Impedance analysis of food preservative using Time Domain Reflectometry

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Abstract:

The growing use of electrochemical sensors in environmental applications, industry and in medical field has brought about the urging need to understand molecular properties, surface properties and the important analytical systems as a whole. The impedance and conductance of the system are the main parameters for electrochemical signal analysis. The present work is based on the study of food preservative, Lactic acid. A low frequency Time Domain Reflectometry (TDR) was developed and used for the analysis. Different concentrations (volume percentage 0 - 100%) of the preservative were prepared with freshly collected distilled water. These different concentrations were kept at different temperatures (25^{o}C, 35^{o}C, 45^{o}C & 55^{o}C). Various electrical parameters like Resistivity, Conductivity, Dielectric Constant and Reflection Coefficient were calculated. The parameter value changes with change in temperature as well as concentration. Lactic acid solution shows decreases in Conductivity and Reflection Coefficient and increase in Resistivity with increase in concentration at various temperatures, Dielectric Constant of Lactic acid solution increases at starting i.e. for low concentration and decreases for higher concentration. The change in values of electrical parameter with temperature indicates the change in properties of solution with temperature. This helps to decide the food preservation strategy.

Key Words: TDR, Electrical conductivity, Resistivity, Dielectric constant, Refection coefficient.

Introduction

Preservatives play an important role in human life. Some of the preservatives like Lactic Acid, Citric Acid etc. have no acceptable intake limit but some preservative like Sodium Diacetate, Sodium benzoate, Sodium propionate have different limit as per mg/Kg body weight [1]. It affects the food quality. Impedance spectroscopy is traditionally used in monitoring corrosion, testing effectiveness of drug preservatives [2, 3] and electro-deposition processes in the coating and characterization assessment of many kinds of sensors and semiconductors [4,5]. Its application in biotechnology for the characterization of cell cultures [6] has, however, been notably expanded in the last decade. The impedance has been applied in the field of microbiology as a means of detecting and quantifying pathogenic bacteria [7, 8].

Impedance spectroscopy is a powerful tool for a fast bio-molecule diagnosis and for analysis in cell cultures [9, 10]. Its superiority over other laboratory techniques lies in that it uses a small signal, thus minimizing the alterations of the properties of the medium, in other words, applied stimulation does not alter the equilibrium conditions of the system. The signal applied to the samples makes it possible to link the properties of the liquid or solid being studied with the variations or changes obtained in its characteristic impedance. This is due to the physical structure of the material, the chemical processes occurring in it, or a combination of both. Consequently, electrochemical impedance spectroscopy is a non-destructive technique providing robust measurements. [10]

In TDR technique, a voltage step is propagated down the transmission line towards the sample under investigation and reflected voltage waves are monitored by oscilloscope at particular point on line.

Experimental set up:

Used TDR setup is a low frequency Time Domain Reflectometry of the range 200MHz and 5ns rise time. A co-axial transmission line with characteristic impedance of 50 ohm was used for study of the preservatives. Various rod type and strip types of probes were designed and studied to check the impedance and conductivity using standard solution of known factors. Out of those a strip type probe of 5.5cm length is used for the further study. For the study of the properties of liquid under consideration we immerse the probe in the liquid and collect the information on the oscilloscope.

Temperature controller unit was developed to control the temperature during the experiment. It consists of water bath with an electric heater and a test tube holder, PT100 to sense the temperature, computer to monitor and control temperature.

Experimental procedure:

Chemical grade Lactic acid is used to prepare the required solutions. Ten different concentrations (Vol. % of Lactic acid from 0-100) are prepared with freshly collected distilled water. These different concentrations are kept in water bath at different temperatures, 25^{o}C, 35^{o}C, 45^{o}C and 55^{o}C. The selected probe is attached with pulse generator through coaxial cable and immersed in the solution. A fast rising pulse is applied through the coaxial transmission line. The rising pulse gets reflected back from the solution under consideration. The nature of the pulse is depends on the properties of the liquid. This pulse is observed and stored in the Digital Storage Oscilloscope i.e. DSO. This data was then collected in an external storage and further calculations were done. Each time the probe was thoroughly cleaned with acetone and dried with drier.

Result and discussion:

The graph of fig. 1 shows the variations of values of Resistivity R_L for aqueous solution of Lactic Acid of various concentrations at four different temperatures 25^{0}C, 35^{0}C, 45^{0}C and 55^{0}C. For the lower concentration no change is observed in Resistivity.

Figure 2 shows the variations in the values of Electrical Conductivity EC for aqueous solution of Lactic Acid of various concentrations at four different temperatures 25^{0}C, 35^{0}C, 45^{0}C and 55^{0}C. The graph shows the variations of values of Dielectric Constant for aqueous solution of Lactic Acid of various concentrations at four different temperatures 25^0C, 35^0C, 45^0C and 55^0C (Fig. 3). The following graphs (Fig. 4 and 5) shows the variations of values of real and imaginary part complex impedance for aqueous solution of Lactic Acid of various concentrations at four different temperatures 25^0C, 35^0C, 45^0C and 55^0C.

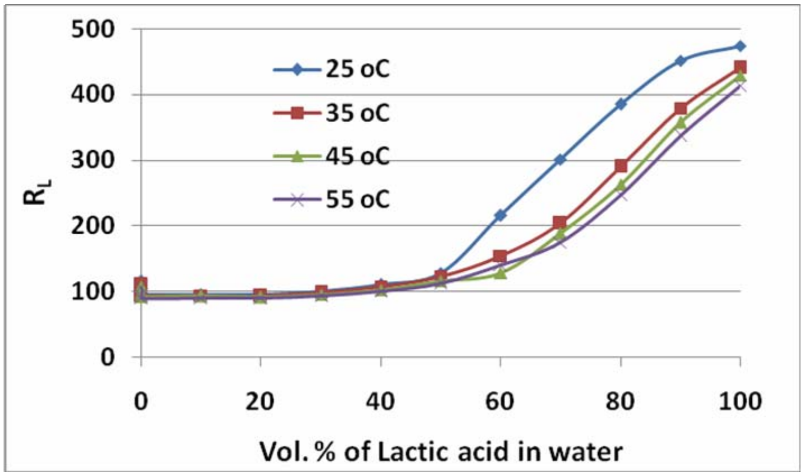

Fig 1. Variation of R_L with vol. % of Lactic acid in water.

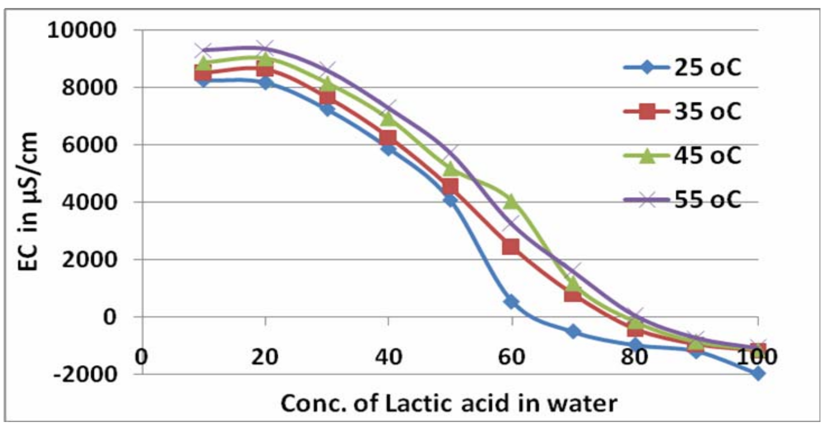

Fig. 2. Electrical Conductivity EC of Lactic acid in water.

The resistivity of aqueous solution of lactic acid shows different behavior. There is no measurable change in resistivity up to 50% concentration and increase remarkably above 50% concentration. Same type of behavior is observed for 25^0C, 35^0C, 45^0C and 55^0C temperatures. However, there is about 10-12 % decrease in resistivity values are observed when temperature is increased from 25^0C to 55 ^{o}C.

The lactic acid is non-conducting liquid in pure form. The solution of lactic acid in water shows electrical conductivity. The conductivity is maximum at lower concentration and decreases with increase in concentration of lactic acid in solution. This decrease in conductivity is observed for all four temperatures. The lactic acid shows initial increase in dielectric constant at lower concentration and decreases with further increase in concentration. For all four temperatures, same variation is observed.

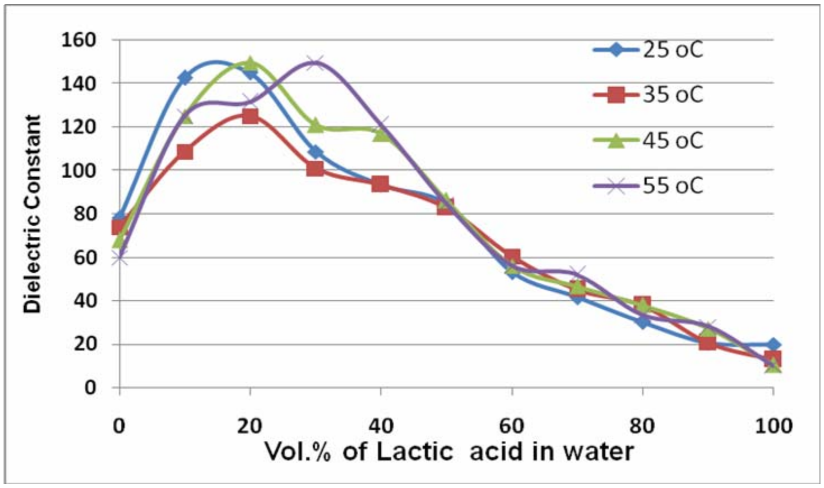

Fig. 3. Dielectric Constant in aqueous solution of Lactic acid.

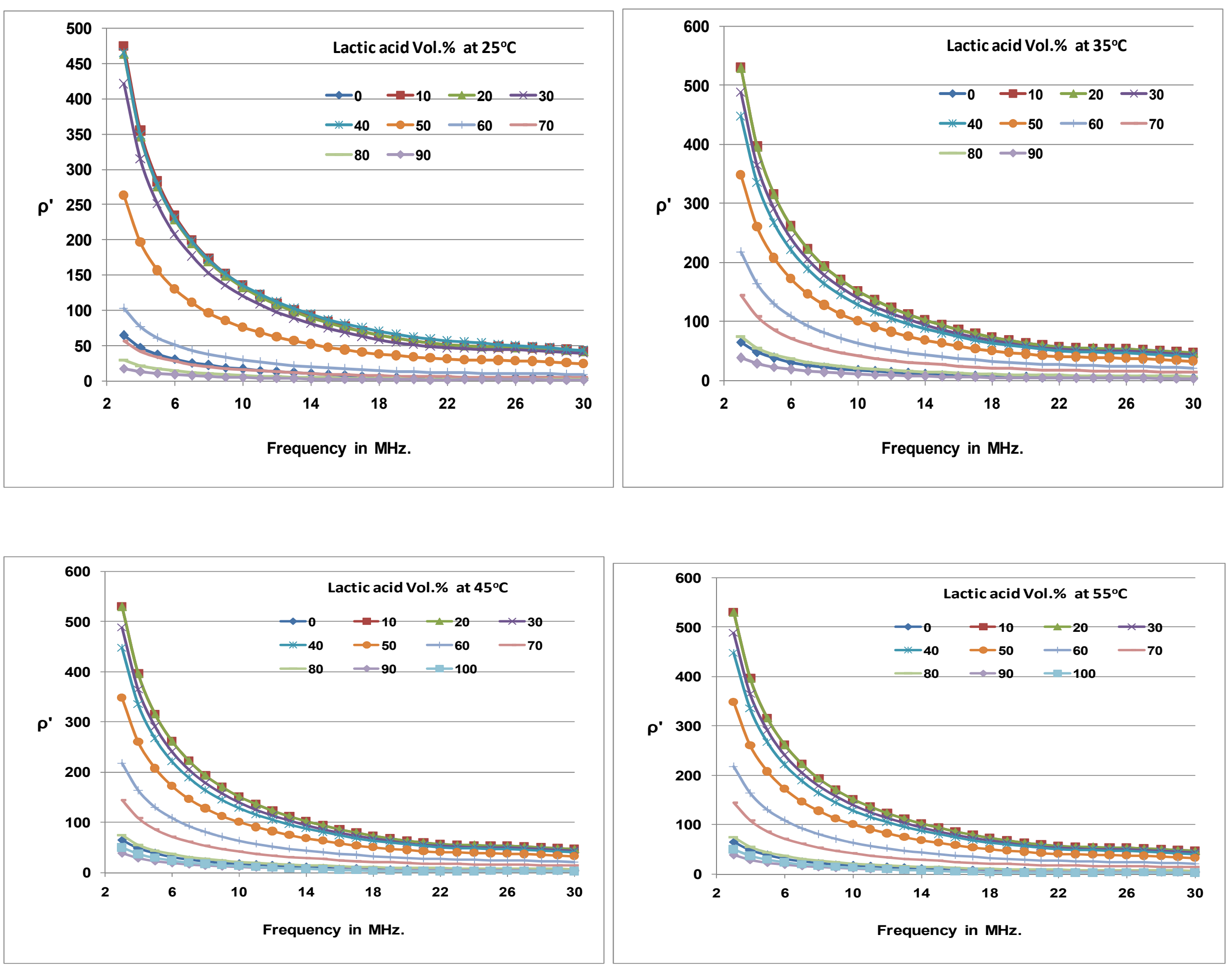

Fig. 4. Real part of ρ* for Lactic acid Solution at various temperature.

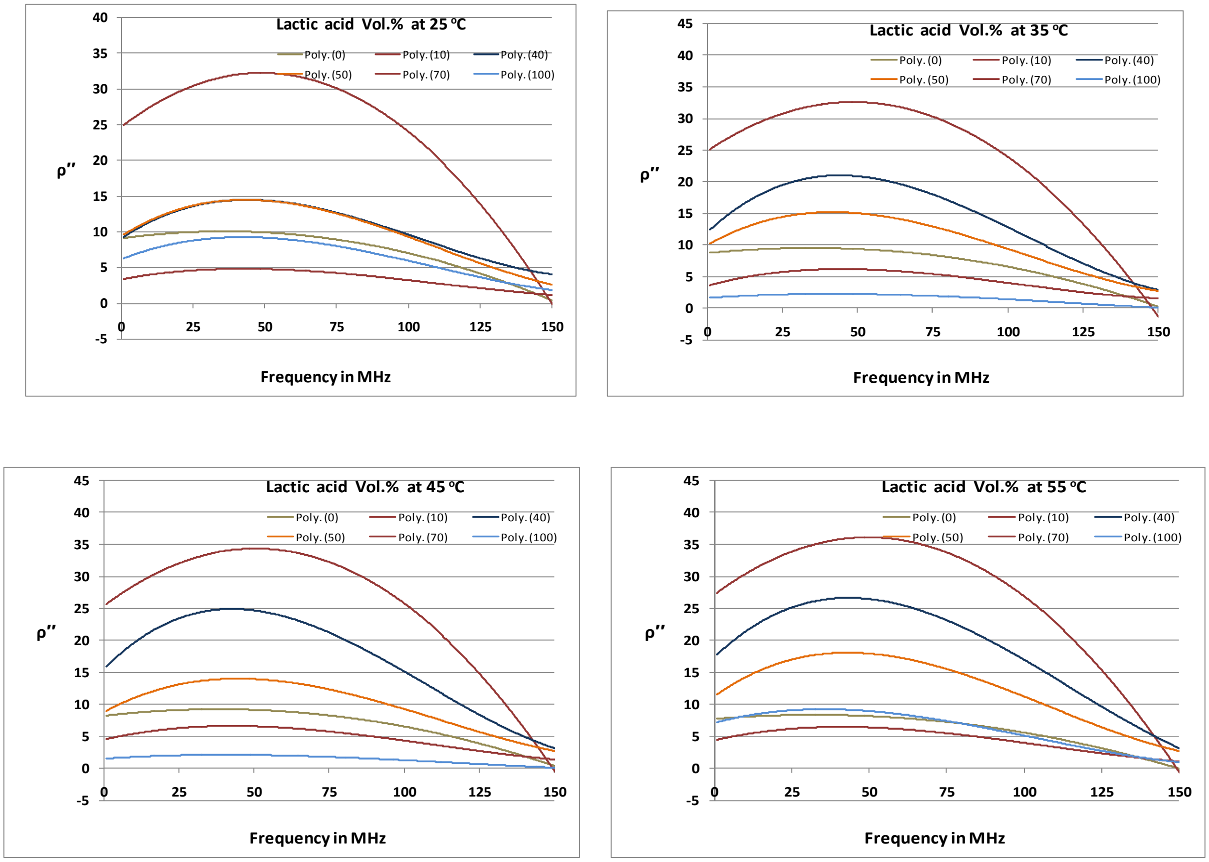

Fig. 5. Imaginary part of ρ* for Lactic acid Solution at various temperature

Conclusion:

Lactic acid solution shows decreases in Conductivity and Reflection Coefficient and increase in Resistivity with increase in concentration at various temperatures, Dielectric Constant of Lactic acid solution increases at starting i.e. for low concentration and decreases for higher concentration. At higher frequencies the real part of impedance of aqueous solution decreases. The variation of ρ' with frequency is different in aqueous solutions of different frequencies. The frequency response of the solutions is observed at lower frequencies in the range of 50 MHz. The imaginary part of complex impedance gives the losses or absorption of energy in the medium. The response of aqueous solutions of preservatives is in the lower frequency range of 150 MHz. The parameter value changes with change in temperature as well as concentration. The change in values of electrical parameter with temperature indicates the change in properties of solution with temperature. The present work helps to study the changes in foodstuff after adding the preservatives.

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