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Construction of an Ohmic Heating Apparatus and Evaluation of Electrical Conductivity of Sweet Lime Juice

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Abstract- Different emerging technologies for thermal food processing were developed and today's era demands for those technologies which result in high quality with minimum processing. Ohmic heating is the volumetric method of heating in which heat is generated internally within the food mass. This study was aimed to design a laboratory scale ohmic heating system and concluded by evaluating the behaviour of electrical conductivity of sweet lime juice with temperature. Sweet lime juice was heated on static ohmic heater at different voltages in the range of 30-60V and measurements were made at 27 to 85.7ºC after regular 2 min intervals with electrical conductivity range of 1.0933 to 3.760 S/m. Electrical conductivity shows linear relationship with temperature up to certain value of temperature and it is the critical parameter for designing of an ohmic heating apparatus.
Keyword- Ohmic heating; Temperature; Electrical conductivity; Sweet lime juice; 1.5% NaCl solution

I. INTRODUCTION

Ohmic heating is a thermal process in which heat is generated internally by passing alternating electrical current through a body such as a food system, that serves as an electrical resistance; therefore this technology can also be referred as electroconductive heating, joule heating, electroheating, electrical resistance heating and direct electrical resistance heating (Sastry, 2008[1]). The main advantage of ohmic heating is the rapid and relatively uniform volumetric heating in which we can use large size heating tubes with lower shear rates and it allows the heating of fragile particles. Electrical conductivity is the main parameter in ohmic heating and for purely liquid foods, the electrical conductivity increases linearly with temperature but in overall it falls as the concentration of solids increases (Palaniappan and Sastry, 1991[2]). Proper electric conductance management is essential to successfully apply ohmic heating (Castro et al., 2004[3]; Fryer & Zhang, 1993[4]; Wang et al., 2001[5]). During batch heating tests, the temperature difference in the smaller ohmic unit (4.8 cm long) ranges from 1 to 2 ºC and in the larger unit (30.4 cm long) it showed considerable differences in temperature along its axis for different voltage gradients (Qihua et al., 1993[6]). A wide range of ohmic heating applications have been reported in different products such as sour cherry juice (Icier and Ilicali, 2004[7]); orange juice (Leizerson and Shimoni, 2005[8]; Icier and Ilicali, 2005a[9]); apple, orange, and pineapple juices (Amiali et al., 2006[10]); grape juice (Icier et al., 2008[11]) and pomegranate juice (Yildiz et al., 2008[12]; Darvishi et al., 2013[13]). Sarang et al., 2009[14] also studied the residence time distributions of particulate foods in a continuous flow pilot-scale ohmic heater. In ohmic heating processing, the effect on the quality and shelf-life of apricots in syrup was studied by using a continuous pilot scale ohmic unit which comprises a hopper containing the product, a pump, a control system, a heating column, a holding and cooling tube, a storage tank for recycling, an aseptic tank to store the treated product and an aseptic filler (Pataro et al., 2011[15]). The objective of this study is to construct an ohmic heating system on laboratory scale and its use to evaluate the critical parameters, such as electrical conductivity and temperature of sweet lime juice.

II. MATERIALS AND METHODS

A. Design of Ohmic Heating System

Experiments were carried out on a lab scale ohmic heating system as shown in Figure 1 with technical specifications as shown in Table 1. The system consisted of a cylindrical pyrex glass chamber (length: 0.2 m and inner diameter: 0.045 m), two SS 304 electrodes polished with teflon coating having 0.18 m gap between them. Variable power supply was obtained using dimmerstat (0-270V) from domestic supply (220 V and 50 Hz). Digital thermometer, ammeter and voltmeter were attached with the system to take the readings manually.

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Figure 1: Experimental Ohmic Heating System

Table 1: Technical Specification of Ohmic Heating Chamber

Parameters	Dimensions
Distance between electrodes	0.18 m
Effective diameter of electrode	0.045 m
Area of electrode	1.59×10^{-3} m^2
Volume of chamber	2.861×10^{-4} m^3

B. Electrical Conductivity Determination

Electrical conductivities of the samples were calculated from voltage and current data recorded by the system, using the following equation:

$$\sigma = (1/R)(L/A) \quad (1)$$

where σ is the electrical conductivity of the sample (S m^{-1}), L is the space between electrodes (m), A is the cross section area of the electrodes (m^2), the ratio of L/A is known as the cell constant of the ohmic heating unit and its value is 1.13 cm when filled to a volume of 2.861×10^{-4} m^3. R is the resistance of the sample (Ω), determined from the voltage (V) and current (I).

C. Experimental Apparatus Testing

Experiments were carried out with 1.5% NaCl solution at different voltages (20, 30, 40 and 50 V) to verify the apparatus.

D. Experimental Apparatus Performance

1) *Sample Procurement:* Fresh, mature, yellowish-green sweet lime fruits without any defect on visual inspection were procured from local market.
2) *Sample Preparation:* Sweet lime fruits were washed, peeled off and cut into pieces. Fruit pieces were crushed in juicer after removal of seeds. The juice was filtered to remove soggy mass and 1.5% NaCl solution was added to balance the sensory parameters of the juice. The flow chart for sweet lime juice preparation is as shown in Figure 2.

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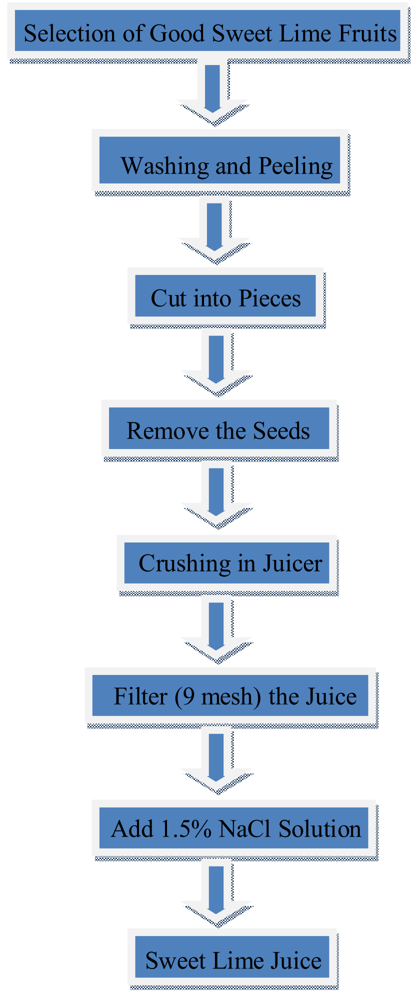

Figure 2: Flow Chart for Sweet Lime Juice Preparation

E. Electrical Conductivity of Sample and Bubble Formation

To evaluate the process applicability in liquid foods, sweet lime juice was heated in the experimental ohmic heating setup. Electrical conductivity values were obtained as a function of temperature. Subsequently, the electrical conductivity of the samples in the temperature range of 27 to 85.7°C was calculated. Temperature, current and voltage applied were noted down after each 2 min interval till the temperature of sample reached at 85.7ºC. During the ohmic heating experiments, using sweet lime juice, bubble formation was observed.

III. RESULT AND DISCUSSION

A. Experimental Apparatus Testing

Experimental apparatus was tested with relationship between temperature and electrical conductivity of 1.5% solution of NaCl as shown in Figure 3.

B. Electrical Conductivity and Possible Causes for Bubble Formation

The change in electrical conductivity of sweet lime juice with temperature during ohmic heating at four different voltages is shown in Figure 4. According to the measurements from experiment, the electrical conductivity increased with temperature but with addition of 1.5% NaCl solution in sweet lime juice, the electrical conductivity were increased to higher values. This variation is due to increased ionic mobility and is a function of concentration of individual ions. Ohmic heating curves were simulated using one empirical model of changed electrical conductivity. The linear model (Sarang et al., 2008[16]; Bozkurt and Icier, 2010[17]; Icier and Ilicali, 2005a[9]) showed a linear trend with increasing temperature values as shown in Equation 2.

$$\sigma = B1T + C1 \tag{2}$$

where B1 and C1 are constants. During heating process, bubbles were formed when the temperature of sample reached above 79ºC and the highest value of electrical conductivity at 60 V is 3.760 S/m. It may be due to the different chemical reactions taking place during heating. Different authors gave different hypotheses and suggestions on bubble formation during ohmic heating. According to Palaniappan and Sastry (1991[2]) reported that fruit juices were acidic resulting in the potential for producing electrolytic hydrogen bubble. Zhao and Kolbe (1999[18]) observed bubble formation near the electrodes during ohmic heating of 2% saline solution. Their possible explanation was that the gas bubbles were the result of either water boiling, due to localized high current densities, or products of various oxidation/reduction reactions. Castro et al. (2004[3]) explained that in an un-pressurized heater, if air is occluded in the sample, the air bubble will expand with temperature, with the pressure remaining constant. This would mean that bubble volume would increase with temperature. Thus air, which can be roughly considered to be at zero electrical conductivity, will increase in area, tending to reduce the electrical conductivity of the mixture. Sarkis et al. (2013[19]) observed that bubbles during ohmic heating were caused by water boiling due to temperature gradients inside the cells and is influenced by a number of factors such as higher solids content and electric field strength.

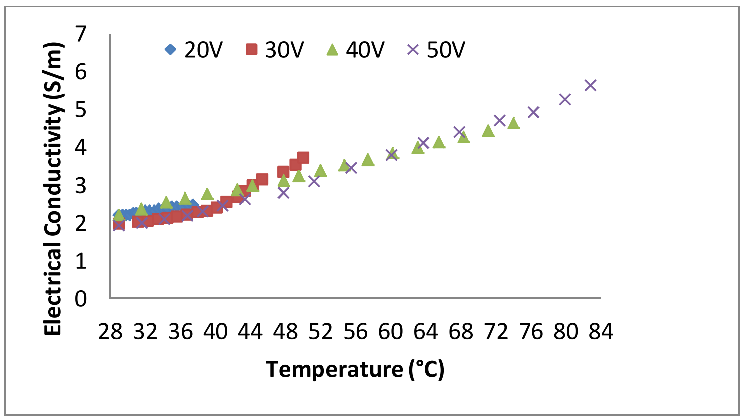

Figure 3: Changes in Electrical Conductivity of 1.5% NaCl Solution with Temperature

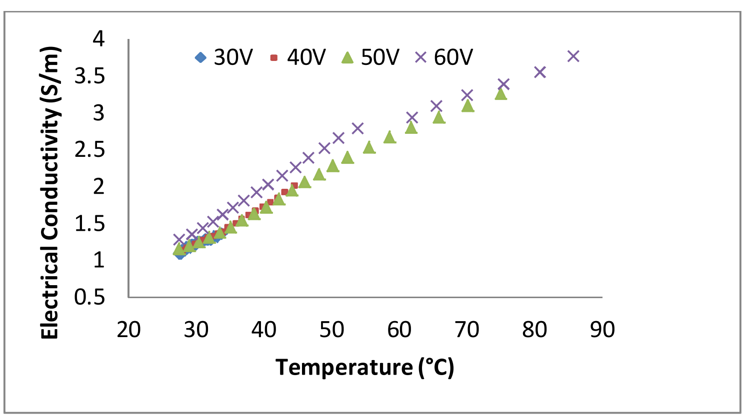

Figure 4: Changes in Electrical Conductivity of Sweet Lime Juice with Temperature

IV. CONCLUSION

Ohmic heating is significantly different from traditional thermal processing techniques in which heating takes place throughout the entire volume of the food. The electrical conductivity depends on temperature linearly. The rate of change of electrical conductivity with temperature at 60 V was higher than other voltages applied. The results showed that the linear model was found to be the most suitable for explaining the electrical conductivity curve of the ohmic heating of sweet lime juice and depends on the product type with R^2 values from 0.9728 to 0.9958.

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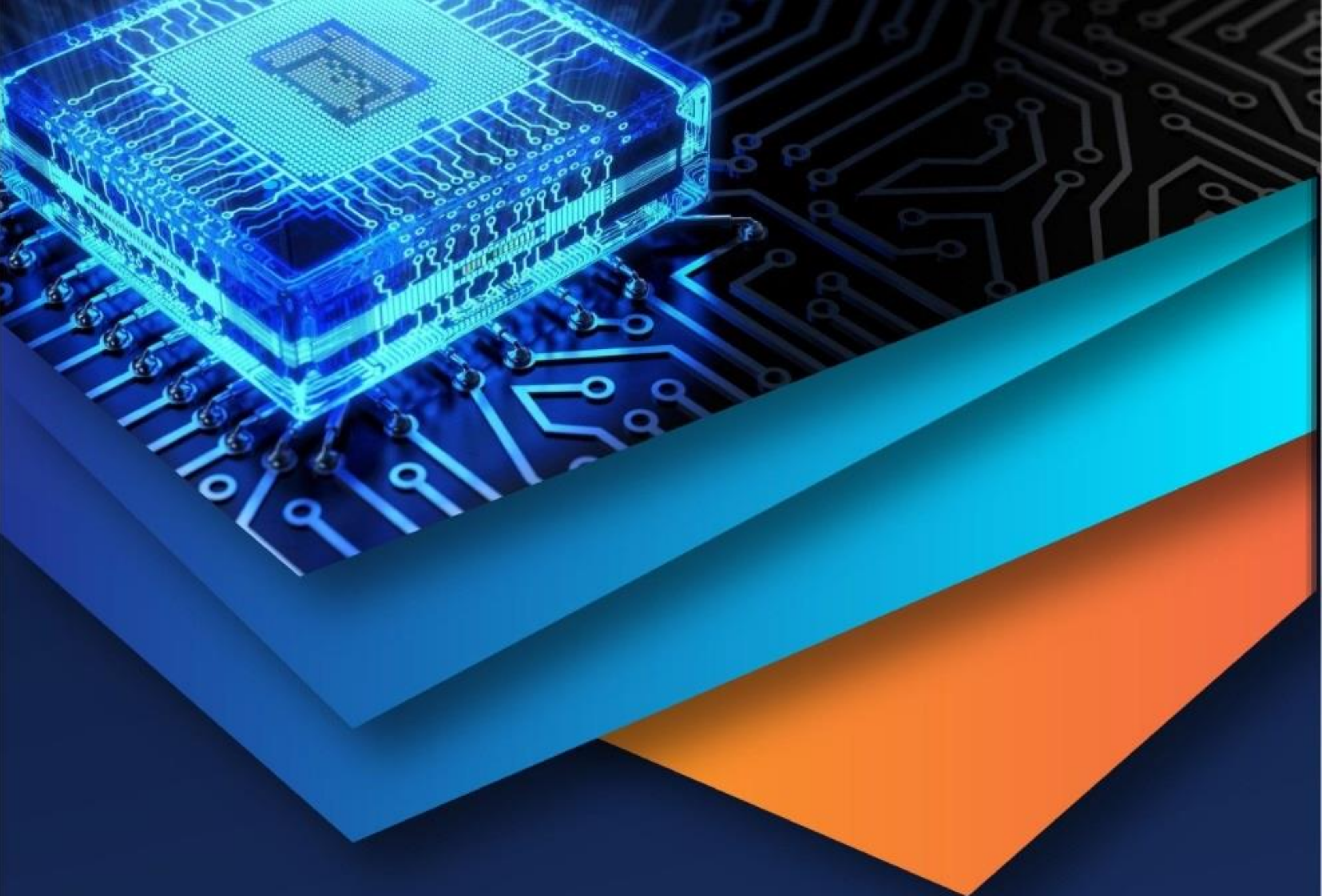

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