Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2013
(ICMERE2013) 1-3 May 2014, Chittagong, Bangladesh

ICMERE2013-PI-196

DESIGN & IMPLEMENTATION OF A DIELECTRIC CONSTANT MEASURING METER FOR WATER

C. K. Das[1], Surajit Biswas[2], Tahzibul Hoque[3] and Shohidul Islam[4]

Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Chittagong- 4349, Bangladesh.

[1]choton46@yahoo.com, [2]surajit_cuet_07cuet@yahoo.com, [3]tahzib_cuet@yahoo.com, [4]shohidcuet95@gmail.com

Abstract*- The dielectric constant is an electromagnetic property of materials. It is the ability to store energy when an external field is applied. At present, in the field of engineering and science, there is a great importance of dielectric constant. By knowing the characteristic of dielectric constant, the other electrical properties such as capacitance, permittivity, susceptibility, effect of polarization can be predicted. In Bangladesh, no significant research has been performed on dielectric constant of material. The aim of this research is to design a meter for the measurement of dielectric constant for water. Dielectric constant of water is measured from the change of capacitance due to influence of liquids between two electrodes. In this work, dielectric constant of clean water and also, water from various river and sea has been measured. A capacitor is formed between two conducting sheets and time for charging and discharging is measured and finally output is shown in LCD.*

Keywords: Dielectric material, Dielectric Constant, Capacitance, Permittivity.

1. INTRODUCTION

A material is classified as “dielectric” if it has the ability to store energy when an external electric field is applied. If a DC voltage source is placed across a parallel plate capacitor, it is found that more charge is stored when a dielectric material is between the plates than if no material (a vacuum) is between the plates. The dielectric material increases the storage capacity of the capacitor by neutralizing charges at the electrodes, which normally would contribute to the external field. The capacitance with the dielectric material is related to dielectric constant [1].

Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. Accurate measurements of these properties can provide scientists and engineers with valuable information to properly incorporate the material into its intended application for more solid designs or to monitor a manufacturing process for improved quality control. A dielectric materials measurement can provide critical design parameter information for many electronics applications [2]. For example, the loss of a cable insulator, the impedance of a substrate or the frequency of a dielectric resonator can be related to its dielectric properties.

The information is also useful for improving ferrite, absorber, and packaging designs. More recent applications in the area of industrial microwave processing of food, rubber, plastic and ceramics have also been found to benefit from knowledge of dielectric properties. The term dielectric constant relates to a few electrical properties such as capacitance, electric permittivity, absolute permittivity, size and distance between the conductors, etc. The dielectric constant is a property of dielectric material itself. The dielectric behavior of different materials under different conditions is reflected in the characteristics of the charging or polarization currents. Since polarization current depends upon the applied voltage and the dimensions of condenser, it is inconvenient to use them directly for the specification of the properties of materials [3].

According to the wave–mechanical theory of the structure of matter, a dielectric is a material which is so constructed that the lower bands of allowed energy levels are completely full at the absolute zero temperature and at the same time isolated from higher unoccupied bands by a large zone of forbidden energy levels. Thus, conduction in the lower, fully occupied bands is impossible because there are no unoccupied energy levels to take care of the additional energy which would be acquired by the electrons from the applied field, while the zone of forbidden energy levels is so wide that there is only a negligible probability that an electron in the

lower band of allowed levels will acquire enough energy to make the transition to the unoccupied upper band where it could take part in conduction. The bound electrons in a completely filled and isolated band of allowed levels can however interact with the applied electric field and make the potential structure of the material and hence in the allowed levels [4].
In this research work, dielectric constant of clean water and river as well as sea water has been measured by the use of a designed meter. The variation of the dielectric constant for different liquids has been observed. By performing some modification in this meter, percentage of water can be measured in different types of solution [5]. Soil water content can also be measured by doing certain modifications [6].

2. SYSTEM OVERVIEW

The complete block diagram of the system is as shown in Fig. 1. A capacitor is formed by two conducting sheets. A reference voltage is applied to the microcontroller. The time for charging and discharging the capacitor is measured by the processing circuit which includes some other resistor and filter capacitor. In the processing circuit, some resistance has been used for the charging and discharging of the test capacitor. The microcontroller used here is PIC16F628A. A comparator has been used here to compare the capacitor voltage with the reference voltage which is half of the input voltage. Finally, the output is shown in the LCD display.

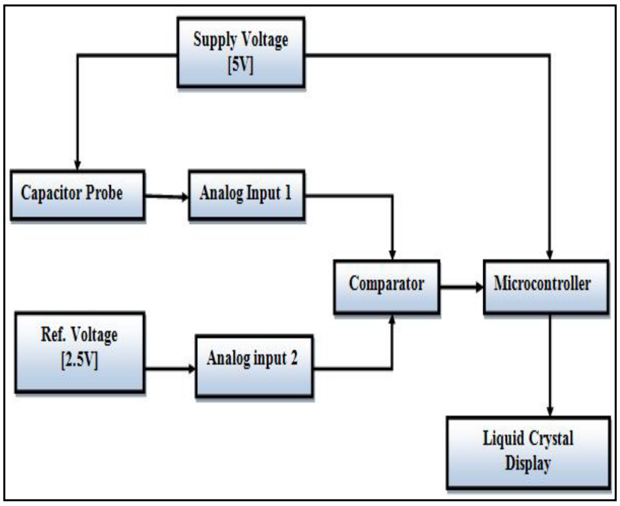

Fig 1: Block diagram of the dielectric constant measuring meter.

The time is calculated when the formed capacitor is charged from 0 to a known voltage with the help of a microcontroller. The microcontroller PIC16F628A has two built-in analog comparators as shown in Fig. 2. In this research, Analog Comparator 2 and TIMER2 modules is used to determine the time required by the capacitor to charge from 0V to 0.5V. The positive and negative inputs of the Analog Comparator are externally accessible through RA2 and RA1 pins of PIC16F628A respectively. In figure 2, two 2.2K resistor create a voltage divider that sets the positive input (RA2) of the comparator to half of the voltage applied to RA0 pin. The negative input (RA1) of the comparator goes to the positive end of the capacitor through a 330Ω resistor. The resistor is used to discharge the capacitor prior to its measurement by setting RA1 low.

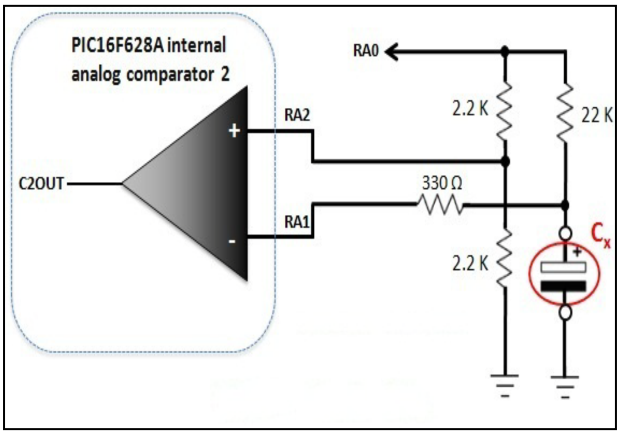

Fig. 2: RC circuit and comparator inputs [7]

3. SYSTEM DESIGN

In the complete circuit diagram (Fig. 3), the 5V DC is used as V_{ss} for both the microcontroller and LCD display. A reset switch and a 10K resistance are used for resetting the whole system. The voltage is also fed to the RB0 pin of the microcontroller. From pin 1, the reference voltage is found and two resistances of 2K are used as the voltage divider while the test capacitor is formed here by two conducting sheets. They discharge through the 330Ω resistance. The capacitor discharging voltage and the reference voltage is fed to the RA1 and RA0 pin, which acts as analog voltage comparator. The microcontroller compares the voltage and calculates the result. The result is displayed in the LCD which comes from the microcontroller pin RB4, RB5, RB6 and RB7 to the LCD pin D4, D5, D6 and D7 respectively. Here, RS (4) is the reset pin and E (6) is the enable pin which gets signal from the RB2 and RB3 pin of the microcontroller respectively.
By knowing the value of the charging resistor (in this case, it is 22K) and the charging time (from Timer2), the capacitor equation can be solved to compute C. For simplicity, the Timer2 is initialized with value 104 so that it overflows in 256-104=152 clock cycles. If we use 4.0 MHz external clock source, this is equivalent to 152 μsec. By doing so, the calculations are much simplified as described below. The final equation suggests that for the given arrangement, the measured capacitance (in nF) is simply 10 multiplied by the number of times the Timer2 overflows, starting from 104 every time. This gives a resolution of 10nF, which can be further improved to 1nF by considering the value of Timer2 itself at the instant when the comparator output switches to low and the Timer 2 module is stopped.

$$V_c = V_{in}\,(1 - e^{-t/RC})$$
$$\Rightarrow \quad C = t/(0.693147 \times R) = 10N(nF)$$

N= no. of times TMR2 overflows starting from (256-152) =104
Then, the value of the measured capacitance C is placed

in Eq. (1),

$$C = €A/d \qquad (1)$$

Where "A" is the area of the sheets and "d" is the distance between the sheets, which are known. So, from the equation the permittivity € is calculated. Then, from the ratio between € and $€_o$ the dielectric constant "K" is calculated by using Eq. (2)

$$K = €/€_o \qquad (2)$$

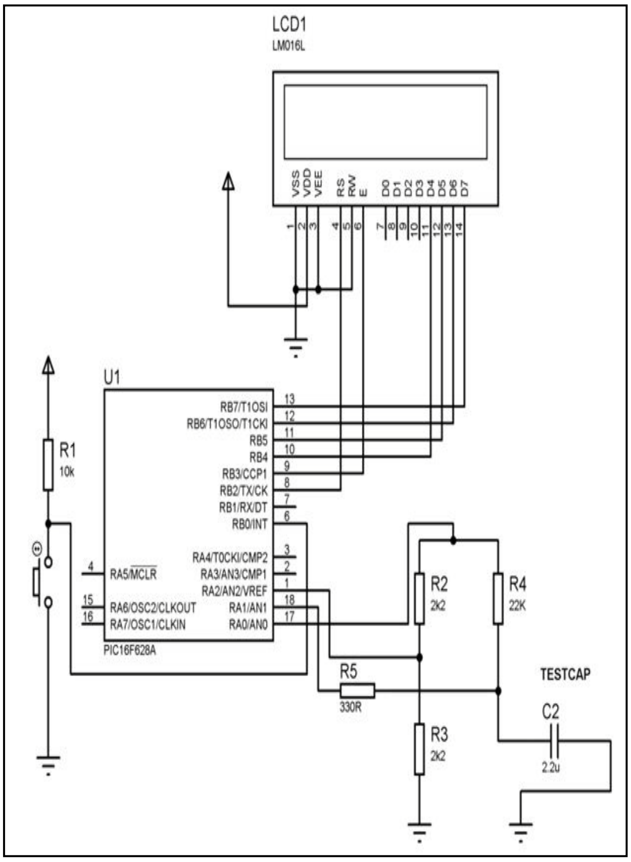

Fig. 3: Circuit Diagram of the system

The circuit with components is shown in fig. 4.

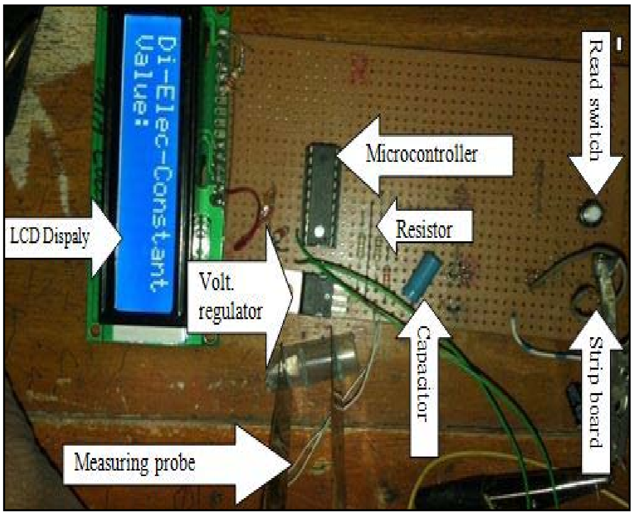

Fig. 4: The implemented circuit with components

4. SYSTEM IMPLEMENTATION

Fig 5: The implemented circuit with the system.

Here, figure 5 shows the implemented circuit. The main circuit is placed into a wooden box with plastic cover and a glass beaker, in which the test liquids are kept.

5. RESULT and ANALYSIS

The implemented circuit is tested by taking the different sample water from different types of sources such as Sea, river, Lake etc. of Chittagong, Bangladesh and then the result is analyzed as described below.

5.1: Change of Dielectric constant of clean water with temperature:

From the experiment, the dielectric Constant of clean water is found 80.309 at room temperature (20˚C). The volume of sample water is 90 ml. At first, the temperature is increased to 80˚C using a water heater. Then it is decreased to 5˚C using refrigerator.

Table 1: Variation of Dielectric constant of clean water with temperature.

Temperature (˚C)	Dielectric Constant
5	90.648
10	90.005
20 (at room temp.)	80.309
30	70.602
40	60.701
50	60.301
60	50.930
70	40.302
80	30.706

In table 1, the change of dielectric constant of water with temperature has been recorded. Figure 6 shows the plotted graph.

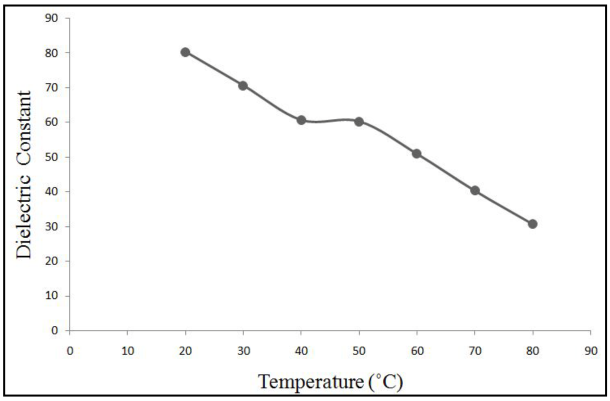

Fig.6: Dielectric Constant Vs Temperature (Clean Water)

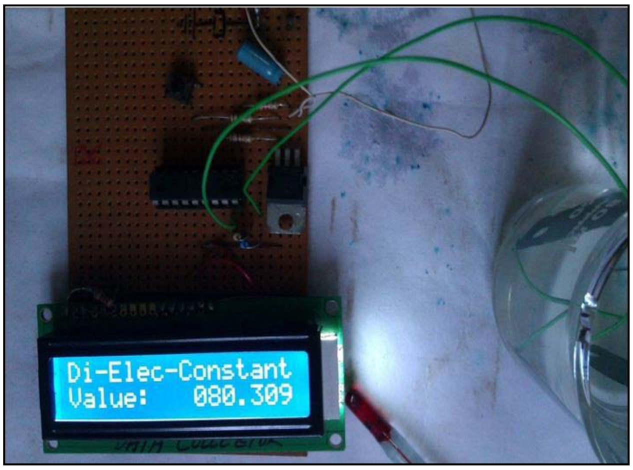

Fig. 7: Dielectric constant of clean water at room temperature 20˚C

In Fig. 7, dielectric constant of water at room temperature is shown. The reading of dielectric constant has been recorded at different temperatures and the graph has been plotted. Hence, it has been observed that the dielectric constant decreases with the rising temperature and increases with decreasing temperature [8].

5.2: Change of Dielectric Constant of sea water (Saint Martin's water) with temperature:

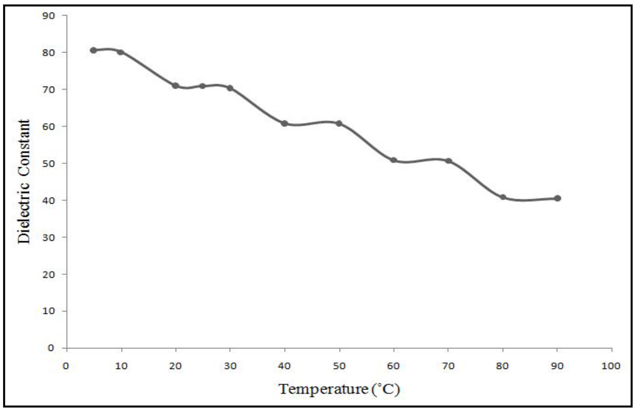

Fig. 8: Change of Dielectric constant of sea water (Saint Martin's water) with temperature

The experimental dielectric constant value of Sea water (Saint Martin's water) is found 70.909 at room temperature 25˚C. The volume of this sample sea water is 90 ml. Similarly, the different data are taken at different temperature by increasing and decreasing the temperature within the range 90˚C to 5˚C.

Fig 9: Dielectric constant of sea water (at temp. 5˚C)

In Fig. 8 the change of dielectric constant of sea water with temperature has been shown and Fig. 9 is an image of dielectric constant at 5˚C.The reading is similar to that of clean water. The dielectric constant decreases with the increase in temperature and vice-versa which is shown via graph too.

5.3: Change of Dielectric Constant of sea water (Patenga's water) with temperature:

From another analysis it is observed that the dielectric constant of Sea water (Patenga's water) is 50.105 at room Temperature (25 ˚C) with the same volume of Sea water (90 ml). The experimental data are recorded as it is before in different temperature and plotted as shown in Fig. 10.

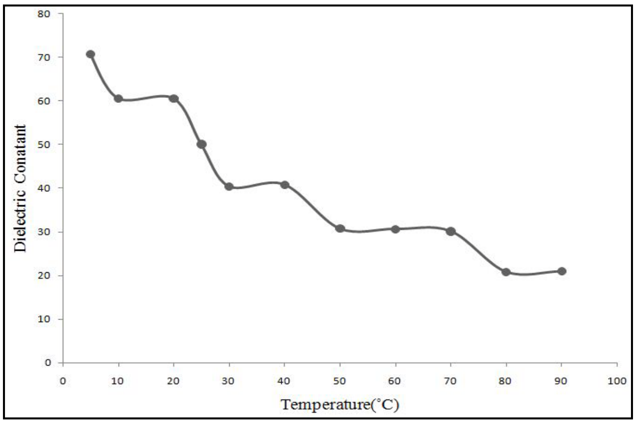

Fig 10: Change of Dielectric constant of sea water (Patenga's water) with temperature.

In Fig.10, the variation of dielectric constant of sea water (Taken form Patenga) with temperature has been represented. The result is similar to the clean water which is shown via graph.

5.4: Change of Dielectric Constant of river water (Halda's water) with temperature:

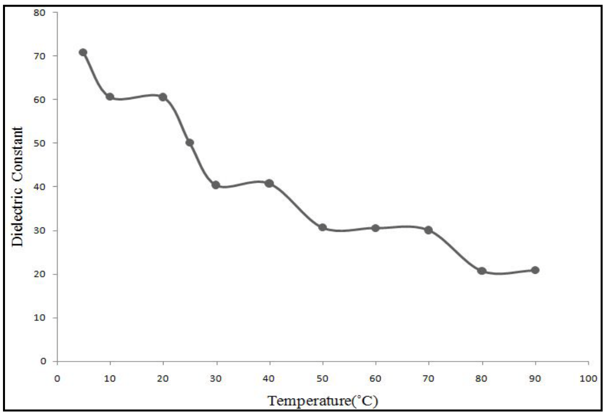

Fig. 11: Variation of Dielectric constant of river water (Halda's water) with temperature

In another analysis with river Halda's water the dielectric constant is found 50.400 at Room Temperature 25˚C. The volume of this river water is 90 ml. By following all previous steps the data are taken and plotted in Fig. 11. In Fig.11, the change of dielectric constant of river water with temperature has been shown. The result is similar to clean water which is represented in Fig. 6.

5.5: Change of Dielectric Constant of river water (Karnafully's water) with temperature:

In another case of river water taken form Karnafully, the dielectric constant is found 50.403 at room temperature (25 ˚C). The volume of sample river water is 90 ml. Similarly, the data are plotted in Fig. 12.

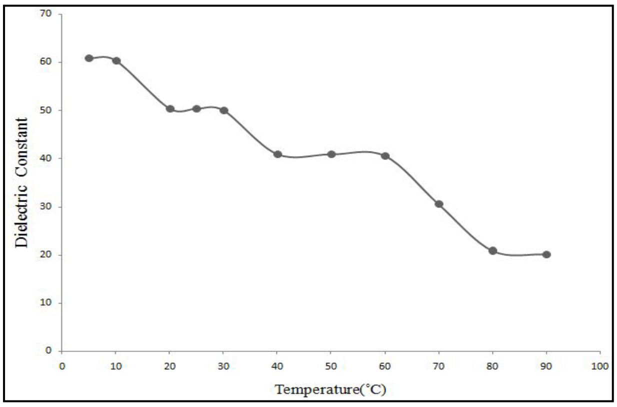

Fig 12: Change of Dielectric constant of river water (Karnafully's water) with temperature

In Fig.12, the change of dielectric constant of river water with temperature has been shown. The result is similar to clean water which is shown in graph. Fig. 13 shows the dielectric constant of river water (Karnafully's water) which was found out to be 40.924 at 50°C.

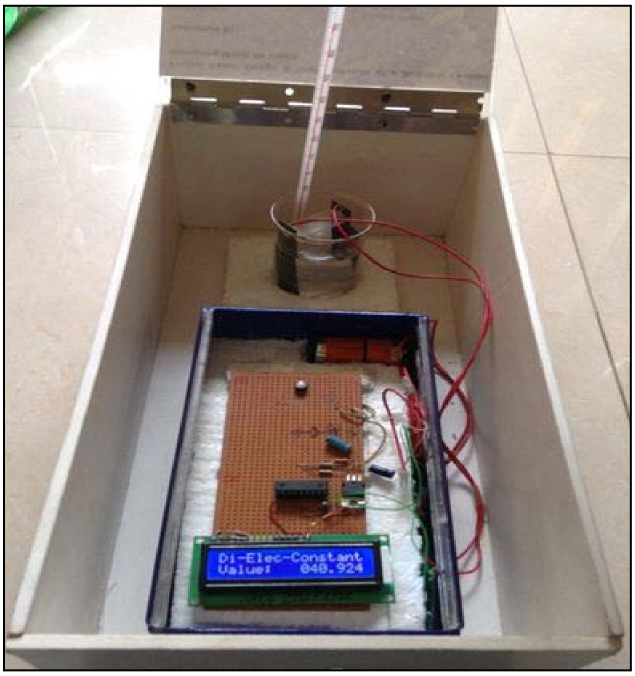

Fig 13: Dielectric constant measurement of river water (Karnafully's water) at temp.50°C.

5.6: Change of Dielectric Constant of water (taken from Kaptai Lake) with temperature:

In further analysis of river water collected from Kaptai Lake the dielectric constant is found 60.006 at room temperature (25 ˚C). The volume of sample river water is 90 ml. As like before, the data are taken and plotted as shown in Fig. 14.

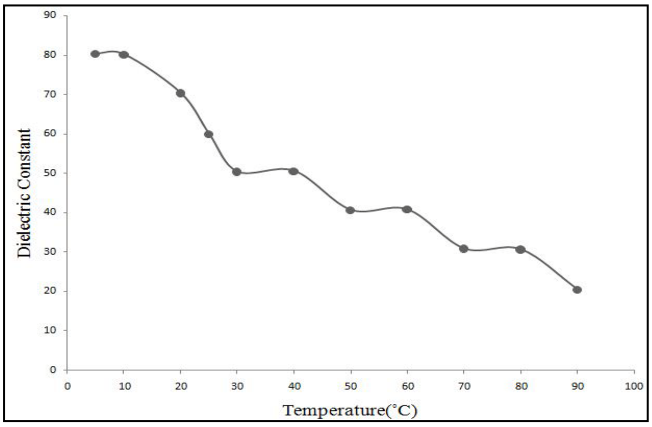

Fig 14: Change of Dielectric constant of water (Kaptai lake's water) with temperature

In Fig.14, the change of dielectric constant of river water with temperature has been depicted. The result is similar to clean water as shown in Fig. 6.

From the above graph and data, it has been observed that the dielectric constant decreases with increasing temperature. Due to rise in temperature, the molecules of these different solutions become polarized. As the polarization increases in the molecules, the ability to store energy in the dielectric materials decreases. As a result the dielectric constant decreases [9, 10]. Because of the ability to store the charge in the dielectric material is closely related to the dielectric constant. It has been observed that the dielectric constant of the different water is different at same temperature. It is due to the molecular structure of different solute and due to salinity of the water at different place. This data has resemblance with the data of other research work on dielectric constant of sea water [11, 12]. Thus, the dielectric constant is inversely related with temperature.

6. LIMITATIONS OF THE SYSTEM

The system has some limitations which have been stated below:

1. In this project fixed frequency is used.
2. The meter has a fixed range due to the limitation of equipment used.
3. Low voltage source is used using voltage controller.
4. It is difficult to measure the dielectric constant of higher density liquid due to the sensitivity of measuring meter.
5. This measuring meter is slightly vulnerable.

7. ADVANTAGES

The dielectric constant measuring meter is a device with many advantages such as:

1. By this meter, the dielectric constant of different liquid is measured easily.
2. A brief idea about the dielectric properties of some liquids can be gathered.
3. The change of dielectric constant with the change of temperature is known.
4. Adding some modification in this meter, percentage of water can be measured in different types of solution.
5. Soil water content can be measured by doing some modification.
6. Molecular structure of different types of material can be studied using this meter.
7. Low cost device.
8. Using this meter, variation with temperature of dielectric constant can be studied.

8. CONCLUSION

In this research, the frequency passing method and the time of charging and discharging have been used to determine the capacitance and from that the dielectric constant has been measured. A fixed frequency has been used, so that the meter has a fixed range from 10 to 100. By this meter some of the liquids such as oil, kerosene, benzene which has low dielectric constant value cannot be measured. It is due to the limitation of devices. So, in future some research has to be done on this topic to improve this instrument by using better equipment to measure different kinds of liquid and to improve the range. Here, the response of dielectric constant with the change of temperature has been analyzed and the change of capacitance and other electrical properties of different materials can be predicted. This meter can be a useful one to measure not only the dielectric constant of water but also the dielectric constant of other liquids such as Sodium Chloride, Potassium Per-Manganate, Ammonium Sulphate etc. Thus, this low cost device (1,200 BDT only) can be used fruitfully in any developing country like Bangladesh to measure the dielectric constant of various types of liquid

.

9. REFERENCES

[1]. K. Kundert:"Modelling Dielectric Absorption in Capacitors", *Journal of power sources*, Version 2nd, June 2008, pp. 7-13.

[2]. J. W. Steed, J. L. Atwood, "Supramolecular Chemistry", *Journal on Wavelength Electronics*, 2nd edition, pp. 844. ISBN 978-0-470-51234-0,2009.

[3]. D. V. Blackham, R. D. Pollard:"An Improved Technique for Permittivity Measurements Using a Coaxial Probe", *IEEE Trans. On Instr. Measurement*, vol. 46, No 5, October 1997, pp. 1093-1099.

[4]. Application note, Agilent Basics of Measuring The Dielectric Properties of Materials, May 6, 2003, pp. 4-7, 17-28.

[5]. P. Wang, Andrzej, Anderko, Journal on "Computaiton of dielectric constants of solvent mixtures and electrolyte solutions", Elsevier Journal *"Fluid Phase Equilibria 186 (2001)"*, Received January 26, 2001, Accepted April 12, 2001, pp. 103-122.

[6]. M. Uematsu, E. U. Frank, "Static dielectric constant of water and steam", *J. Phys. Chem. Ref. data*, Vol. 9, No. 4, 1980, pp. 1291-1306.

[7]. About Comparator, available online, August 31, 2013, at: http://embedded-lab.com/blog/?p=4400.

[8] H.S. Kim, J. H. Kweon:" Cleaning of Lubricating Products from Machinery Parts Using Subcritical Water", *KSCE Journal of Civil Engineering (2010)* 14(1):1-6, DOI 10.1007/s12205-010-0001-3.

[9]. Dlego, P. Fernandez, Y. Mulev, ARH Goodwin and J.M.H. L. Sengers. Journal on "A database for the static dielectric constant of water and steam". *J. Phys. Chem. Ref. Data*, *Thermo physics division*, Vol. 24, No.1, Received Jan 6, 1995, Revised manuscript received March 1, 1995, pp. 33-69.

[10].T. Meissner and F. J Wentz, Paper on "The complex dielectric constant of pure and sea water from microwave satellite observations." *IEEE Transfusion on geosciences and remote sensing*, Vol. 42, No. 9, September 2004, pp. 1836-1849.

[11] L. Russiniak, Article on "Electric properties of water". Journal "*ACTA GEOPHYSICA POLINICA*", Institute of geophysics, Polish Academy of Sciences, Vol. 52, No. 1, Poland, 2004, pp. 63-76.

[12] Article on "The Physical Chemistry of Water and Aqueous Solution" available online, July 6, 2013, at: http://www.kth.se/polopoly_fs/Menu/general/Water c_ny.pdf