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FULL LENGTH ARTICLE

Ohmic heating of pomegranate juice: Electrical conductivity and pH change

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Abstract Ohmic heating is an alternative fast heating method for food products. In this study, the effect of ohmic heating technique on electrical conductivity, heating rate, system performance and pH of pomegranate juice was investigated. Ohmic heating rate, electrical conductivity, and pH are dependent on the voltage gradient used (30–55 V/cm). As the voltage gradient increased, time, system performance and pH decreased. The electrical conductivity of the sample increased with temperature rise (20–85 °C). The range of electrical conductivity during ohmic heating was 0.209–1.013 (S/m). Among the two models tested to fit the electrical conductivity of pomegranate juice, the linear model gave the best fit for all the data points. Bubbling was observed above 81 °C especially at high voltage gradients. The system performance coefficients for pomegranate juice samples were in the range of 0.764–0.939.

1. Introduction

Currently, Iran is one of the biggest producers and exporters of pomegranate fruit in the world, producing over 800,000 ton annually (Ghourchi and Barzegar, 2009), the majority of which is converted to juice and juice concentrate. Pomegranate juices are important commercial products responsible for bitterness and astringency and are used to color and flavor a wide range of juice, beverage and other food products (Alper and Acar, 2004). The juice of the pomegranate has been found to be effective in reducing heart disease risk factors, including LDL oxidation (Sumner et al., 2005). Fruit juices in general are characterized by high acidity conditions, which lead to the growth of yeast and mold, in addition to a few types of low-aid-tolerant bacteria. To avoid microbial spoilage, it is necessary to cause inactivation by applying heat by high temperature heating with very short exposition.

Conventionally heating is the most common method in the heating of foodstuffs. Classic convective methods for heating process fluids, using plate heat exchangers, are still the most popular methods in the food industry. The major drawbacks of conventional heating are the low energy efficiency and long drying times during heating.

Ohmic heating is a thermal processing method in which an alternating electrical current is passed through food products to generate heat internally (Jha et al., 2011; Marra et al., 2009; Shirsat et al., 2004). Electrical fields, applied during ohmic

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Nomenclature

L	distance between the electrodes (m)	T_i	initial temperature of sample (°C)
σ	electrical conductivity (S/m)	T_{amb}	ambient temperature (°C)
I	current (A)	T_w	outer wall temperature (°C)
t	time (s)	SPC	system performance coefficient (–)
V	voltage applied (V)	h	heat transfer coefficient (W/m^2 K)
P	electrical energy given to the system (J)	D	outer diameter of the cell (m)
Q	energy required to heat the sample (J)	σ_0	initial electrical conductivity (S/m)
E_{loss}	energy loss (J)	n, B	temperature factors (S/m °C)
E_h	heat loss by natural convection (J)	k	power constant (–)
HR	heating rate (°C/s)	A_s	cross sectional area of the electrocutes (m^2)
m	mass of the sample (kg)	R^2	determination of coefficient (–)
C_p	specific heat capacity (J/kg °C)	RMSE	root mean square error (–)
T	temperature (°C)	χ^2	reduced chi-square (–)
T_f	final temperature of sample (°C)		

heating of lipoxygenase and polyphenol oxidase, caused their faster inactivation than during conventional heating (Castro et al., 2004). Similarly, ohmic heating was found to be more efficient for the required microbial and pectin esterase inactivation due to a shorter residence time while released flavor compounds were not degraded as quickly as during conventional pasteurization (Leizerson and Shimoni, 2005).

Ohmic heating yields better products, clearly superior in quality than those processed by conventional heating (Allali et al., 2010). Its advantages compared to conventional heating also include the more uniform and faster heating, cleaner and more environmentally friendly; higher yield and higher retention of nutritional value of food (Vikram et al., 2005; Nolsoe and Undeland, 2009; Sagar and Kumar, 2010; Ghnimi et al., 2008; Zareifard et al., 2003; Castro et al., 2004). This is mainly due to its ability to heat materials rapidly and uniformly leading to a less aggressive thermal treatment. For example, De Halleux et al. (2005) concluded that ohmic heating provided 82–97% of energy saving while reducing the heating times by 90–95% compared to conventional heating. They suggested that it could be possible to obtain efficiencies greater than 90% in an industrial process in which these losses were controlled by the wall insulation. Additionally, it is comparatively less difficult to clean an ohmic heater than traditional heat exchangers because of reduced product fouling on the heater's food-contact surface.

The important parameter in ohmic heating of a liquid food product is its electrical conductivity behavior. It depends on temperature, applied voltage gradient, frequency, and concentration of electrolytes (Icier and Ilicali, 2005c; Ye et al., 2004). The temperature dependency of the electrical conductivity liquid products follows linear or quadratic relations, depending on product type tested such as strawberry pulps (Castro et al., 2004); sour cherry juice (Icier and Ilicali, 2004); namely apple, orange, and pineapple juices (Amiali et al., 2006); pomegranate juice (Yildiz et al., 2008); orange juice (Leizerson and Shimoni, 2005; Qihua et al., 1993; Icier and Ilicali, 2005a); lemon juice (Darvishi et al., 2011; Cristina et al., 1999); edible oils (Kumar et al., 2011); and grape juice (Icier et al., 2008).

Icier and Ilicali (2004, 2005a), Darvishi et al. (2011) reported that the performance of heating system decreased with an increase in voltage gradient. Yildiz et al. (2008) discussed the effect of voltage gradient of 10–40 V/cm and temperature from 20 to 90 °C on the quality of pomegranate juice comparable to that of conventional processing method. Also; they reported that the quality of pomegranate juice such as rheological properties, color, and total phenolic content depends on heating rate. But, they did not report about electrical conductivity and system performance.

The objective of the present work was to evaluate the effect of voltage gradient on electrical conductivity, heating rate, system performance and pH of pomegranate juice during ohmic heating.

2. Materials and methods

2.1. Sample preparation

Pomegranates (*Punica granatum* L. cv Malase Saveh) were purchased from a local market in Tehran, Iran and stored at refrigeration conditions (4 °C) prior to experiments. They were washed in cold tap water, drained, and then manually cut into four or six pieces. The juice was then extracted by pressing the samples with manual press at a pressing pressure of 11.25 kPa for 10 min and 62.5 kPa for 5 min (Vardin and Fenercioglu, 2003). Large particles in the juice were removed using a No. 9 mesh filter. The properties of the pomegranate juice at room temperature before the ohmic heating are listed in Table 1. These values are similar to those observed in the literature for pomegranate juice by Ghourchi and Barzegar (2009), Akbarpour et al. (2009); and Vardin and Fenercioglu (2003).

2.2. Ohmic heating unit and procedures

Ohmic heating experiments were conducted in a laboratory scale ohmic heating system consisting of a power supply, an isolating variable transformer, power analyzer (Lutron DW-6090) and a microprocessor board (Fig. 1.). The cell employed was constructed from PTFE (Polytetrafluoroethylene or Teflon) cylinder with an inner diameter of 2.5 cm, outer diameter of 5 cm, and length of 0.15 cm and two removable stainless steel electrodes with thickness of 0.2 cm. The distance between two electrodes was 5 cm resulting in a total sample volume of

Table 1 Some properties of the pomegranate juice used for ohmic heating.

Properties	Values (±SD)
pH (20 °C)	3.15 ± 0.02
Acidity	1.19 ± 0.12 g/100 mL
Total soluble solids	13.92 ± 0.81%
Specific heat capacity	3.56 ± 0.16 kJ/kg °C
Density	1073 ± 63 kg/m^3

26.8 ml. A digital balance (A&D GF 600, Japan) with an accuracy of ±0.001 g was positioned down the cell for mass sample determination (Fig. 1). Temperature uniformity was checked during previous heating experiments by measuring the temperatures at different locations in the test cell. Since the temperature variation at different points inside the test cell was ±1.5 °C during heating, the ohmic heating process was assumed as uniform. Therefore, only the temperature in the center of the test cell was measured. Similar results are found to correspond well with those existing in the literature (Assiry et al., 2010; Zell et al., 2010; Sarang et al., 2008; Icier and Ilicali, 2005a, b, c; Icier and Bozkurt, 2011). Temperature was continuously measured with a K-Type, Teflon coated thermocouple to prevent interference from the electrical field. A hole with diameter of 1 cm was created on the surface of the cell to observe the bubbles formation, insertion of thermocouple, and exit of vapor in the cell.

The samples were placed in the test cell; the thermocouples were inserted and fitted into the geometric center of the sample. The ohmic heating was operated at four voltage gradients 30, 35, 45 and 55 V/cm at 60 Hz from 20 to 85 °C. Temperature, current and voltage applied were monitored and this information was passed to the microcomputer with an RS 232 port at 1second intervals.

2.3. Electrical conductivity

Electrical conductivity (S/m) was calculated from voltage and current data using the following equation:

$$\sigma = \frac{I}{V} \times \frac{L}{A_s} \tag{1}$$

The ratio of L/A_s is known as the cell constant of the ohmic heating unit. The cell constant of the ohmic heater was 1.02 cm when filled to a volume of 26.8 ml.

2.4. Accuracy

The accuracy of ohmic system was compared and calibrated with the standard conductivity. The calibration results for the accuracy of electrical conductivity of 0.1 M NaCl solution revealed that there was no significant difference between standard electrical conductivity of 0.1 M NaCl solution and the experiment data (maximum 4.3%). The electrodes were thoroughly rinsed using a brush and dematerialized with twice-distilled water after each run.

2.5. System performance coefficient (SPC)

The ohmic heating system performance coefficients (SPCs) were defined by using the energies given to the system and taken up by the juice samples. To simplify the calculation of SPC, the following assumptions were made: (i) specific heat capacity of the pomegranate juice is constant within the range of temperatures considered; (ii) SPC is constant, (iii) Prior to commencing ohmic heating it is assumed that the entire sample is at a uniform temperature of 20 °C.

The energy given to the system and the heat required to heat the sample to a prescribed temperature were calculated by using the current, voltage and temperature values recorded during the heating experiments. The energy given to the system

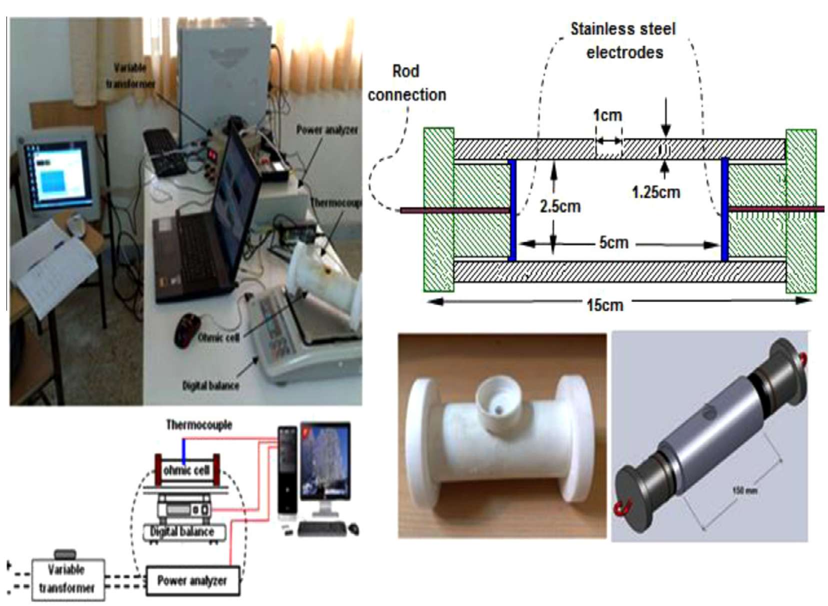

Figure 1 Schematic diagram of the experimental ohmic heating system.

will be equal to the energy required to heat the sample plus the energy loss.

$$P = Q + E_{loss} \quad (2)$$

$$\Sigma(VIt) = mC_p(T_f - T_i) + E_{loss} \quad (3)$$

A system performance coefficient, SPC, was defined as:

$$SPC = \frac{Q}{P} \quad (4)$$

The energy loss is the sum of the heat required to heat up the test cell, the heat loss to the surroundings by natural convection, the heat loss for physical, chemical and electrochemical changes of juice, and the electrical energy which has not been converted into heat. The energy loss calculations for the experimental data were performed by using the method in Icier and Ilicali (2005b). The heat loss to the surroundings by natural convection was calculated from the following equation:

$$E_h = \bar{h}(\pi DL)(\overline{T}_w - T_{amb})\Delta t \quad (5)$$

The average heat transfer coefficient was obtained as follows:

$$\bar{h} = 1.32\left(\frac{\overline{\Delta T}}{D}\right)^{\frac{1}{4}} \quad (6)$$

where $\overline{\Delta T}$ was the average temperature driving force calculated from the initial and final outer wall temperatures and the ambient temperature. The calculated natural convection heat transfer coefficients were small, roughly 3.6–8.7 W/m^2K. The increase in the surface temperature of the test cell at the end of the ohmic heating experiments was between 15 and 42 °C. The heat transfer area was also small. Due to these reasons, the heat loss to the surroundings was very small and could be neglected without any loss in accuracy.

2.6. Properties measurement

Pomegranate juice density was determined by applying the pycnometric method. The sample kept in a 25 ml standard volumetric pycnometer was weighed using a digital balance (A&D GF 600, Japan) with an accuracy of ±0.001 g. Specific heat was measured using the method described by Magerramov (2007), based on an adiabatic calorimeter.

Total soluble solids in the juice were determined with a digital refractometer (ATAGO RX-5000) at 20 °C, calibrated using distilled water (Akbarpour et al., 2009).

Total titratable acidity (TA) was determined potentiometrically using 0.1 M NaOH to the end point of pH 8.1 and expressed as grams of citric acid per liter (Ghourchi and Barzegar, 2009).

pH was determined using a membrane pH meter (HI 8314, Hanna Instrument, USA). The percentage of the pH change was calculated according to the following equation:

$$\Delta pH = \frac{pH_0 - pH}{pH_0} \times 100 \quad (7)$$

2.7. Statistical analysis

Non-linear regression, linear regression, One-way ANOVA and post hoc comparison (at significance level $\alpha = 0.05$) statistical analyses were performed by using SPSS 17. The results were reported as an average of three replicates.

3. Results and discussion

3.1. Heating rate

The voltage gradient had a significant effect on the heating rate of pomegranate juice samples during ohmic treatment

Table 2 Results of one-way analysis of variance of the parameters.

Parameters	Source of variation	Sum of squares	df	Mean square	F-ratio	Sig.
σ	Between groups	4.8×10^{-5}	3	1.6×10^{-5}	244.93	0.000**
	Within groups	2.5×10^{-6}	8	3.1×10^{-7}		
	Total	4.8×10^{-5}	11			
HR	Between groups	13.768	3	4.589	344.19	0.000**
	Within groups	0.107	8	0.013		
	Total	13.874	11			
Q	Between groups	27692	3	9231	0.573	0.648*
	Within groups	128806	8	16101		
	Total	156498	11			
P	Between groups	4447470	3	1482490	46.21	0.000**
	Within groups	256662	8	32083		
	Total	4704132	11			
SPC	Between groups	0.053	3	0.018	30.81	0.000**
	Within groups	0.005	8	0.001		
	Total	0.058	11			
pH	Between groups	0.030	3	0.010	5.34	0.026**
	Within groups	0.015	8	0.002		
	Total	0.044	11			

* Not significant ($p > 0.05$).
** Significant ($p < 0.05$).

($p < 0.05$; Table. 2). The heating rates may be affected by varying either the electric-field strength or product electrical conductivity. The ohmic heating rate of pomegranate juice is shown in Fig. 2. At higher voltage gradients, the current passing through the sample was higher and this induced the heat generation faster. When higher voltage gradients were applied, samples showed an ideal range where there was an exponential or linear trend of temperature rise from 20 to 85 °C. The ohmic heating rates were 4.171, 2.755, 1.688 and 1.392 °C/s at voltage gradients of 55, 45, 35 and 30 V/cm, respectively. The time required to heat the pomegranate juice from 20 to 85 °C at 55 V/cm was 1.5, 2.44 and 3 times shorter than at 45, 35 and 30 V/cm, respectively.

Formation of bubbles was observed during the heating process, especially when the temperature of heated samples reached around 81 °C, and heating was stopped when bubbling started. The reason for this phenomenon 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 result 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.

3.2. Electrical conductivity

One way analysis of variance (Table 2) showed that voltage gradient had a significant effect ($p < 0.05$) on the electrical conductivity of pomegranate juice. Also, the paired comparison t-test for the voltage gradient dependence showed that of the six comparisons made for electrical conductivities, voltage gradient was significant between each of the voltage gradients. The changes in electrical conductivity of pomegranate juice with temperature during ohmic heating at four different voltage gradients are given in Fig. 3. Electrical conductivity increased with temperature, as is expected and consistent with literature data (Kumar et al., 2011; Icier et al., 2008; Darvishi et al., 2011; Kemp and Fryer, 2007; Icier and Ilicali, 2004, 2005a; Amiali et al., 2006; Castro et al., 2004). Icier and Ilicali (2005a) reported that the increase in the electrical conductivity values with temperature has been explained by reduced drag for the movement of ions. It was observed that electrical conductivities decreased with temperature rise after bubbling started. 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. The highest value of the electrical conductivity of pomegranate juice was 1.037 S/m during boiling at the highest voltage gradient of 55 V/cm. Palaniappan and Sastry (1991) found that the drag for ionic movement increased when the solid content increased, which might be a reason for the decreasing trend in electrical conductivity with increasing solid content.

The values of electrical conductivity are comparable with the reported values of 0.1–1.6 S/m mentioned for apple and sour cherry juices at 20–60 V/cm and 30–75 °C (Icier and Ilicali, 2004), 0.4–1.0 S/m for lemon juice at 30–55 V/cm and 20–74 °C (Darvishi et al., 2011), 0.38–0.78 S/m for grape juice at 20–40 V/cm and 20–80 °C (Icier et al., 2008), 0.15–1.15 for orange juice at 20–60 V/cm and 30–60 °C (Icier and Ilicali, 2005a), 0.51–0.91 S/m for peach puree and 0.61–1.2 S/m for apricot puree at 20–70 V/cm and 20–60 °C (Icier and Ilicali, 2005c).

Akbarpour et al. (2009) reported conductivity of different pomegranate cultivars, 0.058–0.511 S/m at 20 °C. From Fig. 3, it can be observed that the conductivity at 20 °C of pomegranate juice is 0.209–0.397 S/m at different voltage gradients from 30 to 55 V/cm. The observed difference between the data presented here and earlier data can be attributed to this natural variation occurring in biological tissues.

Ohmic heating curves were simulated using two empirical models of changed electrical conductivity. The linear model (Sarang et al., 2008; Bozkurt and Icier, 2010; Icier and Ilicali, 2005a,b):

$$\sigma = \sigma_0 + nT \quad (8)$$

The nonlinear model (Icier and Ilicali, 2005a,b):

$$\sigma = BT^k \quad (9)$$

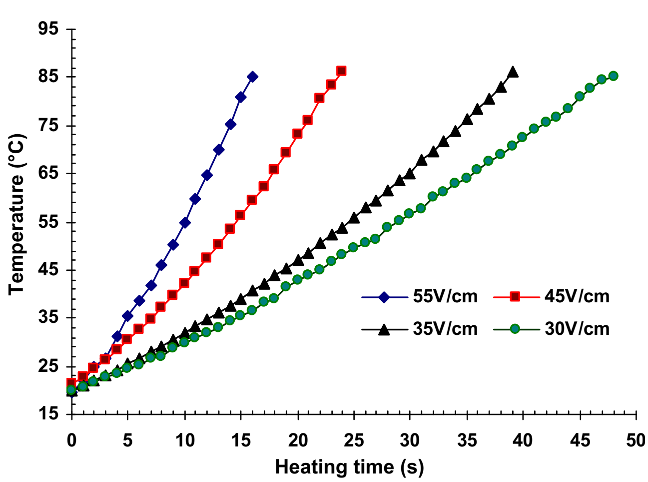

Figure 2 Ohmic heating curves of pomegranate juice at different voltage gradients.

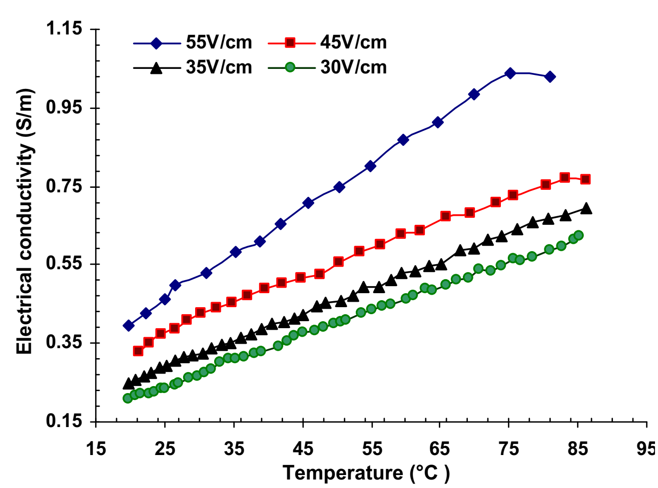

Figure 3 Changes in electrical conductivity of pomegranate juice with temperature during ohmic heating.

Table 3 Results of statistical analysis on the modeling of electrical conductivity with temperature for pomegranate juice.

Model	Voltage gradient	Parameter	R^2	χ^2	RMSE
σ_0 + n.T	55	σ_0 = 0.fboz; n = 0.011	0.9931	0.0025	0.0406
	45	σ_0 = 0.2133; n = 0.0068	0.9930	0.0017	0.0334
	35	σ_0 = 0.1193; n = 0.0068	0.9986	0.0005	0.0179
	30	σ_0 = 0.0843; n = 0.0063	0.9985	0.0006	0.0195
$B.T^k$	55	B = 0.0473; k = 0.7081	0.9957	0.0020	0.0368
	45	B = 0.0545; k = 0.5963	0.9972	0.0006	0.0202
	35	B = 0.0297; k = 0.7041	0.9963	0.0014	0.0306
	30	B = 0.0204; k = 0.7632	0.9978	0.0007	0.0214

The coefficient of determination (R^2) is one of the primary criteria for selecting the best model to define the ohmic heating curves. In addition to R^2, reduced chi-square (χ^2), and root mean square error (RMSE) are used to determine the goodness of the fit. The higher values of the coefficient of determination (R^2) and the lower values of the reduced chi-square (χ^2), and root mean square error (RMSE) were chosen as the criteria for goodness of fit (Icier and Bozkurt, 2011; Assawarachan, 2010).

The statistical results from the models are shown in Table 3. In all cases, the R^2 values for the models were greater than the acceptable R^2 value of 0.963, indicating a good fit. From Table 3, the statistical parameter estimations showed that R^2, χ^2 and RMSE values ranged from 0.9635 to 0.9986, 0.0005 to 0.0155, and 0.0195 to 0.1017, respectively. As expected, the linear model gives the highest value of R^2 and lowest of χ^2 and RMSE values. Thus, the linear model may be assumed to represent the electrical conductivity of pomegranate juice during ohmic heating. The linear model has also been suggested by others to describe the ohmic heating of apricot and peach purees by Icier and Ilicali (2005c); red apple, golden apple, peach, pear, pineapple and strawberry by Sarang et al. (2008); meat by Zell et al. (2010) and orange juice by Icier and Ilicali (2005a); seawater by Assiry et al. (2010) and lemon juice by Darvishi et al. (2011).

3.3. System performance coefficient (SPC)

The electrical energies given to the system and the heat taken by the pomegranate juice samples were calculated by using the experimental data, and the system performance coefficients, SPC calculated for each ohmic heating experiment are also shown in Table 4.

The results indicated that the SPC depended strongly on the voltage gradient applied (p < 0.05, Table 2). For the pomegranate juice samples the SPCs increased from 0.764 to 0.939 as the voltage gradient decreased, which indicated that 6.1–23.6% of the electrical energy given to the system was not used in heating up the test sample. Icier and Ilicali (2005b) reported that the SPC values for the liquid samples were in the range of 0.47–0.92 during ohmic heating. For low voltage gradients, the conversion of electrical energy into heat was larger. Therefore, the system was performing better. System performance coefficients, SPC, were defined to quantify this effect. Similar results have been reported by Icier and Ilicali (2005a, b, c) for orange juice, apricot and peach purees, minced beef, tylose, and Darvishi et al. (2011) for lemon juice.

The difference between the energies given and taken was called energy loss in this study. The increase in the voltage gradient applied was statistically significant in the energy losses during ohmic heating (p < 0.05, Table 2). As the voltage gradient decreased, energy losses decreased. Similar trends were also observed by Icier and Ilicali (2005a, b, c). The energy loss to heat up the test cell was approximately 10–14% of the energy given to the system. Heat transfer area was also small. For this reason, the energy losses to the surroundings by natural convection during ohmic heating were just 0.002–0.06% of the energies given to the system, and they could be neglected without any loss in accuracy. At low voltage gradients, the difference between the energy given to the system and the energy taken by the pomegranate juice can be explained partly by these losses. However, at higher voltage gradients the energy losses mentioned above is only a small portion of the total energy losses. The energy losses can be mostly explained by the energies used for the purposes of physical, chemical and electrochemical changes during heating (Icier and Ilicali, 2005b; Assiry et al., 2003; Zhao et al., 1999). It is rather difficult to comment on the exact nature of this loss. These reactions are not beneficial and further study must be conducted on the effects of them on food. In conclusion, SPCs can be used to determine the system performance of ohmic heaters.

3.4. pH

In the light of experimental results shown in Table 5, there was a slight change in the pH of the pomegranate juice based on the applied voltage gradient. The voltage gradient had significant effect on the pH change of pomegranate juice samples during ohmic treatment (p < 0.05, Table 2). The range of the pomegranate juice pH after ohmic treatments was 3.22–3.35. The percentage of change of pH based on the pH_0 of the pomegranate

Table 4 System performance coefficients for different voltage gradients applied during ohmic heating.

V (V/cm)	Q (J)	P (J)	SPC	T_f (°C)	T_i (°C)	t (s)
30 ± 0.34	6569 ± 95	7062 ± 221	0.939 ± 0.030	85.0 ± 0.8	19.7 ± 0.5	48 ± 3
35 ± 0.15	6538 ± 127	7783 ± 109	0.840 ± 0.019	86.2 ± 1.2	21.2 ± 1.3	39 ± 2
45 ± 0.31	6668 ± 168	8409 ± 195	0.792 ± 0.028	86.1 ± 0.9	19.8 ± 0.5	24 ± 1
55 ± 0.38	6588 ± 105	8626 ± 172	0.764 ± 0.016	85.3 ± 1.5	19.8 ± 0.5	16 ± 2

Table 5 The average pH and the standard deviations of pomegranate juice at room temperature as affected by the voltage gradient; ($V = 0) refers to the control samples where no ohmic heating was applied.

$V (V/cm)	pH
55	3.24 ± 0.06
45	3.22 ± 0.02
35	3.26 ± 0.05
30	3.35 ± 0.03
0	3.15 ± 0.02

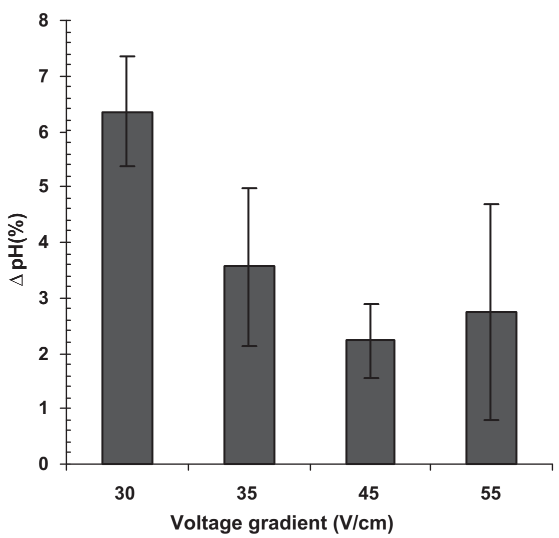

Figure 4 The percentage of pH changes of pomegranate juice at different voltage gradients.

juice at different voltage gradients is shown in Fig. 4. The maximum increase in the pH was 6.35% at 30 V/cm. The change in the pH at voltage gradients of 30–45 V/cm decreased and then as the voltage gradient increased the change increased. This behavior was probably due to the residence time of different reactions such as hydrolysis of the pomegranate juice and corrosion of electrodes that might occur during the ohmic heating. For example, at high voltage gradient, 55 V/cm, the heating rate was high (4.171 °C/s), therefore the residence time for the sample to heat up from 20 to 85 °C was short, thus the change of the pH was limited (2.7%) because the reaction time was short. In comparison, at low voltage gradient, 30 V/cm, the heating rate was 1.392 °C/s, which means high residence time at which the change in the pH was maximum (6.34%) because of the longer reaction time. It has been reported that during ohmic heating, hydrolysis and corrosion reactions between the electrodes and the electrolyte solution may occur, where at high electrical power and salt content, a significant loss of buffering capacity was noted (Assiry et al., 2010, 2003). Generally, the effect of ohmic heating on the pH was limited since the max percentage change was 6.34%.

4. Conclusions

Ohmic heating takes its name from Ohm's law; the food material switched between electrodes has a role of resistance in the circuit. The pomegranate juice was heated on a laboratory scale static ohmic heater by applying voltage gradients in the range of 30–55 V/cm. The voltage gradient was statistically significant on the ohmic heating rates, electrical conductivity, SPCs, electrical energy given to the system and pH for pomegranate juice. As the voltage gradient increased, time and pH decreased. The results showed that the linear model was found to be the most suitable model for describing the electrical conductivity curve of the ohmic heating process of pomegranate juice with R^2 of 0.9986–0.9930, χ^2 of 0.0005–0.0025 and RMSE of 0.0179–0.0406. The results showed that as the voltage gradient increased the role of energy losses increased, in other words SPC values decreased.

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