Vol. 17, No. 2, pp. 255-260 (2017)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Study of Electrical Impedance Parameters of Potassium Chloride Solution for Potential Applications in Food and Agriculture Processing

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ABSTRACT

Electrical properties are finding increasing applications in food and agriculture processing industries. Potassium chloride is known to be the most common, cost-effective salt used as a substitute application for reducing sodium salt concentrations in foods. In the present study, electrical parameters of *KCl* (Potassium Chloride) in distilled water have been studied with 10 different concentrations (0.1-1.3%) of *KCl*, at temperature of 29.3±0.4°C. Variations in resistance and capacitance with different concentration were taken using LCRQ bridge meter for frequencies 100 Hz and 1 KHz. The electrical resistance and impedance was found to be exponentially decreasing with concentration, while the conductivity was increasing with increase in concentration and vice versa. Many agricultural and food materials contain water and salt ions as the major constituents including potassium. Since salt ions can influence significantly the dielectric properties, it is urgent need to study the dielectric phenomenon related to different concentrations and nature of salt solutions. The study findings are useful in detection of freshness of various types of foods and have potential utility for quality assessment and control of concentrations of additives and other internal ingredients in samples of agricultural and biological origin, also including detection of preservatives and other toxicants in various types of cereals, beverages and dairy products.

Key words: Potassium chloride, Salt substitute, Electrical conductivity, Electrical impedance, Food freshness

Introduction

The method of electrical impedance is widely used for analysis of various ingredients and hence determining quality and safety of food and other agricultural products. Apart from electrical impedance resistance, capacitance and electrical conductivity have also been used in earlier studies for studying the electrochemical phenomenon taking placing in the agricultural processes and produce. Potassium chloride is used in food products for two purposes. Firstly for providing potassium enrichment to foods and secondly used as salt replacer to reduce sodium content in foods. Potassium chloride provides a salty flavour and can also play other functional roles like microbial management, protein modification, flavour enhancement etc. that can impact the taste, texture, and shelf life of food products (Chekri *et al*., 2012). Potassium chloride is widely used in many food products including baby formulas, cereals, frozen entrees, meats, snack foods (chips

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or crisps),sports or electrolyte drinks (Ali *et al*., 2011) and soups (Ghawi *et al*., 2014). Nowadays the healthy lifestyle and the healthy eating demand to minimize the sodium chloride salt (NaCl) intake. The salt concentration should be in appropriated proportion to provide the healthy eating (Kaltenecker *et al*., 2013). Food processors and researches now-a-days are keen to find novel technologies for the assessment of concentrations of various salts commonly used in foods. Potassium chloride is known as the most common and less expensive salt used as a substitute in applications in food industries demanding reduction of sodium concentrations in foods. It is the only salt that is generally recognized as safe (GRAS) status as most suitable replacement of sodium chloride (NaCl) salt. In a reported study conducted for the assessment of the effect of potassium chloride and potassium based emulsifying salts on sensory and textural properties of pasteurized process cheese, it has been found that the potassium chloride can serve as an effective replacer of commonly used salts (Patel, 2012). Studies have been conducted to replace sodium chloride by potassium chloride in cooked sausages with different level of replacement using an effective masking agent (Lilic *et al*., 2008). In various reported studies the electrical properties of aqueous solutions of potassium salts with various concentrations and sodium salts are determined by Impedance Spectroscopy (Szyplowska *et al*., 2013). Impedance spectroscopy is a rapid method that can detect bacteria in food within 24 h (Yang and Bashir, 2008). Electrical impedance studies to calculate tissue resistance and reactance of kiwifruit during ripening provide an insight of physicochemical interactions within the cell wall (Bauchot *et al*., 2000). Operational amplifier based modified Wheatstone bridge network has been used for measuring conductivity of potassium and sodium chloride solutions with change in concentrations (Rajendran and Neelamegam, 2004). Electrical conductivity has been found to be dependent on various factors such viscosity of solvent, inter-ionic interactions, concentration of solution etc (Fig. 1). The researches on properties and behaviour of food materials when subjected to

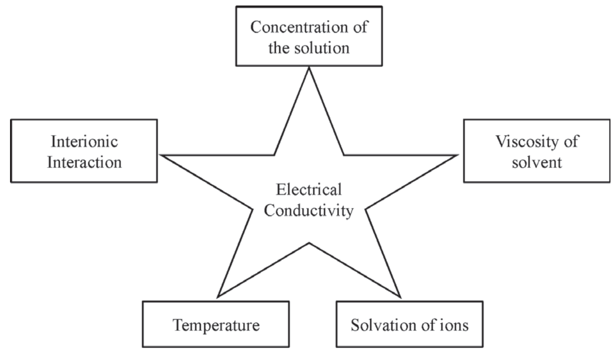

Fig. 1. Dependence of electrical conductivity on various factors

electromagnetic waves opens new perspectives and dimensions for food high value of impedance between electrode and tissue causes the power loss in the applications relating to implantable electrical stimulation (Li *et al*., 2005). Studies on dielectric properties of salt solutions suggest trends in the dielectric behaviour of many food materials (Venkatesh and Raghavan, 2004).

Materials and Methods

KCl and *NaCl* of chemically extra pure grade purchased from Sisco Research Laboratories (SRL) Pvt. Ltd., Mumbai was used. Distilled water was used for preparation of solutions. The concentrations of both the salts individually in distilled water were varied within 0.1-1.3% with 0.2% increments. A digital pen type thermometer (MEXTECH, Maharashtra) with resolution: 0.1 °F/ °C and range from -50°C to 300°C was used for temperature measurements. The experiment was repeated three times for each concentration at temperature 29.3±0.4°C. The experimental setup consists of a cylindrical plastic container fitted with one circular stainless steel electrode at base and another adjustable electrode on the top (Table 1). The setup of parallel plate capacitor is designed and constructed in institute workshop. The diameter of each circular stainless steel electrodes is 9.7 cm and thickness 0.4 cm. The distance between the plates was kept fixed at 4.5 cm. A 6018 LCRQ Bridge, scientific made, has been used for measurements. The 6018 is microprocessor controlled LCR Bridge and four point techniques ensure better measurement accuracies

Table1. Characteristic parameters of experimental set-up for electrical impedance analysis

Material of electrode	Stainless steel
Shape and size of electrode	Circular diameter 9.7 cm and thickness 0.4 cm
Distance between electrodes	4.5 cm
Temperature	29.3±0.4°C
Test frequency	100 Hz, 1 KHz
Modes	Series and parallel

(0.25%). The instrument also works in series and parallel modes. The test frequency modes that it provides are 100Hz and 1 kHz. Capacitance does depend on them indirectly through electrical conductivity. The variation in capacitance of salt solutions with concentration has been found to be based upon the following relation (Aqil, 2010),

$$C = \frac{\sigma A}{\omega d} \qquad \ldots(1)$$

The electrical conductivity (σ) depends upon resistance (R), area (A) and distance between electrodes (d) as,

$$\sigma = \frac{d}{RA} \qquad \ldots(2)$$

All the physical quantities (resistance, capacitance, electrical conductivity and electrical impedance) for two different salts (i.e. potassium chloride and sodium chloride) solutions have been studied in two different modes (series and parallel).

Results and Discussion

In series mode for the distilled water at 100 Hz the resistance measured is 3.272 KΩ, and at 1 KHz it is 3.250 KΩ (Fig. 2a). Thus the variation in resistance with frequency is 22 Ω. Ideally the resistance is independent of frequency. Here the difference could be because of some ions already present in distilled water. For parallel mode also the same variation was observed (Fig. 2b). In series mode for air gap as dielectric between the plates the resistance is 60 MΩ and capacitance is 8.6 pF, at 100 Hz, while the quantities are 5 MΩ and 7.5 pF at 1 KHz frequency. The resistance is 200 MΩ and capacitance is 5pF at 100 Hz, while the same quantities are 108 MΩ and 4pF at 1 KHz in parallel mode. Resistance varying with concentration follows exponential law (Fuller *et al*., 1968). The electrical resistance can be widely applied in diverse ionic systems to study various interactions in solution (Rogaè and Habe, 2006).It decreases due to availability of more and more ions to conduct electricity (Shackelford *et al*.,

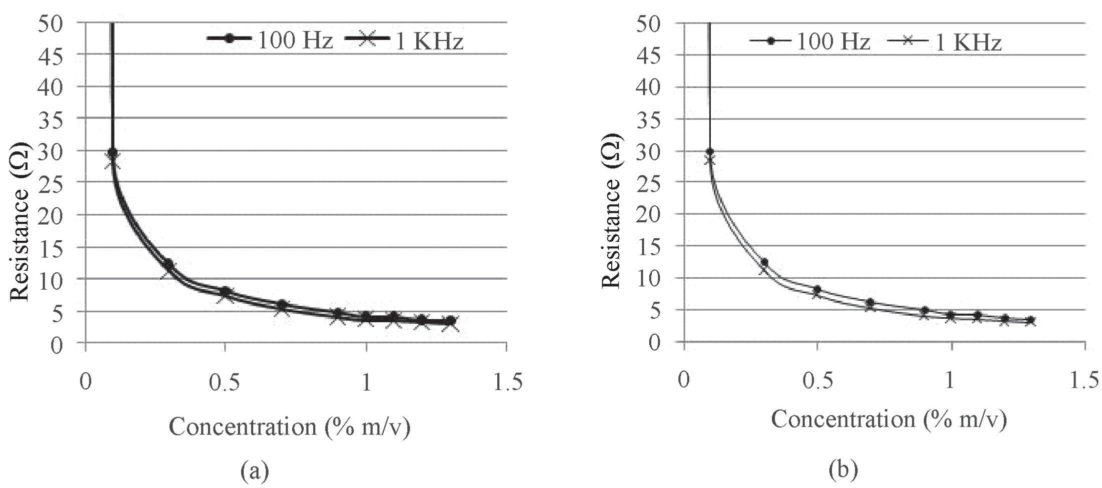

Fig. 2. Variation of resistance with concentration of *KCl* solution in (a) series mode, and (b) parallel mode

1999). On the dissolution of a strong electrolyte (KCl) in water, it has been found that the number of ions per unit volume gets enhanced due to which the solution resistance gets decreased. This fall in the resistive values causes the increase in the current values. This way the resulting current can be related to the ions in the solution. The relative permittivity of liquids depends on frequency and conductivity. The variation of capacitance with concentration can be explained from capacitance dependency on conductivity derived and given by equation 1. Thus the liquids with high electrical conductivity have greater capacitance (Behzadi and Fekri, 2013). The inverse relation between capacitance and frequency in equation 1 shows that the capacitance decreases as frequency is increased (Meraz *et al*., 2009) and vice versa. At low frequencies, the capacitor poses high reactance and currents are diverted to flow through the resistive branch. While as the applied frequency increases, the capacitive reactance decreases and more current is diverted away from the resistance (Fig. 3(a) and 3(b)). This is due to the fact that frequency changes will affect the condition of the ions in the material. The same behaviour has been obtained experimentally. The electrical conductivity has been calculated using equation 2 and for both series and parallel modes it increases with increase in frequency and vice versa (Fig.4 (a) and 4(b)). This is due to decrease of resistance and availability of more ions for conduction (Saeed *et al*., 2012). Thus electrical properties of potassium chloride solution can be studied finding electrical conductivity using impedance method (Shilajyan, 2013). Impedance is a frequency-dependent complex quantity and measured in Ω (Howey *et al*., 2013). Impedance of a series RC circuit is determined by the resistance (R) and the capacitive reactance (X_c) (Iqbal, 2013) using following formula,

$$|Z| = \sqrt{R^2 + X_c^2} \quad \ldots(3)$$

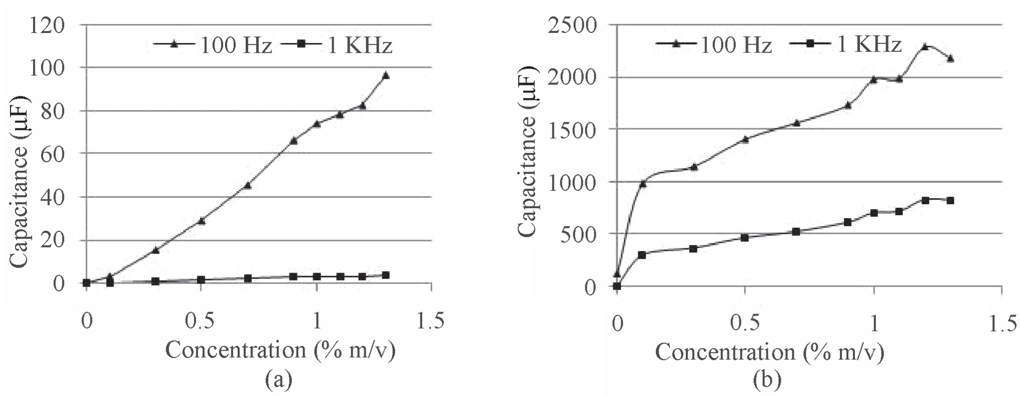

Fig. 3. Variation of capacitance with concentration of *KCl* solution in (a) series mode, and (b) parallel mode

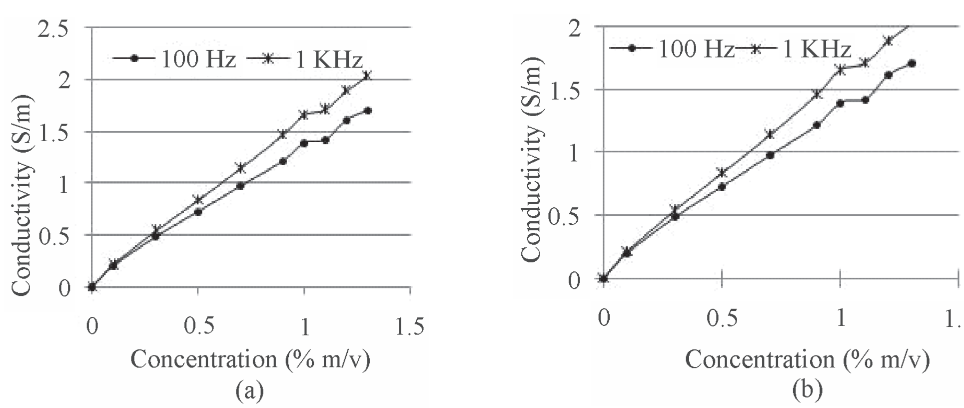

Fig. 4. Variation of conductivity with concentration of *KCl* solution in (a) series mode, and (b) parallel mode

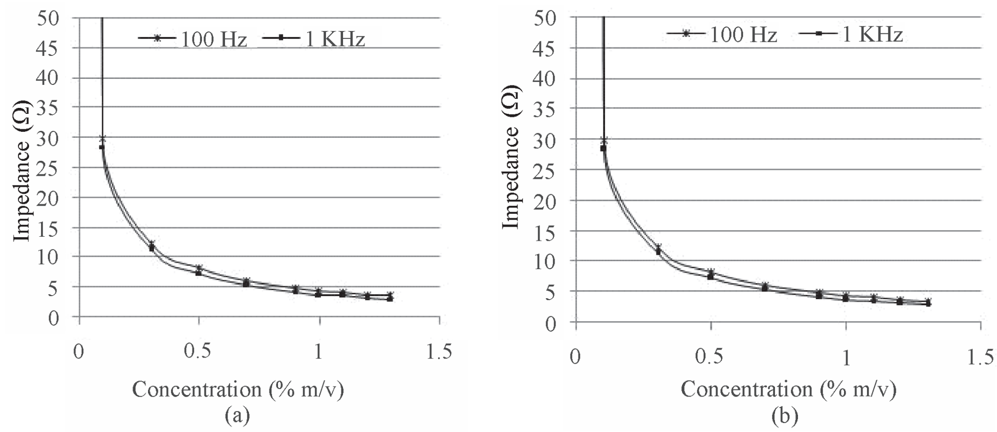

Fig. 5. Variation of Impedance with concentration of *KCl* solution in (a) series mode, and (b) parallel mode

and for parallel RC circuit impedance was determined using,

$$|Z| = \sqrt{\left[\left(\frac{RX_c^2}{X_c^2 + R^2}\right)^2 + \left(\frac{-X_c R^2}{X_c^2 + R^2}\right)^2\right]} \quad \ldots(4)$$

Impedance of *KCl*-water solution was found to decreases with increasing frequency (Fig. 5(a) and (b)). It is due to decreasing trends of R and X_c as concentration increases. This enlightens electrical impedance spectroscopy as a revolutionary tool for detecting freshness of liquid food items. The change in concentration of salts in fluids in intracellular and extracellular regions significantly affects the wellness of plant or animal tissues (Weyer *et al.*, 2012). This change in salts concentration can easily be detected non destructively using electrical impedance spectroscopy technology (Kaltenecker *et al.*, 2013). This research will find significant role in detecting freshness of foods and agricultural commodities. After harvesting the fruits/vegetables the electrical properties of fresh produce changes with storage time and conditions. Also in fish/other meat foods after mortality the intracellular fluid exudates through cell membrane to extracellular region causing change of electrical properties of skin and muscle tissues. Thus the present research study finds use in developing freshness index for such foods.

Conclusions

Potassium is a predominant intracellular mineral which is an important component of a variety of cellular processes. Not only this but it is found that it is responsible for good bone and heart health. The resulting definite trends of electrical impedance (decreasing with increasing concentration and vice versa) are useful for detection of salt concentrations in food products by means of developing suitable sensors. The study of electrical properties arising due to changes in the biophysical processes taking place in the agricultural produce is of great importance in various scientific and industrial applications. The food processing industries and agriculture today is in great shortage of smart portable technologies for the real time study of electrical properties of agricultural and biological samples for further evaluation of their correlation with the various phenomenons to ultimately contribute to sustainable food production. The research study revealed that the alterations in various factors affecting food quality are reflected through alterations in electrical properties of foods. Due to the strong demand from food industry for use of non-destructive methods for assessing food quality, electrical properties are potential indicators for quality evaluation.

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Received: August 05, 2017; Accepted: November 27, 2017