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Impact of Ohmic Heating on Electrical Conductivity and Specific Heat of Black Cumin Seed Slurry

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aim: This study examined the effects of ohmic heating on the electrical conductivity and specific heat on slurry of black cumin seeds. Both the properties are taken into consideration in heat and mass transfer operations.

Materials and Methods: The slurry was heated from 26 ºC to 90 ºC in a batch-type laboratory-scale ohmic heater at different electric field strengths (650, 750 and 850 V/m) and end point temperatures (40, 50, 60, 70, 80 and 90 ºC), respectively.

Results and Conclusion: It was statistically investigated that the electric field strengths and end point temperatures had a significant effect ($p<0.01$) on both electric conductivity and specific heat at a 1% level of significance. The results of the current study clearly showed that, with rising end point temperatures and electric field strengths, respectively, electrical conductivity and specific heat values grew linearly. The value of R^2 (>0.97) of the linear model showed that the linear model was

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suitable for the describing the electrical conductivity curve and specific heat of the ohmic heating process of the black cumin seed slurry.

Keywords: Black cumin seed; ohmic heating; electric conductivity; specific heat.

1. INTRODUCTION

The oil of black cumin seed is considered as one of the new sources of edible oil [1]. The oil from the seeds are associated with many advantages, particularly helpful for preserving a robust immune system and supplementing in dietary foods. It is still believed to be used to raise body temperature and speed up metabolism. Today, black cumin seed is utilized to treat respiratory disorders as a dietary supplement. Additionally, it is utilized to promote kidney and liver function as well as stomach arthritis, circulation issues, allergies, hay fever, acne, and intestinal health [2,3].

In addition, heat was produced as a result of the food's internal energy generation. Hence, ohmic heating is also called joule heating, electrical resistance heating, direct heating or electro conductive heating. Ohmic heating technology has become popularized in the past few years due to the accessibility of energy at a reasonable cost and improved design [4,5]. The application of ohmic heating as a pretreatment for oil seed slurry may have resulted in an enhancement of oil yield. The main mechanism involved in the ohmic heating is their electroporation effect, making cell disruption and a path for maximum ooze of oil from oil globules into the outer layer. Electrical conductivity and specific heat are the key risk variables in ohmic heating because they are crucial in the production of internal energy in a slurry and explain the behavior of the sample during ohmic heating. Electrical conductivity, evaluate in siemens per meter (S/m), is a property of a substance that determines how well it carries an electric charge [6]. In ohmic heating, the specific heat of the material governs the temperature increase that results from heat generation within the material. The specific heat of the slurry can be calculated by, taking the ratio of theoretical heat supplied through electricity to the actual heat supplied. With this simplifying assumption, the specific heat of slurry was determined [7]. The efficiency of ohmic heating depends on the material's ability to conduct electricity, making it the most significant parameter. As a result, understanding the conductivity of the material and specific heat as a whole and its constituent parts are crucial in designing a successful heating process.

The electrical conductivity and specific heat of materials heated the product using an ohmic process were measured using a variety of designs and setups, which were investigated by various researcher. Different researchers have reported electrical conductivities during ohmic heating of different materials [8,9]. This includes fresh fruits under ohmic heating such as apple, peach, pear, pineapple and strawberry (electrical conductivity in the range 0.05–1.2 S/m), and different types of meats such as chicken, pork and beef [10,11] and red bean *Phaseolus vulgaris* L. [12]. For the present study two independent variables such as electric field strength (EFS) and end point temperature (EPT) were taken at 650, 750 and 850 V/m and 40, 50, 60, 70, 80 and 90 ºC respectively with no holding time. Currently, limited studies available on black cumin seeds related to its processing, machines, designs and developments, and optimization of process parameters. Therefore, it would be important to study the engineering characteristics of seeds, to help in the futuristic development and optimization process. Taking into consideration of above points, the objective of this investigation was to acquire knowledge of the impact of ohmic heating on electrical conductivity and specific of the black cumin seed slurry during ohmic heating.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Undamaged and bold kernels of black cumin seeds were chosen for the investigation after they had been completely cleaned using a particular gravity separator to remove undesirable foreign material. The cleaned black cumin seed grains were dried in hot air oven up to 10 % (d.b) moisture content [13]. The black cumin seed was ground in a laboratory mixer-grinder for a period of 30 seconds and the ground sample was allowed to pass through a 250 µm sieve size. The dehulled powder was packaged and sealed in airtight polythene bags and kept in the refrigerator at 4 ºC until utilized for additional experiments to prevent rancidity and the generation of free fatty acids [14].

2.2 Ohmic Heating System

A T-shaped cylindrical geometry was adopted for the construction of ohmic heating chamber in which black cumin seed slurry was heated at desired temperature. The ohmic heating chamber, 8 cm in diameter, 18 cm in length and 5 mm in thickness was made of borosil glass material for a capacity of 600 g (100 g powder: 500 ml water) black cumin seed slurry. The heating chamber's dimensions and capacity were decided upon based on the volume and density of the slurry, using a 1:5 slurry ratio [15,16]. The glass state material is non-toxic, corrosion-resistant, non-adhesive and has good insulation properties. To make the heating chamber more heat-resistant, the interior and exterior surfaces were painted with teflon liquid using a cotton cloth.

2.3 Measurement of Electrical Conductivity of Black Cumin Seed Slurry

Electricity conductivity in slurries depends on a variety of factors like temperature, ionic constituents, and the microstructure of the material [16,15]. The amount of current flowing through a food component at a specific electric field strength depends on its electrical conductivity, which also affects how much heat is produced during ohmic heating [17]. Electrical conductivity of samples was calculated from voltage and current data using the following equation1 [18].

$$\sigma = \left(\frac{1}{R}\right) \times \left(\frac{L}{S}\right) \times 100 \qquad \ldots \quad (1)$$

Where,

σ = Electrical conductivity of the sample (S/m);
R = $\frac{V}{I}$; L= Distance between two electrodes (m);
S= Cross sectional area of the electrodes (m^2);
V=Voltage (V); I= Current (A)

2.4 Measurement of Specific Heat of Black Cumin Seed Slurry

The specific heat of a material governs the temperature increase due to heat generation within the material. The specific heat of the slurry can be calculated by equation 2. The theoretical heat supplied through electricity was converted into actual heat supplied by multiplying the electricity to heat conversion efficiency of ohmic heating system. The specific heat of samples was calculated by using following equation 2 [7].

$$C_s = \frac{V^2 \times \sigma\ av \times \frac{S}{L} \times \eta ET}{ms \times \frac{dT}{dt}} \ldots \qquad (2)$$

Where,

C_s=Specific heat of slurry (J/kg ºC);
V=Voltage applied (V);
σ_{av}=Average electrical conductivity of slurry (S/m);
S=Electrode area (m^2);
L=Distance between electrodes (m);
$\frac{dT}{dt}$=Rate of heating (ºC/s);
m_s= Mass of slurry poured in ohmic heater (kg)

3. RESULTS AND DISCUSSION

The engineering properties of black cumin slurry were determined by measuring current, temperature, and voltage during ohmic heating. The generation of heat during ohmic heating largely depends on electrical conductivity, heating rate and specific heat of slurry. Determination of electrical conductivity and specific heat was done by experimental data collected for computation of ohmic heating characteristics and their variation with different parameters has been presented in the following subsections.

3.1 Electrical Conductivity

Electrical conductivity (σ) is defined as the ability of a material to carry an electric current. The electrical conductivity of slurry at different electric field strength (EFS) and end point temperature (EPT) was recorded with no holding time. The average electrical conductivity of slurry ranged from 0.8834 to 1.4128 S/m. The ANOVA (Table 1) shows that both EFS and EPT had significance ($p<0.01$) effect on electrical conductivity of slurry at 1 % level of significant as F_{cal} value for applied EFS and EPT (48.61 & 32.66) are greater than F_{tab} (7.56 & 5.64) values respectively. The electrical conductivity increased linearly with an increase the EFS and EPT respectively (Fig. 1). The following models represented the relationship between EFS and EPT. The models were reasonably precise as R^2 values were greater than 0.90 and associated errors were quite small. The above mentioned also demonstrated that slope of line decreased as EFS increased. The maximum value of electrical conductivity (1.4128 S/m) was observed at an EPT of 90 °C when heated at 850 V/m of EFS whereas the minimum value of electrical conductivity (0.8834 S/m) was obtained at a 40 °C of EPT when heated at 650 V/m EFS. The electrical conductivity amplified linearly with temperature for all applied EFS and can be represented by linear regression models (Fig. 1). The models were reasonably precise as R^2 values were greater than 0.90 and associated errors were quite small. The mentioned models also observed that slope of line decreased as EFS increased with increase in EPT. This may be due to the fact that at higher EFS; heat was generated faster, which evaporated more water vapor and make slurry more concentrated. The result obtained here are in fully agreement with [19] and [20].

At 650 EFS (V/m) $\sigma = 0.009\ T + 0.474$ ($R^2 = 0.993$)
At 750 EFS (V/m) $\sigma = 0.008\ T + 0.655$ ($R^2 = 0.989$)
At 850 EFS (V/m) $\sigma = 0.007\ T + 0.723$ ($R^2 = 0.976$)

Table 1. ANOVA for electrical conductivity (S/m) of black cumin slurry

Source	DF	SS	MSS	F_{cal}-value
EFS (V/m)	2	0.0175	0.0875	48.61**
EPT (°C)	5	0.2941	0.0588	32.66**
Error	10	0.0185	0.0018	-
Total	17	0.3301	0.0194	-

(Solid: water ratio = 1:5)

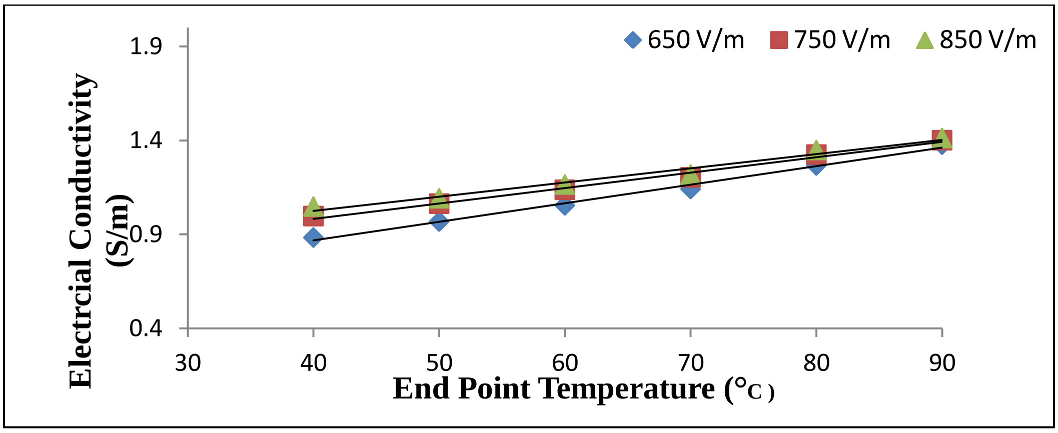

Fig. 1. Variation in electrical conductivity of slurry with electric field strength and end point temperature

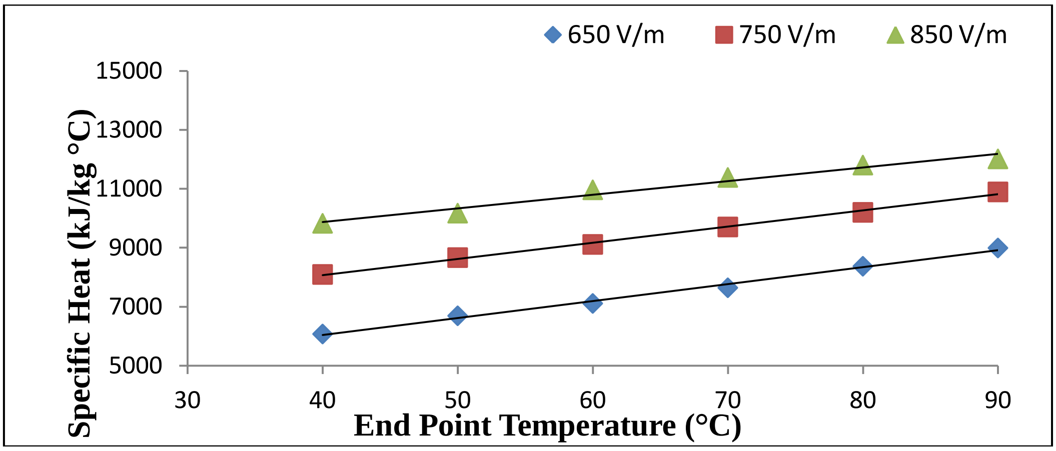

Fig. 2. Variation in specific heat of black cumin slurry with electric field strength and end point temperature

3.2 Specific Heat

The maximum value of specific heat (12015 (kJ/kg °C) was calculated at a temperature of 90 °C when heated at 850 V/m applied EFS whereas minimum value of specific heat (6073 (kJ/kg °C) was calculated at a temperature of 40 °C when heated at 650 V/m EFS. Electric field strength and temperature were highly significant at 1 % level of significant as F_{cal} values for applied EFS and EPT were greater than the F_{tab}. The specific heat of the slurry increases linearly with temperature at all EFSs used and can also be represented by a linear regression model. The increase in EFS enhanced the internal rate of heat generation responsible for rise in the temperature from initial t to final point. The similar kinds of trends were found by [21],[22] for soybean heating.

At 650 EFS (V/m) $C_s = 57.62\ T + 3734$ ($R^2 = 0.994$)
At 750 EFS (V/m) $C_s = 54.85\ T + 5879$ ($R^2 = 0.996$)
At 850 EFS (V/m) $C_s = 46.42\ T + 8011$ ($R^2 = 0.972$)

Where,

C_s = Specific heat of black cumin slurry (kJ/kg °C)
T = Temperature generated in slurry during ohmic heating (°C)

Table 2. ANOVA for specific heat (kJ/kg °C) of black cumin slurry

Source	DF	SS	MSS	F_{cal}-value
Electric field strength	2	39.728	19.864	800.96**
End point temperature	5	16.674	3.3348	134.46**
Error	10	0.248	0.0248	-
Total	17	56.65	3.3323	-

4. CONCLUSIONS

The effectiveness of the current analysis demonstrates the widespread application in the field of designing and developing machines based on unit operations for enhancing the value of black cumin seeds. The technical behavior of slurry during ohmic heating has the potential to study energy evaluation and help in the conservation of energy during processing. Due to applied electric field strength the extraction of oil rate enhanced with less damage of cells due to having electroporation mechanics involved in the ohmic heating process. It can be concluded from the results that the specific heat of the slurry increased with increasing temperature and applied EFS.In order to explain the electrical conductivity curve and specific heat of the ohmic heating process of black cumin seed slurry, the experimental results indicated that the linear model was the most suitable model.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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