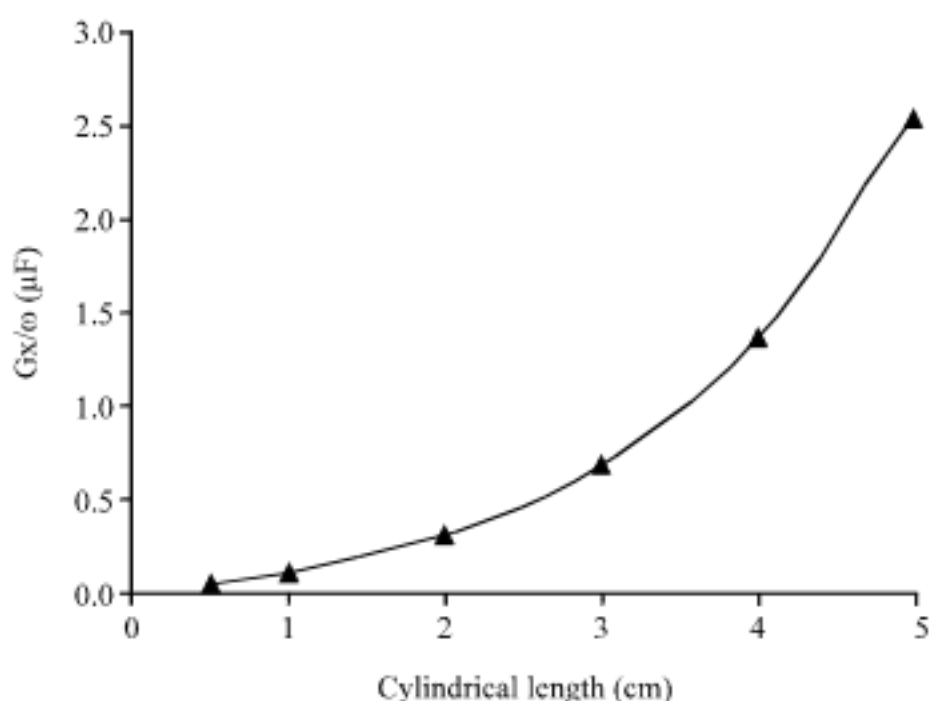


Fig. 6: Computational results of reactance capacitance for distilled water versus the cylindrical length

Table 1: Measurement of the EC, TDS and resistance for different water liquids

Water sample	Conductivity (μS cm ⁻¹)	Conductivity* (μS cm ⁻¹)	TDS (mg L ⁻¹)	Resistance (KΩ)	Resistance* (KΩ)
Distilled	4.2	1-10	2.1	12.624	110
Mineral	440	-----	212	0.121	-----
Tap	673	100-1000	337	0.078	3.3
Salt	831	800-70,000	415	0.064	0.006-130

*Huang et al. (1988)

meter (Sension 5). His conductive meter is a contacting style conductivity sensor. Contacting style conductivity sensors have their electrodes in direct contact with the solution being measure. It provides function for EC and TDS measurements. The EC in the range of 0.00 μS cm⁻¹ to 199.9 mS cm⁻¹ can measured with a resolution of about 0.1 μS cm⁻¹ and TDS in the range of 0.00 to 50,000 mg L⁻¹ can measured with a resolution of about 0.1 mg L⁻¹. The specified accuracy of the Sension 5 device for EC is about ±0.5% of the full range and for TDS is about ±5% of the full scale. A comparison of the results for different water liquids at room temperature is shown in Table 1.

As can be seen, the EC factor increases as well as the TDS in the given order for the tested water liquids. It noted that there is a relation between the increase of the EC of the water liquids and increase of the TDS. Looking at the given values for the EC in Table 1, it is noted that the salt water possess the highest EC value of 831 μS cm⁻¹ while the distilled water shows the least EC value of 4.2 μS cm⁻¹ at the same room temperature.

For different water liquids the resistance as function of cylindrical length is shown in Fig. 7. As can be seen in Fig. 7, for all the tested samples the measured resistances decreased where the cylindrical length is increase from 0.5-5 cm. Because by increasing in the cylindrical length the conductivity effects on the solution is increased. For the mineral water, the measured resistance at 0.5 cm is

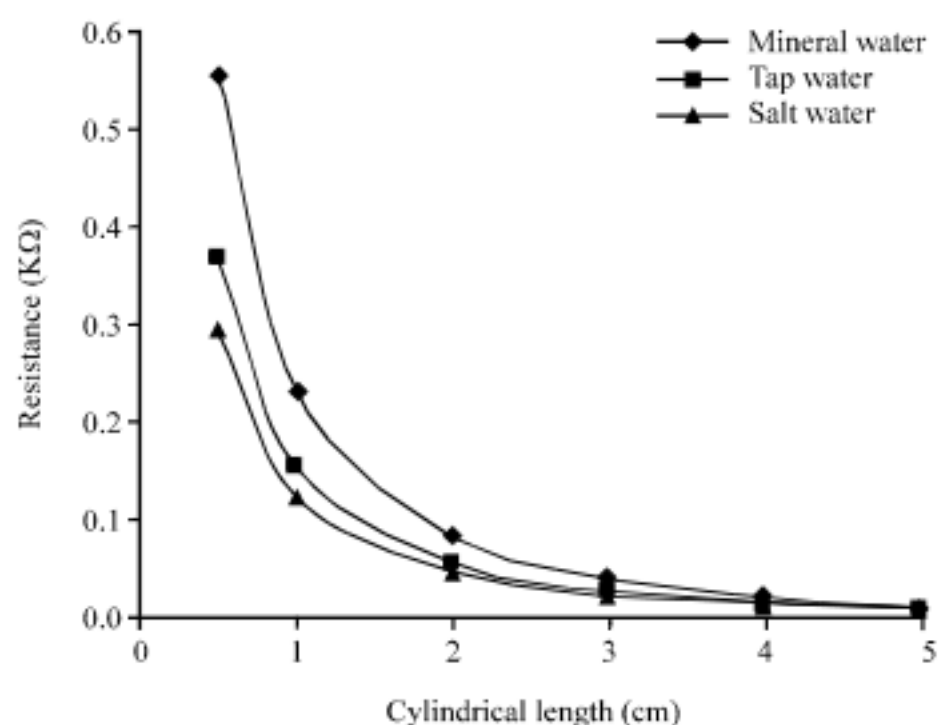


Fig. 7: Computational results of resistance variation for different water liquids versus the cylindrical length

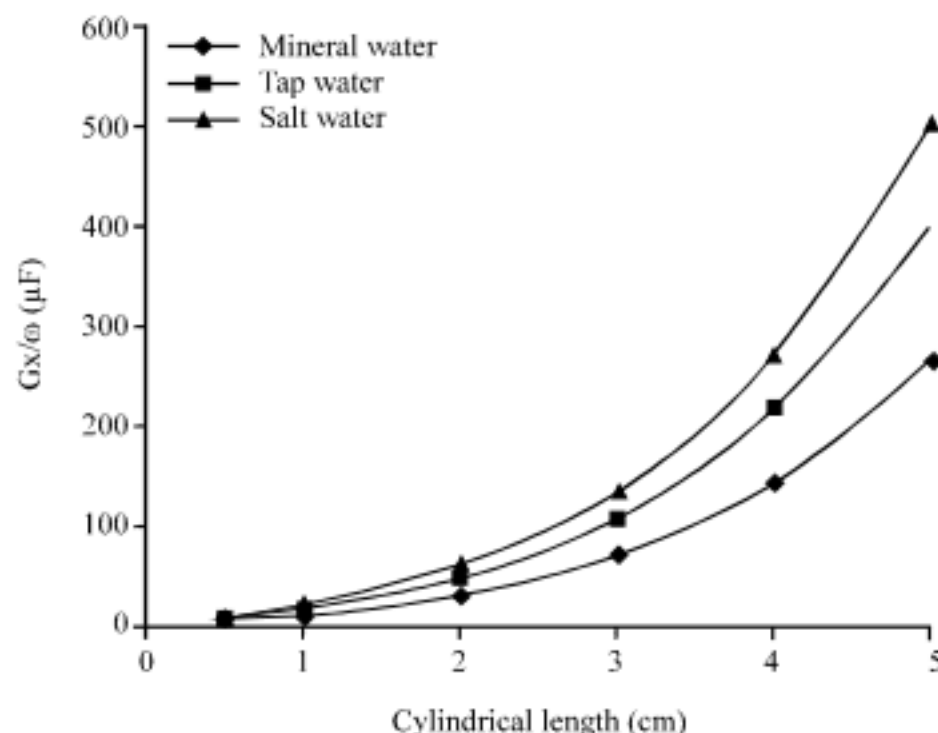


Fig. 8: Computational results of reactance capacitance for different water liquids versus the cylindrical length

about 0.56 KΩ while it drops to about 0.01 KΩ at 5 cm. Similarly, for the tap water the measured resistance at 0.5 cm is about 0.37 KΩ while it drops to about 0.007 KΩ at 5 cm. For the salt water as can be seen in Fig. 7, the measured resistance at 0.5 cm is about 0.29 KΩ while it drops to about 0.005 KΩ at 5 cm.

For the salt water as can be seen in Fig. 8, the measured reactance capacitance at 0.5 cm is about 9.04 μF while it grows to about 502.63 μF at 5 cm. Looking at the given values for the reactance capacitance in Fig. 8, it is noted that the salt water possess the highest TDS value while the distilled water shows the least TDS value at the same room temperature. Comparison of the theoretical and experimental capacitance values for different water liquids at 1.6 cm of cylindrical length is shown in Table 2. The capacitance measurement for the cylindrical cell probe

Table 2: Comparison of the experimental and theoretical capacitance values (for water permittivity of 80)

Water samples	C_x (pF)	C_x (pF)*	Experimental value C'_m (μ F)	Theoretical value C_m (μ F)	Error (%) $(C_m - C'_m)/C'_m$	C_x (μ F)
Distilled	33.5	22.33	0.300	0.290	-3.3	0.010
Mineral	33.5	-----	22.800	22.024	-3.4	0.776
Tap	33.5	22.33	37.500	33.678	-10.2	3.830
Salt	33.5	22.33	47.800	41.596	-12.9	6.200

*Huang *et al.* (1988)

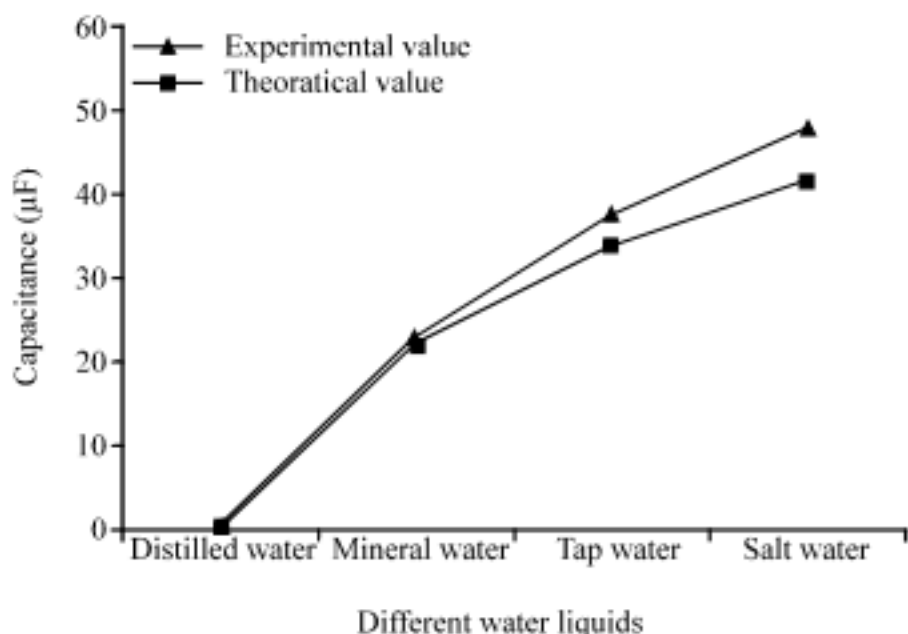


Fig. 9: Comparison of the computational and experimental results of the capacitance measurements

depends on the complex permittivity of the liquids. Theoretical computation of the liquid capacitance of distilled water for permittivity of 80 is about 33.5 pF and capacitance of imaginary part is about 0.29 μ F. A comparison of real and imaginary parts shows that imaginary part is notable in measured capacitance value. The errors shown in Table 2 are small except for salt water, where the theoretical value is considerably lower than the experimentally measured value. This error is about 12.9% and probably arises because the effect of stray capacitances of outer guard electrode C (Fig. 2) is negligible. For mineral water, this error is about 3.4%, tap water 10.2% and similarly this error is about 3.3% for distilled water.

Figure 9 shows the sensitivity of the calculations to the stray capacitances. The differences between theoretical and experimental values indicate that the stray capacitance is highest for the salt water and is lowest for the distilled water. Because, the EC value of the salt water upper than the other water liquids. Therefore, the Eq. 5 should be corrected as:

$$C_m = C_x - j(G_x/\omega) + C_s \quad (7)$$

where, C_s is the stray capacitance that related to connection the water liquid with the outer guard electrode C and x denotes the sample filling the gap and parameter G_x shows the liquid conductance ($1/R_x$). For the distilled water with EC about 4.2 μ S cm^{-1} the stray capacitance is

about 0.01 μ F and for the mineral water with EC about 440 μ S cm^{-1} the stray capacitance is about 0.776 μ F. Similarly for the tap water with EC of about 673 μ S cm^{-1} as can be seen in Fig. 9, the stray capacitance is about 3.83 μ F and for the salt water with EC about 831 μ S cm^{-1} the stray capacitance is about 6.2 μ F.

DISCUSSION

Theoretical computation values of real part of the measured capacitance value for different water liquids is about 33.5 pF that shown in the Table 2. As indicated by Huang *et al.* (1988) the liquid capacitance value for different water liquids is about 22.33 pF. The difference between liquid capacitance values is due to the difference in the geometrical configuration of the cell probes.

As indicated in literature the measured capacitance value of a solution typically depends on the EC of liquids. Eq. 5 shows that by increasing the EC, the reactance capacitance value of the water liquids increases accordingly. The EC values for different water liquids shown in the Table 1. For example, the reactance capacitance value for the distilled water with low EC is about 0.29 μ F and for the dilute salt water with high EC is about 41.596 μ F. A comparison our obtained results indicated the liquid capacitance value in the capacitance measurement is negligible. A simultaneous measurement of the resistance and capacitance using a cylindrical sensor system is reported by Golnabi and Azimi (2008b). This capacitance value for the distilled water in the stabilized condition is about 2.28 μ F and for the tap water is about 39.18 μ F. For the salt water, the measured capacitance value is about 47.80 μ F. In general, there is a reasonable agreement between our theoretical computation data and the one reported in mentioned reference.

Theoretical computation values of the resistance for the distilled water with the low EC, is about 12.624 $\text{K}\Omega$ and for mineral water is about 0.121 $\text{K}\Omega$. Resistance of the tap water is about 0.078 $\text{K}\Omega$ and for the dilute salt water with high EC is about 0.064 $\text{K}\Omega$. As indicated by Huang *et al.* (1988) the resistance value for distilled water is about 110 $\text{K}\Omega$ and for the tap water, this value is about 3.3 $\text{K}\Omega$. For the salt water, the resistance value is in the range 0.006- 130 $\text{K}\Omega$. The difference between resistance values due to geometrical configuration of the cell probe. In

general, there is a reasonable agreement between our theoretical computation data and the one reported in mentioned reference.

However, by increasing the EC value the stray capacitances are also increased. In pure water and solutions with an EC of $10 \mu\text{S cm}^{-1}$ or less, the agreement between computation results and experimental values are permissible and the stray capacitance value is about 3.3% of the full scale. For water liquids with an EC of $600 \mu\text{S cm}^{-1}$ or high, the difference between calculations and experimental values are notable. For instance, the stray capacitance value of the dilute salt water is about 12.9% of the full scale.

In present experimental results and the theoretical computation of the capacitance values for all water liquids show a non-linear increase by increasing in the cylindrical length. Our obtained results indicate an averaged variation of 124.5 pF cm^{-1} in the range 1 to 2 cm and 748 pF cm^{-1} in the range 4 to 5 cm for the liquid capacitance of the distilled water. For the reactance capacitance, average variations of the mineral water is about $20 \mu\text{F cm}^{-1}$ in the range 1 to 2 cm and $123 \mu\text{F cm}^{-1}$ in the range 4 to 5 cm. For the tap water, this value is about $31 \mu\text{F cm}^{-1}$ in the range 1 to 2 cm and $183 \mu\text{F cm}^{-1}$ in the range 4 to 5 cm. Similarly, the reactance capacitance average variations of the dilute salt water is about $38.8 \mu\text{F cm}^{-1}$ in the range 1 to 2 cm and $233 \mu\text{F cm}^{-1}$ in the range 4 to 5 cm. On the other hand, by increasing in the cylindrical middle length the EC effects of the water liquids on the capacitance measurement are increased.

The theoretical computation of the resistance values for all water liquids show a non-linear decrease by increasing the cylindrical probe length. Our obtained results indicate an averaged variation of $-15.51 \text{ K}\Omega \text{ cm}^{-1}$ in the range 1 to 2 cm and $-0.9 \text{ K}\Omega \text{ cm}^{-1}$ in the range 4 to 5 cm for the resistance of the distilled water. An average variation of the mineral water is about $-0.149 \text{ K}\Omega \text{ cm}^{-1}$ in the range 1 to 2 cm and $-0.009 \text{ K}\Omega \text{ cm}^{-1}$ in the range 4 to 5 cm. For the tap water, this value is about $-0.098 \text{ K}\Omega \text{ cm}^{-1}$ in the range 1 to 2 cm and $-0.006 \text{ K}\Omega \text{ cm}^{-1}$ in the range 4 to 5 cm. Similarly, the resistance average variations of the dilute salt water is about $-0.078 \text{ K}\Omega \text{ cm}^{-1}$ in the range 1 to 2 cm and $-0.005 \text{ K}\Omega \text{ cm}^{-1}$ in the range 4 to 5 cm. A comparison between average variations of resistance for the different water liquids indicated the salt water possess highest the drop value, while the distilled water show least the drop value at the same room temperature. Because by increasing in the cylindrical middle length the EC effects on the solution are increased.

Now it is useful to compare the results of this study with the previous ones. The conductivity effects on the capacitance measurements of two-component fluids using the charge transfer method for capacitance measurements

has been reported by Huang *et al.* (1988). The measured liquid capacitance and resistance values for different water liquids in the given reference show a reasonable agreement with our experimental data. Comparing of our results for the measured capacitance values of different water liquids with the measured capacitance values shown by Golnabi and Azimi (2008b) shows a good agreement. In general there is a reasonable agreement between our experimental data and the results of earlier studies.

CONCLUSIONS

The goal here was to implement a CCS to determine the EC effects on the capacitance measurement of the water liquids. The CCS such as the one reported here provided a useful means to study the EC effects on the capacitance measurement. The liquid capacitance and reactance capacitance values for distilled, tap, mineral and dilute salt water theoretically investigated. In our calculation, the measured capacitance for all water liquids shows an increase by increasing in the conductance and vice versa. For distilled water with EC value of $4.2 \mu\text{S cm}^{-1}$ the measured capacitance is about $0.210 \mu\text{F}$ and dilute salt water with EC value of $831 \mu\text{S cm}^{-1}$ measured capacitance is about $41.596 \mu\text{F}$. Present obtained results indicate that the measured capacitance values for all water liquids show a non-linear increase by increasing in the cylindrical length. The error between experimental and theoretical capacitance values due to stray capacitances effect that related to connection of the water liquid with the outer guard electrode (C). The stray capacitance value is about $0.01 \mu\text{F}$ for the distilled water, $0.776 \mu\text{F}$ for the mineral water, $3.83 \mu\text{F}$ for the tap water and $6.2 \mu\text{F}$ for the dilute salt water. In our calculation, the resistance for all water liquids shows a decrease by increasing in the EC. Theoretical computation values of the resistance for the distilled water is about $12.624 \text{ K}\Omega$ and for the dilute salt water is about $0.064 \text{ K}\Omega$. Obtained results verified that the reported sensor could be effectively implemented for the capacitance measurement of low conducting liquids such as water and water mixtures, which have wide spread applications. Such conductance dependence data can provide useful information for percentage of water in a solution. On the other hand, this method provides a sensitive way to measure the reactance capacitance of water liquids.

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