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Effect of temperature and voltage gradient on electrical conductivity of rapeseed slurry during Ohmic heating

Sheshrao Kautkar, JP Pandey, Anupama Singh, Anil Kumar and AK Shukla

Abstract
Ohmic heating, is a novel thermal food processing technique in which alternating electric current is passed through liquid or liquid-particulates foods mainly for heating purpose. The principle behind this method of heating is based on Ohm's law of electricity. The parameters like rate of heat generation in the system, electrical conductivity and composition of the food and applied voltage influence the success of Ohmic heating. In this study, the rapeseed slurry was heated ohmically at different voltage gradient in an Ohmic heating apparatus. The Ohmic heating behaviour of rapeseed slurry was studied in terms of electrical conductivity by applying voltage gradients (9–15 V/cm) at a temperature from 30 to 90˚C. The average electrical conductivity of rapeseed slurry ranged from 34.9 mS/cm to 59.7 ms/cm. It was observed that electrical conductivity increases with increasing both temperature and voltage gradient.

Keywords: Ohmic heating, electrical conductivity, rapeseed slurry, temperature, voltage gradient

Introduction
Ohmic heating, is a novel method of food processing in which alternating electric current is passed through liquid-particulates foods mainly for heating purpose. This environmental friendly approach of processing the food nowadays is getting popularized as "green technology". It is known by various terms like Joule heating, electro conductive heating, electro heating and electrical resistance heating (Pereira and Vicente, 2010) [1], (Kautkar and Pandey, 2018) [2]. The basic principle of this method is very simple and based on the Ohm's law of electricity. The alternating electric current is allowed to pass through electrically conductive food products such as a liquid, liquid-particulates or pumpable foods. Heat is generated directly inside the food due to its electrical resistance (Patel and Singh, 2018) [3]; (Qihua *et al.*, 1993) [4]; (Icier and Llicali, 2005) [5]. The food materials which contain sufficient amount of water and mineral salts can act as electric charge carriers and allows electric current to pass through them resulting generation of internal heat due to electrical resistance of food (Reznick, 1996) [6]; (Bastías, 2015) [7]; (Joshi, 2018) [8]. The basic functional element of any ohmic heating device is the pair of stainless steel electrodes placed apart at fixed distance in direct contact with the food material. The alternating electric current is passed from these electrodes through the food material mainly for heating purpose (Vikram *et al.,* 2005) [9]; (Abedelmaksoud, 2018) [10].

Rapeseed (*Brassica rapa)* belongs to the family Cruciferae, is a rabi season oilseed crop with many number of species and sub species cultivated in India (Mookherjee *et al.*, 2017) [11]. Rapeseed-mustard is a second most important oilseed crop in India after groundnut. It includes traditionally grown indigenous species, namely yellow sarson, toria, brown sarson black mustard, Indian mustard and taramira and non-traditional species like gobhi sarson and Ethiopian mustard (DRMR, 2015) [12]. India is the third largest producer of rapeseed in the world after China and Canada, producing 12 % of world production from around 19.29 % of total acreage area (USDA, 2013) [13]. Total production of rapeseed in India during 2016-17 was 72.29 MT (SEA, 2016-17) [14]. Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana and Gujarat are the highest sown states of rapeseeds accounting for more than 70% of total mustard acreage in the country. It is the third largest source of vegetable oil after soybean and palm oil. Global production of rapeseed oil reported in 2016-17 was 28.35 MT from which contribution of India was 8.25 % (2.35 MT). Rapeseed oil contains around 38-46 % of oil and

20-30 % of high quality protein with some antinutritional compounds like phenols, glucosinolates and phytic acid (Yiu *et al.*, 1982) [15]; (Zhang *et al.*, 2007) [16].

Materials and Methods

Experimental setup

The laboratory size ohmic heating apparatus used to carry out the experiments was developed by Sakharam *et al.* (2016) [17]. It employed a T-shaped geometry as shown in Fig 1. It consisted of two circular stainless steel electrodes of 5.5 cm in diameter and 0.1 cm in thickness fixed in a T-shape heating chamber made up of PVC. The dimensions of ohmic heating chamber were 7 cm diameter, 16.8 cm in length and 2 mm in thickness. To begin the ohmic heating process, the electric power was switched on to pass and the current to the sample. The sample began to heat up due to the passage of electric current and the inherent electrical resistance of the slurry. Voltages gradient from 9 to 15 V/cm with an increment of 2 V/cm were applied with the help of auto transformer, fixed on control panel and samples were heated until its geometric centre temperature reaches the desired end point temperature. The required voltage gradient was maintained with the help of control panel.

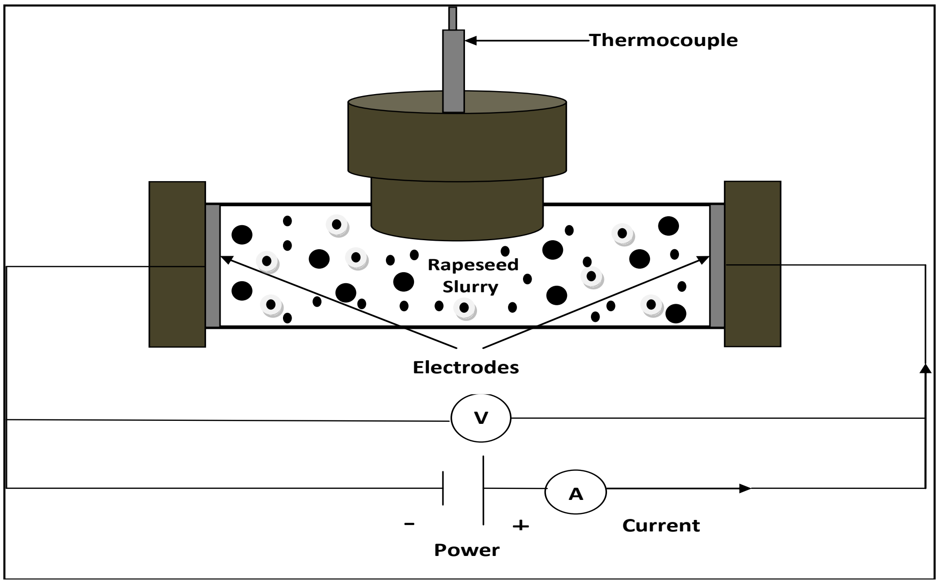

Fig 1: Schematic diagram of Ohmic heating apparatus

Raw material

Rapeseeds of yellow variety were procured from Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar for the study. The grains were thoroughly cleaned to remove the immature and damaged grains, dust, chaff, straw, mud balls, stones and vegetative material.

Preparation of slurry

The procured rapeseeds were grinded in laboratory mixer-grinder for a period of 30 seconds and ground sample was allowed to pass through an 80-mesh sieve. To make slurry, 100 g of rapeseed flour was taken and flour to water ratio was adjusted to 1:3 by adding 300 ml of distilled water. The mixture was properly shaken in the beaker several times to get uniform slurry.

Determination of electrical conductivity

Electrical conductivity (σ) is the materials ability to convey an electric current through it. It is the most important factor in Ohmic heating which depends on temperature, applied voltage, ionic content and micro structure of the food material to be heated. During Ohmic heating of rapeseed slurry, electrical conductivity is likely to change and could be a function of temperature and time. Experiments were planned at different voltage gradients and temperatures to evaluate their effect on electrical conductivity, Electrical conductivity of rapeseed slurry was determined by using a digital electrical conductivity meter (Microprocessor-304) using the standard conductivity probe at temperatures of 40, 50, 60, 70, 80 and 90 ˚C and voltage gradients of 9, 11, 13 and 15 V/cm. The rapeseed slurry was ohmically heated at various voltage gradients and when temperature reached to the desired level, Ohmic heating apparatus was switched off.

Results and Discussion

The rapeseed slurry was ohmically heated in laboratory size Ohmic heating apparatus and variation of electrical conductivity with temperature and voltage gradient were recorded. The values of electrical conductivity of rapeseed slurry at different voltage gradients and temperatures were recorded in triplicates and the mean values are presented in Table-1 which shows that the average electrical conductivity of rapeseed slurry ranged from 34.9 mS/cm to 59.7 ms/cm. The maximum electrical conductivity (59.7 mS/cm) was observed at a temperature of 90˚C when heated at 15 V/cm while the minimum electrical conductivity (34.9 mS/cm) was observed at a temperature of 40˚C when heated at 9 V/cm. It was observed that electrical conductivity increases with increasing temperature and voltage gradient. The slurry gets concentrated by vaporization of water at temperature above 90 ˚C especially at higher voltage gradients.

Table 1: Electrical conductivity (mS/cm) of rapeseed slurry

Temperature (˚C)	Voltage gradient (V/cm)			
	9	11	13	15
40	34.9	38.5	41.85	44.45
50	37.6	41.75	45.89	48.15
60	42.3	45.6	51.54	52.89
70	46.6	49.91	53.73	55.15
80	50.3	54.21	56.26	58.55
90	51.4	55.6	57.42	59.7

The ANOVA of average electrical conductivity of rapeseed slurry is shown in Table-2. Table-2 shows that both voltage gradient and end point temperature had highly significant effect on electrical conductivity (*p*< 0.0001) of rapeseed slurry at 1% level of significant as Fcal (168.61and 273.95) values are greater than the F-tab (5.417, 4.556) values.

Table 2: ANOVA for electrical conductivity of rapeseed slurry

Source	df	SS	MS	F-value	p-value
Voltage gradient	3	301.69	100.56	168.61**	< 0.0001
Temperature	5	816.95	163.39	273.95**	< 0.0001
Error	15	8.95	0.5964		
Total	23	1127.58			

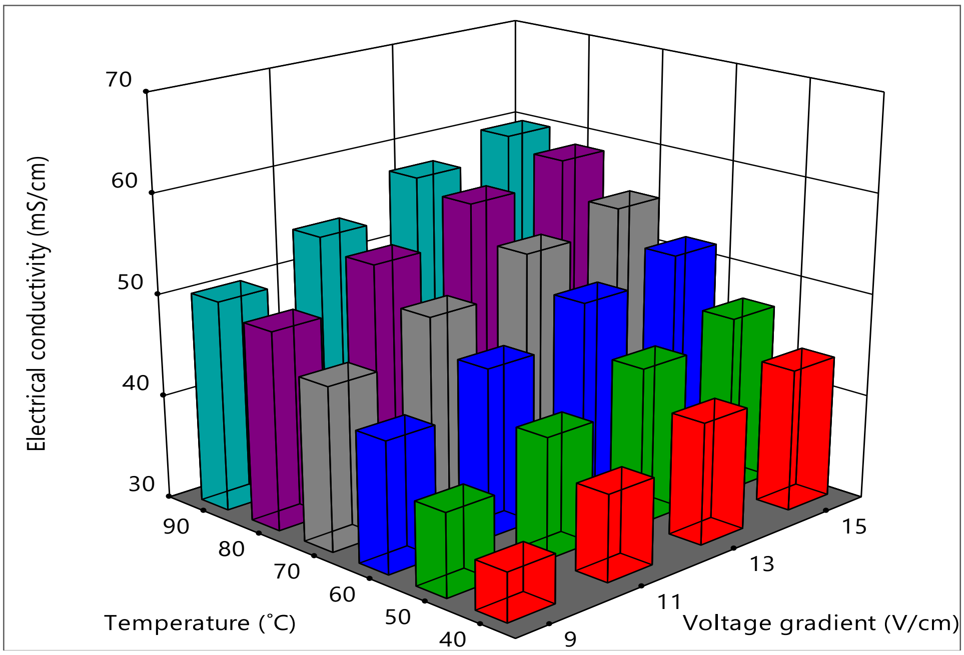

Fig 2: Electrical conductivity variation of rapeseed slurry with temperature and voltage gradients

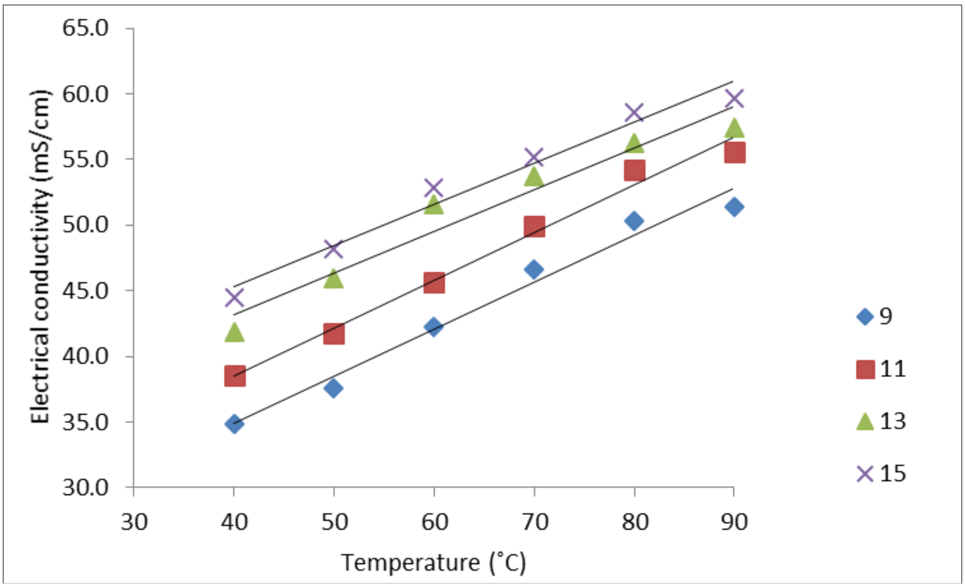

Fig 3: Effect of temperature on electrical conductivity of rapeseed slurry at different voltage gradients

Fig. 2 shows the variation of electrical conductivity of rapeseed slurry with temperature and voltage gradient. It can be observed from Fig 2 that the electrical conductivity of rapeseed slurry increases with both applied voltage and temperature. The effect of temperature on electrical conductivity at different voltage gradients is depicted in Fig. 3 which reveals that the electrical conductivity increased linearly with temperature for all voltage gradients and can be represented by generalized linear regression model shown in Eq. (1). The statistical parameters for electrical conductivity of rapeseed slurry in terms of regression model, the coefficient of determination (r^2), (standard error of estimate (SEE) and E_m (mean error) are given in Table-3. It can be observed from table 3 that the models are reasonably precise as r^2 values are greater than 0.90 and associated errors were quite small.

$$\sigma = a.T + C \quad (1)$$

Where,

σ = Electrical conductivity of rapeseed slurry (mS/cm)
a = Coefficient
T = Temperature generated in rapeseed slurry during ohmic heating (˚C)
C = Constant

Table 3: Statistical parameters for electrical conductivity models

Voltage gradient (V/cm)	Models	r²	SEE	E_m
9	σ = 0.3575T + 20.600	0.9783	1.114	2.76
11	σ = 0.3634T + 23.974	0.9874	0.860	2.79
13	σ = 0.3176T + 30.473	0.9469	1.573	2.49
15	σ = 0.3135T + 32.774	0.9724	1.104	2.43

Table-3 and Fig 3 shows that, the slope of regression line initially increases as voltage gradient increases from 9 to 11 V/cm and then the value of electrical conductivity starts declining slightly as voltage gradient further increases from 11 to 15 V/cm. The increased trend of electrical conductivity at 9 to 11 V/cm voltage gradients may be due to higher amount of initial water and ionic content present in the rapeseed slurry. Similar electrical conductivity changes have been observed by Castro *et al.* (2004) [18] for strawberry based products and Kautkar *et al.* (2015) [19] for ginger paste. However at voltage gradients of 13 and 15 V/cm, heat generation occurs rapidly and temperature increases in faster rate, which cause evaporation of water from slurry making it thick and concentrated which leads to drag in the ionic movement. During the treatment of ohmic heating, if voltage is kept constant, current flow depend only on the electrical conductivity of rapeseed slurry. Therefore the relationships between temperature and electrical conductivity of rapeseed slurry presented in Fig.3 actually showed the change of flow of current from the rapeseed slurry with temperature. Moraveji *et al.* (2011) [20] and Athmaselvi *et al.* (2014) [21] have reported similar results. The results found here are in full agreement with Zareifard *et al.* (2003) [22] and Gomathy *et al.* (2015) [23].

Conclusion

It can be concluded from the present investigation that the electrical conductivity of rapeseed slurry is strongly dependent on temperature and applied voltage. The average value of electrical conductivity of rapeseed slurry ranged from 34.9 mS/cm to 59.7 ms/cm. It increases linearly with temperature for all voltage gradients. The rate of change of temperature and electrical conductivity was higher for all voltage gradients applied. Evaporation of water from rapeseed slurry was occurred above 90˚C especially at higher voltage gradients. The generated linear regression models can be used to predict the electrical conductivity value of rapeseed slurry at various temperatures.

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