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Ohmic Heating Behavior of Certain Selected Liquid Food Materials

Yin-qiu Kong, Dong Li, Li-jun Wang, Bhesh Bhandari, Xiao Dong Chen, and Zhi-huai Mao

Abstract

Ohmic heating is an alternative fast heating technique for food products, which takes its name from Ohm's law. The basic principle of ohmic heating is the conversion of electrical energy into heat, resulting in internal energy generation. In this study, an experimental ohmic heating unit was designed and fabricated. Four kinds of liquid food materials (tap water, fruit-vegetable juice, yogurt and 0.5% aqueous sodium chloride solution) were heated on this laboratory scale static ohmic heater to evaluate the device's performance. Different voltage gradients (7.5V/cm, 11.25V/cm, 15V/cm, 18.75V/cm, 22.5V/cm and 26.25V/cm) were applied to study the heating behavior of liquid food materials. Results indicated that the voltage gradient significantly influenced the ohmic heating rates for all four materials tested. The electrical conductivity also changed significantly with temperature.

KEYWORDS: ohmic heating, heating rate, liquid

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INTRODUCTION

Ohmic heating, also known as Joule heating, is a novel heat treatment process wherein alternating electric current is passed through the food materials with the primary purpose of heating them (Sastry & Barach, 2000). The food material between electrodes has a role of resistance in the circuit (Icier & Ilicali, 2005a). Heat is generated instantly and volumetrically inside the food materials (joule effect) due to the ionic motion. The amount of heat generated is directly related to the current induced by the voltage gradient in the field, and the electrical conductivity of the materials being heated (Icier & Ilicali, 2005b).

Ohmic heating, which utilizes the inherent electrical resistance of food materials to generate heat, is becoming a promising method for food processing (Wang et al., 2007). In conventional heating, heat transfers from heated surface to the product interior take place by means of convection and conduction. Heat transfer is slow and can result in thermal lags in food mixtures. Ohmic heating is volumetric in nature and has the potential to reduce over-processing by virtue of its inside-outside heat transfer pattern (Lima, 2007; Zareifard et al., 2003). Past research works have shown that ohmic heating exhibits several comparative advantages over the conventional food processing technologies. Firstly, liquid-particle mixtures can be heated uniformly under certain conditions. The product does not experience a large temperature gradient within itself, even when particulates are present (Eliot et al., 2001). Heat distribution throughout the product is far more rapid and even, which can result in better flavor retention and particulate integrity compared to conventional processes. Secondly, heating temperature and time could be accurately adjusted or controlled. High temperatures can be rapidly achieved with this technology and energy conversion efficiencies are very high (Lima, 2007). In addition, electro-technologies for food processing are cleaner, more energy efficient and environmentally friendly than conventional methods currently in use (Shirsat et al., 2004). Ohmic heating holds advantages in producing safe, wholesome and nutritious convenience food products for consumers, and recently this renewed technology has been applied in food production successfully.

The ohmic heating concept is not new and was widely used in the 19th century to pasteurize milk. Apparently due to the lack of inert materials for the electrodes this technology was abandoned (Castro et al., 2003). In the 1980s, the technology was once again revived and has achieved some industrial applications, including the pasteurization of liquid eggs and the processing of fruit products (Sastry, 2007). Recently, the world's food industry has focused increasing attention on ohmic heating of pumpable food because the products obtained are of clearly superior quality than those processed by conventional technologies (Castro et al., 2003). Now this processing technology is being used throughout the world on a wide variety of products. The application of ohmic heating include sterilization, pasteurization, processing of fouling-sensitive material, blanching, thawing, on-line detection of starch gelatinization (Li et al., 2004), and as a pretreatment for drying and extraction. However, most of the applications are still at small scale and are yet to be commercially exploited.

In a review of this attractive technology, the use of static heaters has been reported in several studies for the measurement of electrical conductivity of foods during ohmic heating (Halden et al., 1990). Palaniappan and Sastry (1991) studied the effects of insoluble solids and applied voltage on electrical conductivity of the pre-pasteurized carrot and tomato juices during ohmic heating. Qihua et al. (1993) made performance evaluation of an ohmic heating unit for liquid foods. They reported that the temperature affected the electrical conductivity values of fresh orange juice, but the relationships were not given. Castro et al. (2004) studied the effect of electrical field strength during ohmic heating of strawberry products. Ohmic heating is currently being used for the processing of whole fruits in Japan and the United Kingdom (Sastry & Barach, 2000).

Many reports have indicated that a superior product quality can be obtained with a well-designed ohmic heating system because of the decrease in processing time as a result of no thermal lags (Lima, 2007). The objective of this research was to design, fabricate and evaluate the performance of a static laboratory scale Ohmic heating system. The performance of this self-designed setup was evaluated by heating four kinds of liquid materials (tap water, fruit-vegetable juice, yogurt and 0.5% aqueous sodium chloride solution) under different voltage gradients. Effects of different electrical field strengths and temperatures on the heating rate and electrical conductivity were determined.

MATERIALS AND METHODS

MATERIALS

Four types of the most common and typical liquid materials in our daily life were employed in this experiment: tap water; fruit-vegetable juice (mixture of tomato, strawberry and hawthorn flavor, Nongfu Spring Co., Ltd, China); original flavor

Family-Packed Yogurt Series (Inner Mongolia Yili Industrial Group Co., Ltd, China); aqueous sodium chloride solution of 0.5% concentration. Some properties of fruit-vegetable juice and yogurt used are shown in ***Table 1***. The four types of liquid samples' electrical conductivities were 0.058, 0.191, 0.609 and 0.992S/m at room temperature 25^{o}C respectively.

Table 1. Some properties of fruit-vegetable juice and yogurt used

Property	Fruit-vegetable juice	Yogurt
pH (20 ^{o}C)	3.65	4.25
Acidity (%)	0.45	1.07
Solid components (%)	Carbohydrate ≥ 6 Protein ≥ 0.01 [K] ≥ 6×10^{-3}	Protein ≥ 2.3 Fat ≥ 2.5 Nonfat milk solids ≥ 6.5

ELECTRICAL CONDUCTIVITY

The most important parameter in ohmic heating is the electrical conductivity of the materials. Electrical conductivity is a function of food components. Ionic components (salts), acids, and moisture increase the electrical conductivity, while fats, lipids, and alcohols decrease it. Electrical conductivities of samples can be calculated from voltage and current data using the following equation (Wang & Sastry, 1993):

$$\sigma = I\mathrm{L}/U\mathrm{S}$$

Where σ is specific electrical conductivity (S/m), I is the current through the sample (A), U is the voltage (V), S is the area of cross section of the sample (m^2), L is the gap between the electrodes (m).

DESIGN OF OHMIC HEATING SETUP

Important design considerations in ohmic heating setup include power requirements (personal and equipment safety to avoid unforeseen accidents), frequency of alternating current (usually 50-60 Hz), current density, applied voltage, heater geometry, electrode configuration, the distance between electrodes and electrolysis (metal dissolution of electrodes, especially at low frequencies). Additional design considerations while using the food system in an ohmic heater include the type of product and its properties, especially electrical conductivity and heating rate (Lima, 2007).

The schematic diagram of ohmic heating experimental setup designed and fabricated in this work is shown in ***Fig. 1***. It composes of two major parts: an ohmic heating unit and a data acquisition system. The ohmic heating unit include a variable transformer power supply (AC, 50Hz, Rated Load: 0.5, 0-250V, 2.5A, WuXi Voltage Regulator Factory, China), which was used to supply single-phase alternating current (50Hz sine wave), flat stainless steel electrodes and a heating trough made of Teflon. The data acquisition system consisted of the following elements: Digital Conductivity Meter and Thermoscope (DDS-12, ShangHai KangYi Co., Ltd, China) connected to the T type thermocouple covered with silicon, by which the temperature and electrical conductivity can be read and recorded with a digitron meter; two digital multimeters (DT9105A digital multimeter & ME-540 digital multimeter, SOAR Corporation, Japan) monitored the voltage across and current intensity through the samples.

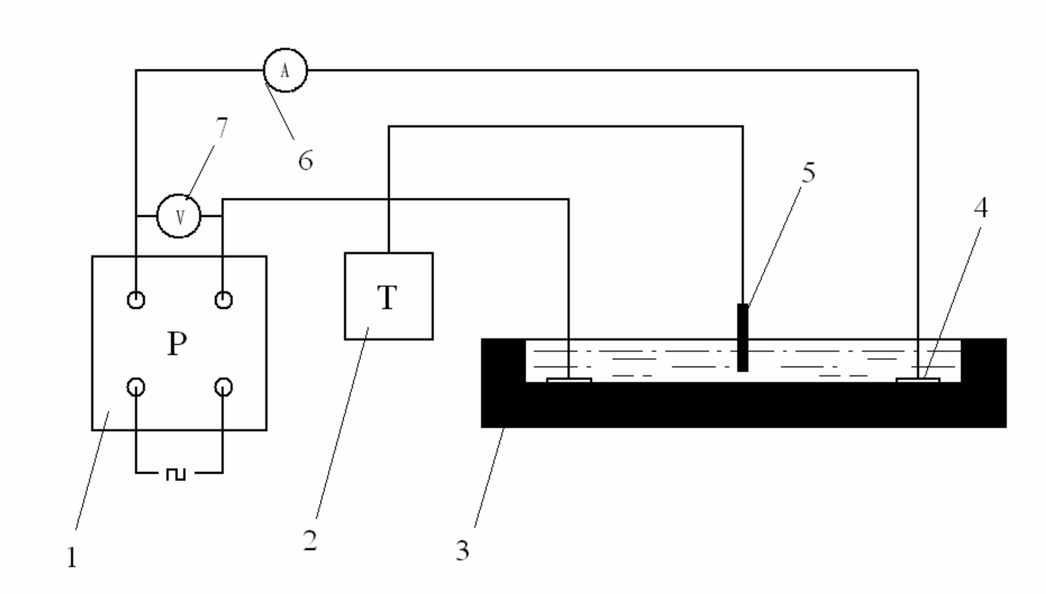

Fig. 1. Schematic diagram of the laboratory scale ohmic heating experimental setup: 1, variable transformer power supply; 2, digital conductivity meter and thermoscope; 3, ohmic heating trough; 4, electrodes; 5, T type thermocouple; 6 and 7, digital multimeters.

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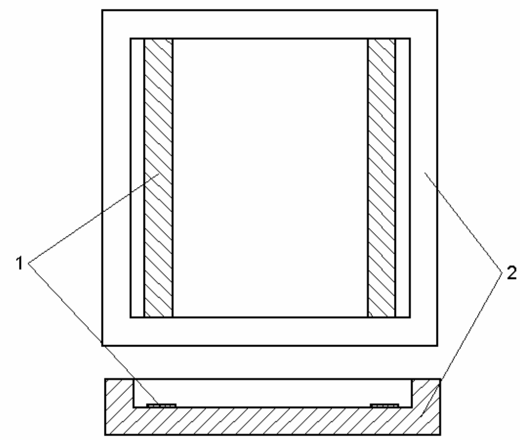

Fig. 2. Detail of the ohmic heating trough: 1, Stainless steel electrodes all along the length; 2, Teflon trough.

Detail of the heating trough used in the experiments appears in ***Fig. 2***. The home-made rectangular trough (100×100×10 mm) was employed in which the liquid samples were held and heated. The heating trough was made of Teflon block of 10mm thickness, which is corrosion-resistant, non-adhesive, thermally stable, has good lubrication and insulation property, and is nontoxic. Different from the traditional placement of the electrodes, in this study, two flat electrodes (100×10 mm) were both positioned at the bottom of the trough with 80mm midline distance between two electrodes. Electrodes in ohmic heating play a vital role by conveying the current uniformly into the heating medium. Various materials, so far, have been used as electrodes in different ohmic heating studies and applications. We used the stainless steel electrode, which has been reported to be the most electrochemically active electrode material during ohmic heating at all the pH values (Samaranayake & Sastry, 2005). Electrodes were connected to the variable transformer power supply. The samples were placed in the heating trough, and then the thermocouple was inserted and fitted into the center of the sample appropriately.

OHMIC HEATING OF LIQUID FOOD MATERIALS

The performance of the ohmic heating unit was evaluated based on the batch experiments. Samples of approximately 70 mL were poured into the ohmic trough, and then the thermocouple was inserted and fixed into the geometric center of the trough to continuously monitor sample temperature. The conductivity of each sample was measured by the digital conductivity meter prior to the ohmic heating. All the ohmic heating experiments were started at room temperature (about 25^{o}C). Power source was turned on and the samples were ohmically heated up to a steady temperature using different output voltages to obtain different voltage gradients (tap water 26.25V/cm; fruit-vegetable juice 11.25, 15, 18.75 and 22.5V/cm; yogurt 7.5, 11.25 and 15V/cm; 0.5% aqueous sodium chloride solution 7.5 and 11.25V/cm). Values of voltage, current and temperature were recorded at 30 s intervals. The time constants of the silicon coated temperature sensors were determined by calibrating them in calibration solutions.

RESULTS AND DISCUSSION

The whole experimental setup showed ideal performance in principle. Variable transformer provided steady output voltage, which was directly monitored by the digital multimeter. The voltage and current could be varied from 0 to 250 V and from 0 to 2.5 A. Most of the liquid materials could be heated from room temperature to 70-80 ^{o}C efficaciously. The data acquisition system performed satisfactorily and measured the temperature, voltage and current of an AC field simultaneously.

During the batch heating tests, uneven heating throughout the samples were observed clearly through visual observation if heated for long period. When the samples boiled severely in the middle region between the two electrodes, the lateral regions remained plain. One factor contributing to the temperature difference may be the nonuniform electrical field and heat dissipation. Since the twin electrode plates were both positioned at the bottom of the trough, the formation of the electric field in the whole trough was not parallel or uniform. Electric field distributed more evenly and its intensity was comparatively stronger in the middle region between the two electrodes; but in the electrode plates and lateral regions, the electric field intensity was much weaker, where the heating phenomenon was not very obvious. As a matter of fact, the design of the trough may have been a bit unreasonable. In other study, De Alwis et al. (1990) found that during ohmic heating electrode surface temperature were usually 2-3 ^{o}C lower than the bulk. They attributed that the electrode can only heat by its resistance which is very low. It is only the conduction from the liquid that will cause the

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temperature rise. So if the system is not well mixed, temperature differences between the electrode and the food materials could be observed.

Formation of bubbles was observed during the heating process, especially when the temperature of heated samples reached around 50 °C. The reason for this could be the release of gas in the liquid due to some electro-chemical reactions. Palaniappan and Sastry (1991) reported that fruit juices are acidic resulting in the potential electrolytic hydrogen bubble formation. Zhao et al. (1999) also discussed that the gas bubbles were the results of either water boiling due to localized high current densities or the formation of by-products of various oxidation/reduction reactions (e.g. H_2 or O_2 gas). The bubbles occurred much more quickly in high voltage gradient operations. Therefore releasing the bubbles needs serious consideration in designing the static ohmic heaters.

Typical ohmic heating curves for the samples under different voltage gradients are presented in ***Figs. 3, 4 and 5***. The non-linear and non-exponential heating curves observed were unexpected under a constant voltage gradient in the static ohmic heating system. As the temperature increased, the slope of temperature curves decreased i.e. the heating rate decreased. The highest temperature liquid materials could reach was merely 80 °C, less than expected up to 100 °C boiling. The concave shape of curves indicated that considerable heat losses occurred to the surroundings during the heating process. This is probably because the heating trough was not sealed and adiabatic. During the heating process, vapor evaporation and heat transfer to the outside environment resulted in a large amount of heat dissipation. Especially at high voltage gradients the heat loss due to vapor formation from the samples was observed. As shown in ***Figs. 3, 4*** and ***5***, the heating rate increased considerably as the voltage gradient increased. The heating rates may be affected by varying either the electric-field strength or product electrical conductivity. At higher voltage gradients, the current passing through the sample was higher and this induced the heat generation faster. When higher voltage gradients was applied, samples showed an ideal range where there was an exponential or linear trend of temperature rise from 30 °C to 60 °C at the first 5minutes. This may be as a result of lag of heat dissipation. During the ohmic heating process, heat penetrates into the whole juice and yogurt samples rapidly and accelerates the collision between internal molecules, causing the surface dehydration of juice and yogurt. Meanwhile, lipid acts as a surface-active agent. It moves to water-air interface quickly and also interacts with protein by hydrophobic bonding, which enhances the film formation on the surface. The film formation on the surface was observed distinctly for the juice and yogurt samples above 50 °C.

The relationships between temperature and current with time are shown in ***Figs. 3, 4*** and ***5***. The profiles showed that the temperature of the samples always increased up to a critical temperature with time and the heating rate decreased until the temperature became relatively constant. The changes in the current profiles were also remarkable. As shown in ***Figs. 3(b), 4(b)*** and ***5(b)***, the current first increased with time to a certain level, and then remained steady or decreased (especially under high voltage gradients). During the ohmic heating process, while the voltage is kept constant, current flow changes only depend on the electrical conductivity of liquid materials. So, the relationships between temperature and current presented in ***Fig. 6*** actually showed the electrical conductivity change of the liquid material samples with temperature during ohmic heating.

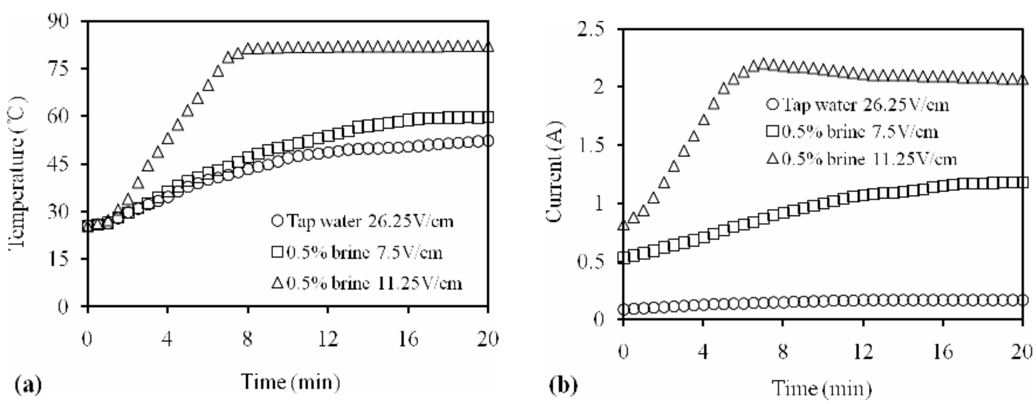

Fig. 3. Ohmic heating curves of tap water and 0.5% aqueous sodium chloride solution at different voltage gradients: (a), temperature profiles; (b), current profiles.

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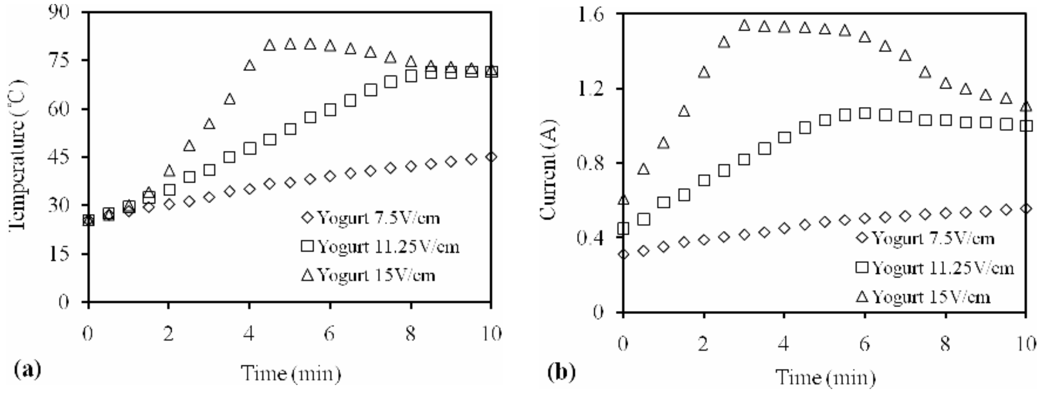

Fig. 4. Ohmic heating curves of Yili original flavor yogurt at three different voltage gradients: (a), temperature profiles; (b), current profiles.

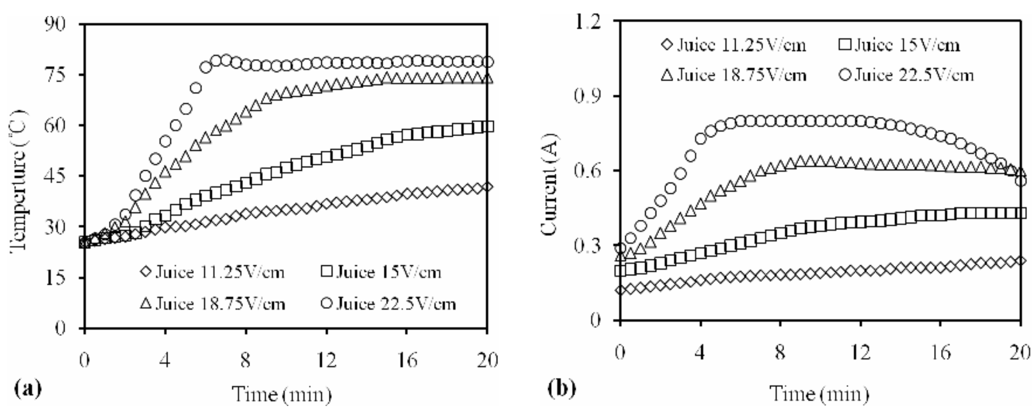

Fig. 5. Ohmic heating curves of fruit vegetable juice at four different voltage gradients: (a), temperature profiles; (b), current profiles.

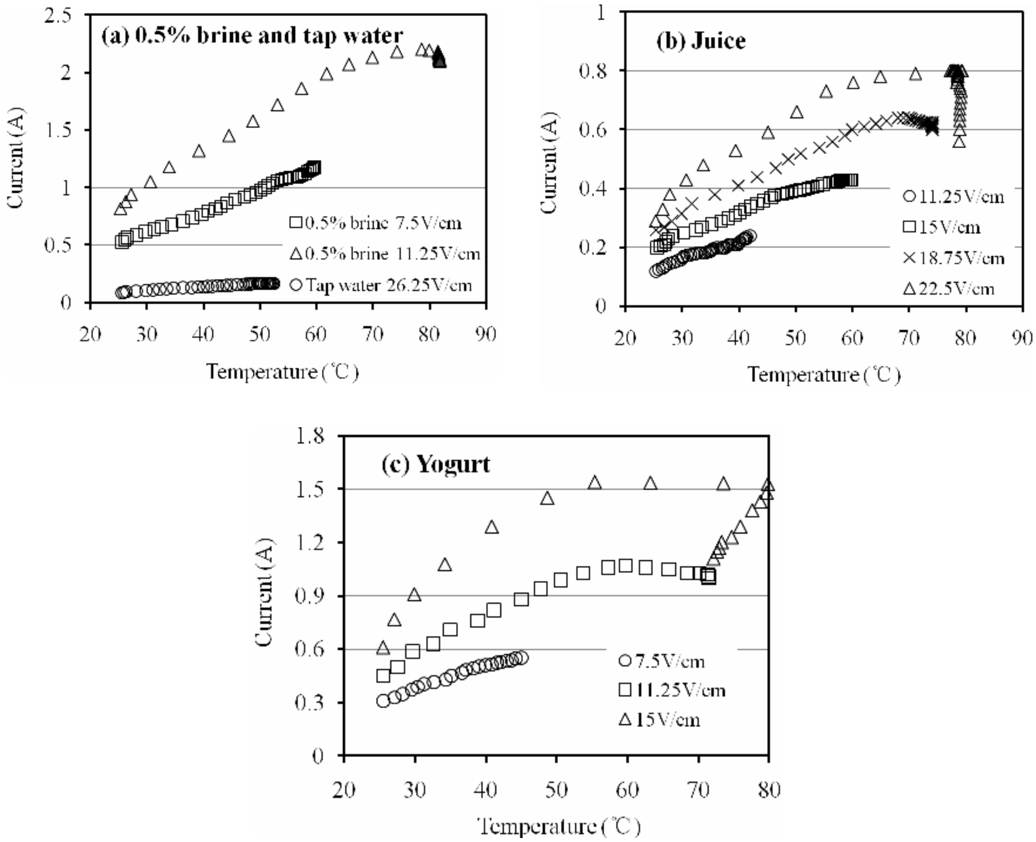

Fig. 6. Current changes of the liquid material samples with temperature during ohmic heating: (a), 0.5% brine and tap water; (b), Juice; (c), Yogurt.

The electric current is carried by movement of ions (electrolytic) in liquids (Shirsat et al., 2004). The electrical conductivity of liquid depends on the amount of ions that can move freely in the liquid. So, the electrical conductivity could be enhanced by the increased ionic movement as the samples' temperature is rising. Some of the water in the liquid samples was observed to form vapor at approximately 50 ^{o}C. The decrease in electrical conductivity may be caused by increased concentration of solids (due to evaporation of water) causing a drag in the ionic movement. As shown in ***Fig. 6***, with the increasing of temperature, the electrical conductivity of the liquid samples increased up to a critical temperature of 50-60 ^{o}C and then the rate decreased. The lower critical temperature values were obtained at the high-voltage gradients. For the juice and yogurt samples under higher voltage, it was thought that electrical conductivity might be decreased as a result of water loss induced by the effect of temperature increase, which caused the reduction in the current flow. For water samples, the tap water with little removable ionic concentration has a very low electrical conductivity even under high voltage gradient. Due to this effect, the temperature of water was raised slowly. As the salt is added into the tap water, which enhanced the ionic concentration and movement, the electrical conductivity increased markedly at the same temperature, even under lower applied voltage gradients.

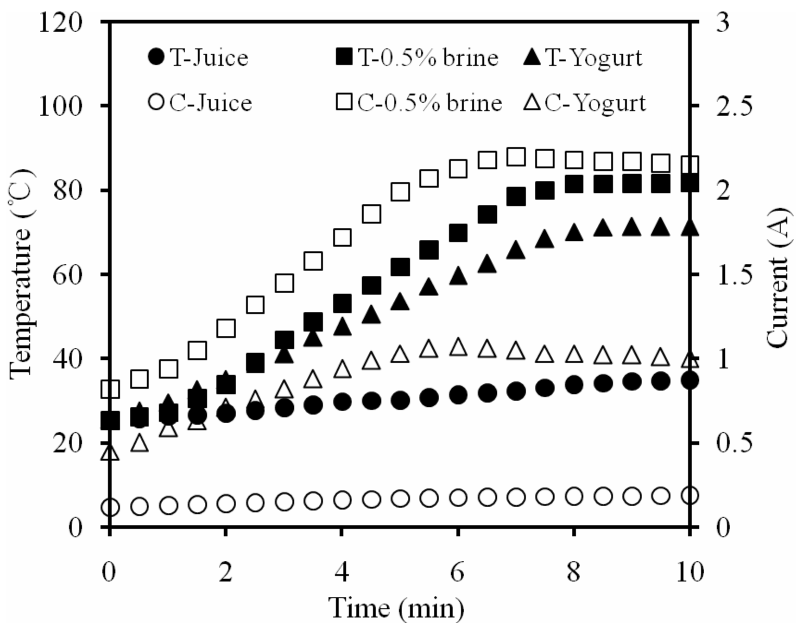

Fig. 7. The comparison of temperature and current curves of fruit-vegetable juice, yogurt and 0.5% aqueous sodium chloride solution under the same voltage gradient 11.25V/cm.

The comparison of temperature and current curves of fruit-vegetable juice, yogurt and 0.5% aqueous sodium chloride solution under the same voltage gradient are presented in ***Fig. 7*** Aqueous sodium chloride solution of 0.5% concentration gave the shortest time to raise the temperature. It was followed by the yogurt and then the fruit-vegetable juice samples. Tests with 0.5% aqueous sodium chloride solution showed the ohmic heating to be fast and uniform, the heating rate for brine was higher than juice and yogurt at the same voltage gradients applied.

The main conclusion from ***Fig. 7*** is that the ohmic heating efficiency was dependent on electrical conductivity under the same voltage gradient. For liquid materials, heating rates followed the same trend as electrical conductivity values (Marcotte et al, 1998), which increased with the temperature linearly regardless of the mode of heating. When an electric field was applied, the increase of electrical conductivity occurs over a wider range of temperature. As the electrical conductivity values increased, the heating time to reach a target temperature decreased.

CONCLUSIONS

The experimental ohmic heating units showed a good performance. The liquid samples could be heated up to 80 ^{o}C from the room temperature efficaciously. The ohmic heating behavior of selected liquid materials was studied as influenced by the voltage gradient and temperatures. The heating rate was affected by varying either the electric-field strength or product electrical conductivity. Under the same voltage gradient, ohmic heating rate of different materials was influenced by the electrical conductivity values. These different effects of voltage gradient on different products show the importance of the determining of electrical conductivities of foods to be processed by ohmic heating. Further work will be done to improve the performance of this ohmic heating system, particularly the heating trough which requires modification since there was a great deal of heat loss and non-uniform electrical field.

REFERENCES

Castro, I., Teixeira, J. A., Salengke, S., Sastry, S. K., & Vicente, A. A. Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics. Innovative Food Science and Emerging Technologies, 2004, 5, 27-36.

Castro, I., Teixeira, J. A., Salengke, S., Sastry, S. K., & Vicente, A. A. The influence of field strength, sugar and solid content on electrical conductivity of strawberry products. Journal of Food Process Engineering, 2003, 26(1), 17-30.

De Alwis, A. A., & Fryer, P. J. The use of direct resistance heating techniques in the food industry. Journal of Food Engineering, 1990, 11, 3-27.

Eliot-Godéreaux, S. C., Zuber, F., & Goullieux, A. Processing and stabilisation of cauliflower by ohmic heating technology. Innovative Food

DOI: 10.2202/1556-3758.1378

Science & Emerging Technologies, 2001, 2, 279-287.

Halden, K., de Alwis, A. A. P., & Fryer, P.J. Changes in the electrical conductivities of food during ohmic heating. International Journal of Food Science & Technology, 1990, 25, 9-25.

Icier, F., & Ilicali, C. Temperature dependent electrical conductivities of fruit purees during ohmic heating. Food Research International, 2005, 38, 1135-1142.

Icier, F., & Ilicali, C. The use of tylose as a food analog in ohmic heating studies. Journal of Food Engineering, 2005, 69, 67-77.

Li, F. D., Li, L. T., Li, Z. G., & Tatsumi, E. Determination of starch gelatinization temperature by ohmic heating. Journal of Food Engineering, 2004, 62, 113-120.

Lima, M. Ohmic Heating: Quality Improvements, Encyclopedia of Agricultural, Food, and Biological Engineering, 2007, 1, 1-3.

Marcotte, M., Ramaswamy, H. S., & Piettea, J. P. G. Ohmic heating behavior of hydrocolloid solutions. Food Research International, 1998, 31(6-7), 493-502.

Palaniappan, S., & Sastry, S. K. Electrical conductivity of selected juices: influences of temperature, solids content, applied voltage, and particle size. Journal of Food Process Engineering, 1991, 14, 247-260.

Qihua, T., Jindal, V. K., & van Winden, J. Design and performance evaluation of an ohmic heating unit for liquid foods. Computers and Electronics in Agriculture, 1993, 9, 243-253.

Samaranayake, C. P., & Sastry, S. K. Electrode and pH effects on electrochemical reactions during ohmic heating. Journal of Electroanalytical Chemistry, 2005, 577, 125-135.

Sastry, S. K. Ohmic heating. Encyclopedia of Agricultural, Food, and Biological Engineering, 2007, 1(1), 707-711.

Sastry, S. K., & Barach, J. T. Ohmic and inductive heating. Journey of Food Science, 2000, 65(4), 42-46.

Shirsat, N., Lyng, J. G., Brunton, N. P., & McKenna, B. Ohmic processing: electrical conductivities of pork cuts. Meat Science, 2004, 67, 507-514.

Wang, L. J., Li, D., Tatsumi, E., Liu, Z. S., Chen, X. D., & Li, L. T. Application of two-stage ohmic heating to tofu processing. Chemical Engineering and Processing, 2007, 46(5), 486-490.

Wang, W. C., & Sastry, S. K. Salt diffusion into vegetable tissue as a pre-treatment for ohmic heating: determination of parameters and mathematical model verification. Journal of Food Engineering, 1993, 20, 311-323.

Zareifard, M. R., Ramaswamy, H. S., Trigui, M., & Marcottea, M. Ohmic heating behavior and electrical conductivity of two-phase food systems. Innovative Food Science and Emerging Technologies, 2003, 4, 45-55.

Zhao, Y., Kolbe, E., & Flugstad, B. A method to characterize electrode corrosion during ohmic heating. Journal of Food Process Engineering, 1999, 22, 81-89.

DOI: 10.2202/1556-3758.1378