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Temperature dependent electrical conductivities of ginger paste during ohmic heating

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Abstract

Ohmic heating is now regarded as highly attractive advanced technique for food processing wherein electric current is passed through the liquid particulates foods with primary purpose of heating them. The success of ohmic heating depends on the rate of heat generation in the system, the electrical conductivity of the food, method by which the food flows through the system and composition of the food. In this study, the ginger paste at different salt treatment (0-2% w/w) was heated in a laboratory scale ohmic heater by applying voltage gradients (5–13 V/cm). The temperature dependent electrical conductivity was obtained at different time interval of 0, 5 and 10 minute at different temperatures (30-60˚C). Bubbling was observed above 70˚C especially at high voltage gradients. The electrical conductivity measured in terms of point and bulk electrical conductivity. Point electrical conductivity was greater than bulk electrical conductivity. The point and bulk electrical conductivity values were in the range of 4.41 to 6.63 and 3.75 to 5.87 mS/cm respectively.

Highlights

- The electrical conductivity measured in terms of point and bulk electrical conductivity
- Point electrical conductivity was greater than bulk electrical conductivity
- The electrical conductivity of the ginger paste linearly increased with temperature and ionic concentration
- The determination of electrical conductivity changes and system performance coefficients during ohmic heating are important in the design of ohmic heaters.

Keywords: Joule heating, point and bulk electrical conductivity, ginger, temperature, voltage gradient

Ohmic heating also called as electric heating or joule heating is a process wherein alternating electric current (AC) is passed through liquid-particulates foods with primary purpose of heating them. The heating occurs in the form of internal energy generation within the product (Asgar *et al.*, 2012). AC voltage is applied directly to the electrodes at both ends of the product body which cause internal energy generation within the food material. The rate of heating is directly proportional to the square of the electric field strength, and the electrical conductivity of material (Palaniappan and Sastry, 1991). However, the most important factor is electrical conductivity and its temperature dependence (Legrand *et al.*, 2007). The electrical conductivity increases with increasing temperature, suggesting that ohmic heating becomes more effective as temperature increases. Since electrical conductivity is influenced by ionic content (Icier and Illicali, 2005; Gangola *et al.*, 2013), it is possible to adjust the electrical conductivity of the product with ion (e.g. salts) levels to achieve effective ohmic heating.

Ginger (Zingiber officinale Rosc.) is tropical spesis native to South East Asia and belongs to the family zingiberaceae which is one of the largest family of plant kingdom and one of the most important herbaceous group and occupy an important place in traditional Indian texts due to antispasmodic, anti-inflammatory, antioxidant, anthelmintic, hepatoprotective and antidiarrhoeal activities(Arora *et al.*, 2012). Ginger is the most popular hot spice in the world (Mohammed *et al.*, 2011). India from time immemorial is the "home of spices" producing almost all the spices of the world. There are over 80 spices grown in different parts of the world out of which 50 spices are grown in India (Purseglove *et al.*, 1981). Fresh spices are perishable in nature and the causes of spoilage are improper handling, growth of spoilage microorganisms, action of naturally occurring enzymes and chemical reaction during storage. The post harvest losses of ginger could be considerably reduced if processed immediately after the harvest. Ginger is typically consumed as fresh, in the form of paste, in preparation of powder, bread, confectionary, ginger ale, table souse, ginger preserved and candy (Siddiqui, Bhuiyan and Easdani, 2012), in food beverage industries (Ding *et al.*, 2012) for manufacturing of cordials, cocktails, carbonated drinks, beer, wine etc (Shukla and Singh 2007). Furthermore conventional processing of ginger which include washing, peeling, drying, grinding can cause several quality and hygiene problems (Legrand, 1986; Rejano, Sanchez and Montano 1997; Schweiggert *et al.*, 2008). Therefore it is the need to manufacture safe and good quality ginger paste by using an advanced thermal processing method like ohmic heating. The objective of this research is to study the temperature and time dependence of electrical conductivity of ginger paste.

Materials and Methods

The laboratory size ohmic heating device used to carry out the experiments was designed and fabricated by Patil, (2008) it employed a rectangular geometry as shown in figure 1. It consisted of two rectangular electrodes made of stainless steel placed on a rectangular plate of Perspex sheet. The dimensions of electrodes were 5 x 12 cm and thickness of 0.1 cm. The AC electric power was supplied to these units through an autotransformer. A constant voltage stabilizer was used before the autotransformer to control voltage fluctuations. The electrical variables were recorded using an ammeter, voltmeter and wattmeter.

Raw materials

Fresh, fully matured, yellowish coloured ginger rhizomes without any defect on visual infection was procured from local market at Pantnagar.

Sorting, washing and peeling

Ginger rhizomes were washed in cold water to remove soil and other foreign materials. For peeling, ginger were conditioned by dipping in water at room temperature for 15 min and dried in open air for one hour, this result in development of cracks on outer skin. The peel was manually removed with the help of a sharp stainless steel knife.

Preparation of puree

After removing the peels manually, ginger puree was prepared by grinding the ginger rhizomes in grinder with fruit to water ratio of 1:1 which was recommended by Patil, (2008) and Shetey, (2005). Grinding was done for 3 min to obtain average particle size of 0.353 mm (Mondal, 2006) and puree was taken in to 250 ml glass beaker.

Preparation of paste

Paste was characterized as the product obtained after adding salts and organic acid to the puree

(Ahmed and Shivhare, 2001) For this study, the paste was obtained after adding required amount of salt (according to the experimental design) to the puree. The pH was adjusted to 4.2 using 30% (w/v) citric acid solution. The enzymatic browning was prevented by adding KMS at the rate of 2g/kg of paste for treated samples. Then ginger paste was transferred to ohmic heating device and heated at different voltage gradients (5, 7, 9, 11 and 13 v/cm) up to 80˚C.

Measurements techniques

During ohmic heating of ginger paste, electrical conductivity is likely to change and could be a function of temperature and time. To evaluate the effect of time on bulk and point electrical conductivity, experiments were planned at the time interval of 0, 5 and 10 min at four temperature levels, namely, 30, 40, 50 and 60˚C.

Point electrical conductivity

Point electrical conductivity of ginger paste was determined by Microprocessor-304 conductivity meter using the standard conductivity probe at the temperatures of 30, 40, 50 and 60˚C. The ginger paste was ohmically heated at voltage gradient of 5, 7, 9, 11 and 13 V/cm, when temperature reached to the desired level (80˚C), ohmic heating device was switched off and conductance readings were taken after 10 s to avoid transient effect of electric field.

Bulk electrical conductivity

The bulk electrical conductivity was determined in single experiment at voltage gradient of 5, 7, 9, 11 and 13 v/cm and salt level of 0, 0.5, 1, 1.5 and 2%. Approximately 80g of ginger paste was filled in ETM unit and ohmically heated up to 60˚C. The readings of current and the area across which current flows at particular voltage gradient were noted. The bulk electrical conductivity was calculated according to the following equation given by Palaniappan and Sastry, (1991)

$$\sigma = \frac{I \times X}{V \times a} \times 1000 \quad (1)$$

Where, σ = electrical conductivity, mS/m

I = electric current, A

X = distance between electrode, m

V = voltage, V

a = area across which current flows, m2

Results and Discussion

The ginger paste was ohmically heated in laboratory size ohmic heating device and changes of electrical conductivity with temperature were obtained. It was observed that electrical conductivity increases with increasing temperature and time of heating and bubbling was observed above 70˚C especially at high voltage gradients. Similar electrical conductivity changes have been observed by Castro *et al.*, (2004) for strawberry based products.

Time dependence of electrical conductivity

Due to the structural changes during ohmic heating of product the electrical conductivity is likely to change with temperature and time. However, it may possible that ginger paste undergoes certain biochemical changes under the influence of temperature which influence the electrical conductivity of paste. Hence it is important to study the time dependence of point and bulk electrical conductivity. The present study is conducted to measure the point and bulk electrical conductivities at different time interval of 0, 5 and 10 minute and different temperature levels namely 30, 40, 50 and 60 ˚C. Data shows that point electrical conductivity varied from 4.41 to 6.63 mS/cm while bulk electrical conductivity varied from 3.75 to 5.87 mS/cm for above mentioned time interval.

ANOVA (Table 1) for time dependence of point electrical conductivity indicates that temperature had significant effect on point electrical conductivity at 1% level of significance which indicates that point electrical conductivity is a function o temperature of ohmic heating. Similarly ANOVA (Table 2) for time dependence of bulk electrical conductivity indicates that temperature and interaction of temperature and time had significant effect on bulk electrical conductivity at 1% level of significance.

Table 1: ANOVA for time dependence of point electrical conductivity

Source	df	ss	ms	Fc	Ft
Time (A)	2	0.12736	0.063680	0.72	2.53
Temperature (B)	3	23.00315	7.667716	85.88***	4.71***
A×B	6	0.20730	0.034550	0.39	2.03
Error	24	2.14290	0.089287		
Total	35	25.48071			

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 2: ANOVA for time dependence of bulk electrical conductivity

Source	df	ss	ms	Fc	Ft
Time (A)	2	0.0048	0.0024	0.57	2.53
Temperature (B)	3	18.5951	6.1983	1432***	4.71***
A×B	6	0.1964	0.0327	7.57***	3.66***
Error	24	0.1038	0.0043		
Total	35	18.9003			

* = P<0.05, ** = P<0.01, *** = P<0.001

It can be observed from table 1 and 2 that time had non-significant effect on point and bulk electrical conductivity of ginger paste which indicates that, either ginger paste did not undergo any biochemical changes during the treatment or biochemical changes in ginger paste were so negligible that it did not affect electrical conductivity of paste.

Figure 2 and Figure 3 shows the behavior of point and bulk electrical conductivity with temperature at different salt level. It can be seen from Fig that increases in point and bulk electrical conductivity with temperature followed a linear trend. Also at different salt level, variation in point electrical conductivity trend also different because salt addition to the system had a major effect on electrical conductivity and temperature (Moraveji, Ghaderi and Davarnejad, 2011). Values of point electrical conductivity is more than bulk electrical conductivity indicating that bulk electrical conductivity is more preciously measured than point electrical conductivity of ginger paste and interference of temperature gradient was eliminated by taking conductivity of whole mass. The relation of point and bulk electrical conductivities with temperature (T) can be represented by equations given in Table 3 with their R^2 values.

Table 3. Relation of point and bulk electrical conductivities with temperature

Salt Level	Electrical conductivity			
	σb	R^2	σb	R^2
0	0.058T + 3.69	0.996	0.041T + 3.744	0.995
1	0.058T + 4.108	0.997	0.058T + 3.563	0.995
2	0.057T + 4.752	0.998	0.063T + 3.842	0.997

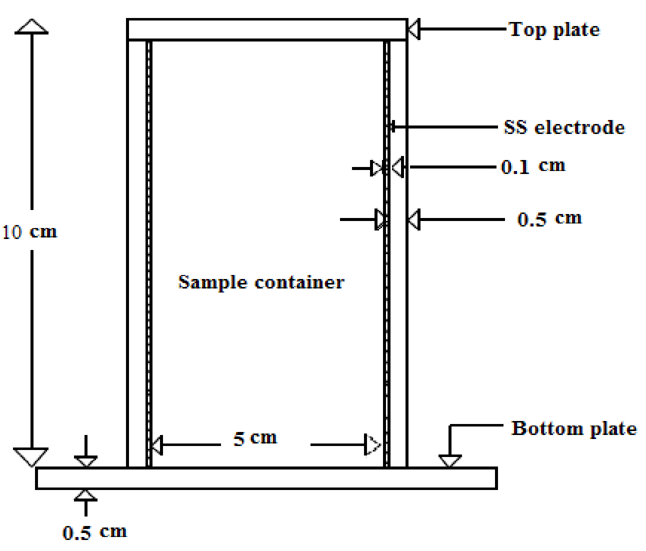

Figure 1. Schematic diagram of ohmic heating device

Heating behavior during ohmic heating

Typical heating behavior of ginger paste during ohmic heating was examined in terms of variation of temperature with time. Heating rate of the process is given by the total time required for the product to heat up to the certain temperature. Higher the heating rate, product will be exposed to high temperature for shorter time duration preserving the product quality.

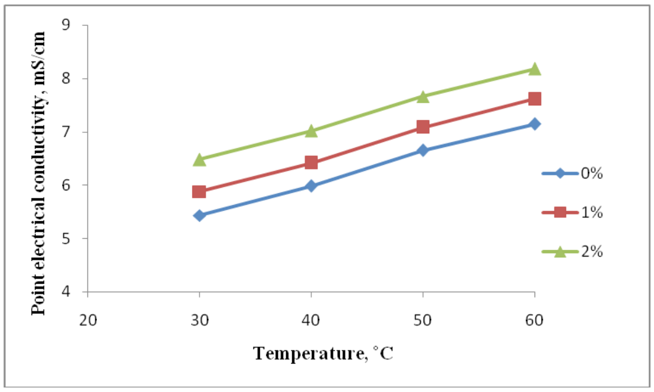

Figure 2: Point electrical conductivity variation with temperature and salt level

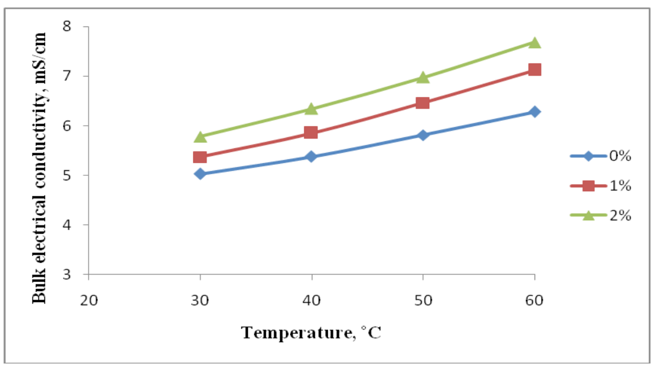

Figure 3. Bulk electrical conductivity variation with temperature and salt level

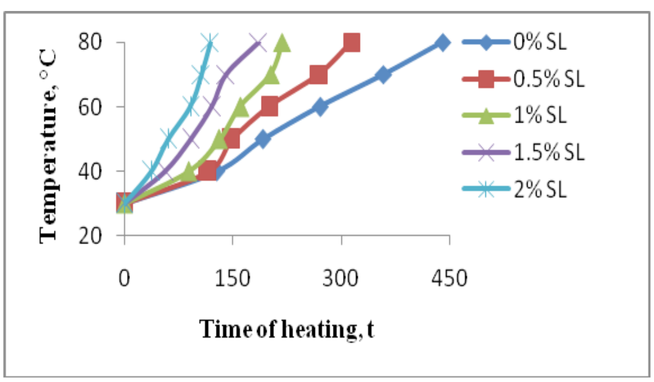

Figure 4: Time of heating variation with temperature and salt level at 9 v/cm

Data were analyzed statistically to see the effect of temperature, salt level and voltage gradients on time of heating of ginger paste. ANOVA (Table 4) shows that temperature, voltage gradient, salt level and their interactions had significant effect on total time for heating of ginger paste. It can also be observed that salt level affect more significantly than voltage gradient and temperature which shows addition of ions to the product increase the rate of heating because of increasing electrical conductivity of product.

The behavior of time of heating of ginger paste under the influence of the temperature and salt level for voltage gradient of 9 and 13 v/cm is depicted in Figure 4 and Figure 5. It is observed from Fig that time of heating reduces with temperature increased from 30˚C to 80˚C. Also heating rate found to be increased with increasing voltage gradient. Relation of temperature (T) at different time (t) and voltage gradients can be represented by the equations given in Table 5 with their R^2 values.

Figure 6 shows the heating behavior of ginger paste in terms of heating rate. It can be observed from fig that heating rate increased from 0.09 to 0.28˚C/s as voltage gradients increased from 5 to 13v/cm. It was also found that heating rate of ginger paste followed linear trend with voltage gradients (R^2 = 0.99).

Table 4. ANOVA for time of heating

Source	df	ss	ms	Fc	Ftab
Salt Level (A)	4	1401890	350472	544.79***	3.44***
Voltage Gradient (B)	2	60473	30236	47.00***	4.74***
Temperature (C)	4	79461	19865	30.88***	3.44***
A×B	8	1221475	152684	237.34***	2.63***
B×C	8	1071764	133970	208.250***	2.63***
A×C	16	878006	54875	85.300***	2.12***
A×B×C	32	3627814	113369	176.226***	.80***
Error	150	96497	643.31		
Total	224	8437382	37666		

* = P<0.05, ** = P<0.01, *** = P<0.001

Table 5. Relation of temperature (T) at different time (t) and voltage gradients

Salt Level (%)	5 V/cm		9 V/cm		13 V/cm	
	T	R_2	T	R_2	T	R_2
0	0.051 t +29.96	0.999	0.116 t +27.95	0.992	0.179 t +27.72	0.979
0.5	0.074 t +27.64	0.985	0.163 t +26.44	0.972	0.261 t + 25.98	0.962
1	0.093 t +27.66	0.987	0.224 t +24.96	0.938	0.371 t +26.55	0.969
1.5	0.117 t +28.07	0.992	0.281 t +26.96	0.978	0.574 t +26.26	0.975
2	0.148 t +27.89	0.985	0.406 t +26.78	0.966	0.743 t +25.63	0.953

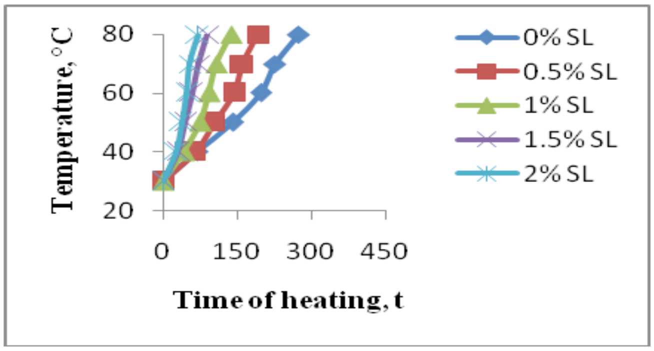

Figure 5: Time of heating variation with temperature and salt level at 13 v/cm

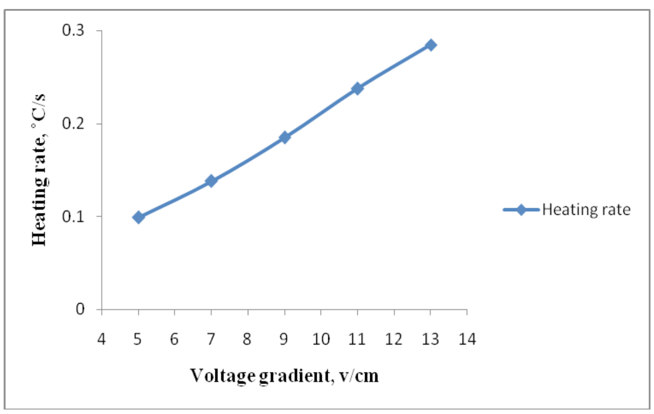

Figure 6. Ohmic heating behavior of ginger paste

Conclusion

It can be concluded that the electrical conductivity of ginger paste is strongly dependent on temperature and ionic concentration. The electrical conductivity of the ginger paste linearly increased with temperature. Point electrical conductivity is always greater than bulk electrical conductivity for all the combinations of voltage gradients. The rate of change of temperature and electrical conductivity was higher for higher salt addition at all voltage gradients applied. Bubbling occurred above 70˚C especially at higher voltage gradients and when salt is added. The mathematical models taking the system performance coefficients into account can be used to predict accurately the ohmic heating times of ginger paste. The determination of electrical conductivity changes and system performance coefficients during ohmic heating are important in the design of ohmic heaters.

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