Development of Ohmic Heating Apparatus for Extraction of Edible oil from Black Cumin Seed

Abstract:

Many innovative thermal food processing methods have been created with great promise, and there is currently a strong need for cutting-edge technologies that require the least amount of processing. Ohmic heating is a volumetric heating technique that involves heating food that contains liquid particles by passing an alternating electric current through it. The study's goals were to design and build an ohmic heating system on a laboratory scale and assess its effectiveness in terms of heating power, heating rate, and energy efficiency. The ohmic heating setup that was constructed on a laboratory scale demonstrated exceptional performance. The system successfully converted a maximum of 62.50 percent of the energy. With this configuration, an 80 V applied voltage may heat the liquid particle meal from 24°C to 50°C in less than minute. For the most part, the heating was volumetrically uniform. This technology holds great promise for creating brand-new, highly valued products that maintain their quality over time on the market.

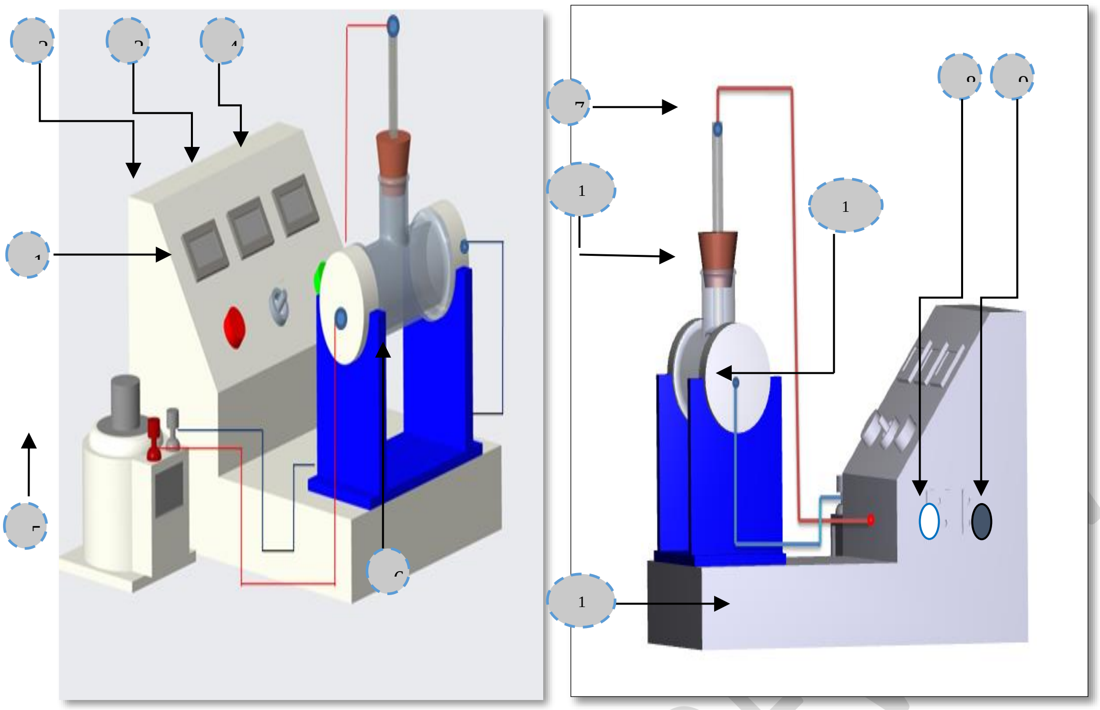
Keywords: Ohmic heating, black cumin oil, electrical conductivity, efficiency of ohmic heater

Introduction

The idea of ohmic heating was created in the early 1900s, when milk and other food items were pasteurized electrically by pumping the liquid between plates that had a voltage differential between them (Sastry and Palaniappan, 1992). The heat energy needed for conventional food heating methods had to be produced outside and then conduction, convection, or radiation had to be used to transmit the heat energy to the food item. Conventional heating methods for particle goods, particularly those with large sizes, necessitated an excessive heat processing system, which led to the destruction of the particulate's outer layer. This method heats food quickly and evenly, producing the desired outcomes without compromising the overall quality of the product. Ohmic heating is the method of concurrently heating food solids and/or liquids by running an electric current through them. For pumpable foods, ohmic heating is a resistance or joule heating method. The apparatus involves transferring the alternate current via the fluid in between the electrodes. Numerous processes, including sterilization, pasteurization, blanching, stabilization, dehydration, fermentation heating, preheating, thawing, and more, involve ohmic heating (Qihua et al., 1994). This technology has a number of benefits, including the ability to heat food materials internally without the restrictions of conventional heat transmission. The product does not encounter a significant internal temperature gradient because of the high volumetric heating. Minimal mechanical damage and improved retention of important components were achieved by lowering the hazards of fouling on the heat transfer surface and burning of the food product (Robberts et al., 1998; Sawant et al., 2019). Because 90% of electrical energy is directly turned into thermal energy, it has a significant potential for energy efficiency. Ohmic heating effectiveness is contingent upon several factors, including the system's heat generation rate, the food's electrical conductivity, the strength of the electric field, residence time, and the manner in which the food passes through the system (Takhistov, 2007; Sawant et al., 2018). Ohm's law of electricity is the foundation for ohmic heating. According to Zell et al. (2009), heat is produced when electrical current flows through a food item that conducts electricity in accordance with Ohm's law. The Division of Agricultural Engineering, I.A.R.I., New Delhi, designed and developed a laboratory-scale ohmic heating device with a volumetric or processing capacity of 6.5 kg/hr. The aim of this investigation was to construct an ohmic heating system on a laboratory size, complete with the requisite data gathering apparatus, and employ it to assess various parameters, including temperature, current, heating power, heating rate, and energy efficiency.

Materials and Methodology

The power supply, the heating units, and the data collecting system made up the three primary components of the experimental ohmic heating system. A lab-scale ohmic heating system (Figure. 1a and b) was used for the experiments, and is technical specifications given in Table 1 were followed. The choice of appropriate building materials for an ohmic heating chamber is crucial for both effective heating and operational safety. Constructive materials must to be chemically inert, able to tolerate elevated temperatures without compromising product quality, completely insulated, and readily accessible at a reasonable price from the market (Sinthiya, 2015). The heating chamber was built using borosil glass cylinders, rubber end caps, electrodes, plywood, and other materials while keeping these considerations in mind. For the building of the ohmic heating chamber, a glass cylinder of 20 cm in length, 6 cm in diameter, and 0.5 cm in thickness has been chosen. In order to determine the capacity of an ohmic heating chamber, the volume and density of black cumin slurry (1:5) was taken into consideration when determining the size of the chamber. The temperature inside the heating chamber was tracked using a multispan digital temperature controller equipped with a copper probe. To regulate the temperature during ohmic heating, a PT-100 I-type thermocouple sensor—which has a temperature range of -17 to 900 °C was positioned in the middle of the heating chamber. The market is filled with a wide variety of conductive materials, such as graphite, aluminum, and stainless steel. The cost, availability, accuracy, and price were taken into consideration when choosing the conductor materials. Food-grade, non-corrosive, chemically inert, and smooth-finishing electrodes are ideal. Preliminary experiments were used to determine the final electrode material and size. Aluminum and stainless steel were chosen as the electrode materials; the diameters of the two electrodes were 3, 5, and 7 cm, and the distances between them were 16, 18, and 20 cm, respectively. Stainless steel was ultimately chosen as a still material with a 5 cm diameter based on energy conversion (%) as a response because of its precision and compatibility for food goods. In order to pass the maximum voltage gradient of 12.77 V/cm from the Indian domestic supply of 230 V and 50Hz, the spacing between the two electrodes has been fixed at 20 cm. The 6 cm diameter and 2 cm length rubber-coated lid is used to connect the electrodes to the power source. It could tolerate temperatures up to roughly 600°C. In the laboratory setup, a single-phase power source from alternating current (AC) mains (230 V, 50 Hz) was utilized. Prior to the autotransformer, a constant voltage stabilizer was employed to regulate voltage functions. The voltage and ampere meters were used to record the electric variables. In order to prevent mishaps during ohmic heating, personal safety and equipment safety were crucial design considerations for the power supply system. The ohmic heating chamber was fixed in a stationary position using a 17-cm-tall wooden stand. The entire ohmic heating setup was fixed using a wooden frame measuring 42 cm in length, 55 cm in width, 32 cm in height, and 3 mm in thickness. A wooden control panel measuring 42 cm in length, 38 cm in width, and 22 cm in height was used to mount the temperature controller, ammeter, and voltmeter. Ionic conduction was the main mode of conduction in electrolytes. Accordingly, ionic components had to be present for heating to happen during ohmic heating (Tulsiyan et al., 2008). The concentration of 1% NaCl was employed in the experimental experiment trials. The device was utilized in horizontal static heating tests (chamber length: 20 cm). With a voltage gradient of 80 V, the solution was heated. At least three replications of each test were conducted. Throughout the test, the temperature, current, and voltage profiles were tracked over time. A water bath maintained at a consistent temperature was used to calibrate the thermocouple. During the experiments, the temperature was recorded and controlled using the auto cut-off temperature controller. During the trials, the current and voltage profiles were recorded using a digital ammeter and voltmeter.



(1-Start button, 2-Ammeter, 3- Voltmeter, 4- Temperature display, 5-Dimmerstat, 6- Wooden Stand, 7-Thermocouple, 8- Main switch, 9- Dimmerstat connection, 10- Rubber cap, 11- Electrodes, 12- Base)

Fig. 1(a). Schematic diagram of laboratory ohmic heating apparatus

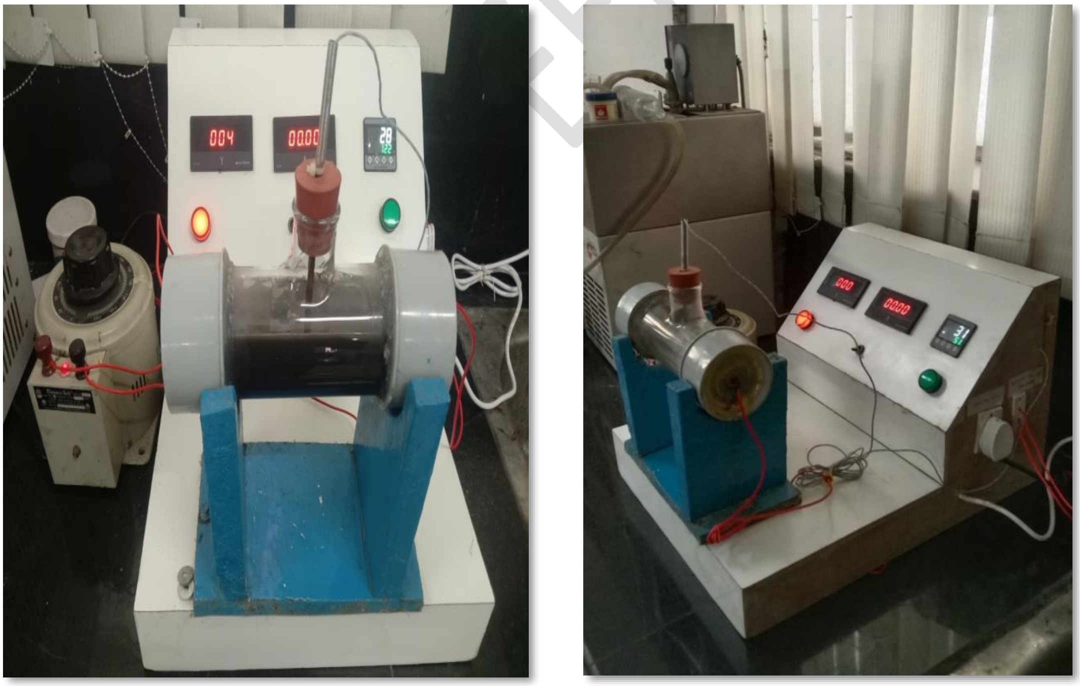


Fig. 1(b). Developed laboratory ohmic heating apparatus for oil extraction from black cumin seed

Table. 1 Different component of ohmic heating system and their function

Sr. No	Name of component	Feature	Material of construction	Dimension	Functions
1	Ohmic heating chamber	T-shape Geometry	Glass with Teflon and anabond 666 paste coated to make it thermally stable	Length= 20 cm Diameter = 6 cm Thickness = 0.5 cm	Hold and heat slurry during experiment
2	Electrode	Disc shape	Stainless steel (SS-316)	Diameter = 5 cm Thickness = 0.3 cm	Transfers electric current from power source to the product to be heated
3	Insulator cap	Circular/disc shape with internal thread for tight fitting	Wood	Diameter = 7.5 cm Thickness = 0.03 cm	Makes ohmic heating apparatus electrically safe and prevents heat loss and leakage from the apparatus,
4	Control panel	Power supply to electrode and monitoring and controlling ohmic heating variables	Wooden box	Length = 42 cm Width = 38 cm Height = 22 cm	Supply power to the electrodes and monitor and control ohmic heating variables (temperature, voltage and time)
5	Base	Entire ohmic heating setup supported by it	wood	Length = 42 cm Width = 55 cm Height =32 cm Thickness = 3 mm	Supports the ohmic heating apparatus and control panel
6	Stand	Removable (Ohmic heating chamber can be removed for cleaning)	wood	Height = 17 cm Width = 14 cm	To fix the ohmic heating chamber at centre of wooden body

7	Variable Autotransformer			0-220 V	Regulates the voltage supply
8	Thermometer	Placed at geometric centre of the sample	Stainless steel	0-200 ºC	Measures and controls the temperature
9	Voltmeter	Fixed on control panel	-	0-220 V	Measures and displays the voltage
10	Ammeter	Fixed on control panel	-	0-5 A	Display current

The created ohmic heating device was assessed in terms of its heating properties, which included heating power, heating rate, and energy efficiency and which needed to be constantly tracked and determined throughout the experiment. The current (I) and voltage (V) values during the heating time (t) can be used to compute the energy (P) provided to the ohmic heating unit at a certain temperature. The following equation (Eq.1) was used to calculate it (Icier and Ilicali, 2005).

$$P = \Sigma VI\Delta t \qquad ....(1)$$

Where, P= heating power (W), V= voltage, I= current, Δt = is heating time

The rate at which energy may be transferred from the ohmic heating unit to the product is known as the heating rate. The material to be heated can generate sensible heat when an electrical current is fed through it, raising its temperature from its starting point (Ti) to its final temperature (Tf). Thus, the following formula can be used to determine the quantity of heat applied to the system (Ghnimi et al., 2008). Where, Q = mcp (Tf-Ti), Q is the heating rate (W), and cp is the water's specific heat (kJ/kg °C).

Ohmic heating systems are evaluated based on their energy efficiency (∊). It may be computed using the following formula (Eq.2) and is defined as the ratio of total energy used to heat the sample to total input energy (Nguyen et al., 2011).

$$\text{Energy efficiency } (\epsilon) = \frac{\text{Energy utilized to heat the sample}}{\text{Total input energy}} \qquad \ldots(2)$$

The amount of black cumin seed slurry injected into the heating chamber determined the size of the laboratory-scale ohmic heating chamber. The following formula can be used to determine the cylinder's volume:

$$\text{Volume of cylinder} = \pi r^2 h \qquad (3)$$

Where, r = radius of the cylinder, h= height of the cylinder, $\pi = 3.14$

$$V = 3.14 \times 6 \times 20 = 380\ \text{cm}^3$$

The weight of the sample (water and seed powder) put into the chamber per unit of time is known as the ohmic heating system's capacity. With no seams or fittings inside the chamber, the cylindrical shape was chosen to minimize heat loss and prevent slurry leaks from the system, as opposed to square and rectangular chamber shapes. The ohmic heating chamber was developed by recording and using the following characteristics.

- The amount of black cumin seed powder consumed was 100 g.
- Density of the black cumin slurry = 1.385 g/cm^3
- Volume of black cumin seed slurry = 433.21 cm3 - Powder to water ratio = 1: 5

These statistics have led to the decision to maintain the laboratory scale ohmic heating at 20, 6, and 0.5 centimeters for length, diameter, and thickness, respectively. Rather of creating a chamber for a black cumin seed slurry with a capacity of 380 cm^3, the ohmic heating chamber was created with a volume of 452 cm^3, accounting for the slurry's expansion and boiling when heated to 100 °C.

- Volume of the cylinder = 452 cm^3
- Weight of total sample taken = 600 g
- Time taken = 5.5 min

On the basis of these data, length, diameter and thickness of the ohmic chamber has been selected to keep 20, 6 and 0.5 cm respectively

$$\text{Capacity} = \frac{\text{Weight of the sample}}{\text{Time taken (hr)}} \quad \ldots(4)$$

$$= 600 \times 60/5.5 \times 1000$$

$$= 6.5\ \text{kg/hr}$$

It was discovered that the ohmic heating chamber has a 4.5 kg/h capacity.

RESULTS AND DISCUSSION

Comparing ohmic heating to conventional heating, there are benefits in terms of better product quality and less nutritional damage. It enables quick and even heating in a straightforward manner. Ohmic heater design is also a fairly straightforward task because it makes use of conductive materials, such as electrodes. Stainless steel was used to create conductive material because it came into direct touch with food.

Ohmic heating system performance was assessed in terms of heating power (P), heating rate (Q), and energy efficiency ($\in$). Two different kinds of electrode materials, such as aluminum and stainless steel (SS-304), were chosen with three distinct diameters: three, five, and seven centimeters, respectively. Tables 2 and 3 present the experimental treatments for materials made of stainless steel and aluminum respectively.

Table 2. Relationship between distance, diameter, heating power, heating rate and efficiency of ohmic heating setup for stainless steel

Treatments	Applied voltage (V)	Distance (cm)	Diameter (cm)	Heating power (W)	Heating rate (W)	Heat loss (%)
T1	100	3	16	354	176	50.28
T2	100	5	16	404	237	41.34
T3	100	7	16	328	194	40.86
T4	100	3	18	368	157	57.34
T5	100	5	18	480	309	34.48
T6	100	7	18	467	243	47.97
T7	100	3	20	340	170	51.29
T8	100	5	20	382	215	43.72
T9	100	7	20	430	262	38.52

Table 3. Relationship between distance, diameter, heating power, heating rate and efficiency of ohmic heating setup for aluminum

Treatments	Applied voltage (V)	Distance (cm)	Diameter (cm)	Heating power (W)	Heating rate (W)	Heat loss (%)
T1	100	3	16	424	230	45.76
T2	100	5	16	458	262	42.82
T3	100	7	16	405	232	42.72
T4	100	3	18	394	204	48.22
T5	100	5	18	510	317	36.72
T6	100	7	18	471	262	44.38
T7	100	3	20	348	211	39.37
T8	100	5	20	384	250	34.92
T9	100	7	20	414	273	34.06

The amount of time needed for the product to reach a specific temperature during processing determines the rate of heating. Throughout all of the trials, the ultimate achievable temperature was maintained at 50 °C. Figure 2 illustrates how applied voltage (80V) affects energy efficiency. T5 treatment resulted in higher heating powers for stainless steel (5cm diameter and 18 cm distance), while T3 treatment resulted in lower heating powers (7 cm diameter and 16 cm distance) (Table 2). The recorded reading indicated that the heating power decreased with increasing distance. The diameter grew from 5 cm to 7 cm, which resulted in a significant rise of bubble forms and a drop in the heating power rate (from 480 W to 430 W).

Similar outcomes were noted for aluminum as well. Aluminum had the maximum heating power (510 W) compared to stainless steel (480 W). Aluminum was more susceptible to corrosion from electrodes in direct contact with food than stainless steel was. Therefore, more hygienic and safe considerations for direct food contact led to the selection of stainless steel as the electrode material.

The efficiency with which the established ohmic heating setup can convert the given heating power (P) into heating rate (Q) is indicated by the energy conversion efficiency (∈), also known as energy efficiency. The devised configuration consisted of a pair of electrodes with a diameter of 5 cm and a thickness of 0.5 cm, spaced 20 cm apart. The stainless-steel material of treatment T5 had the best conversion efficiency of 62.50 % out of all 18 treatments (Figure 2).

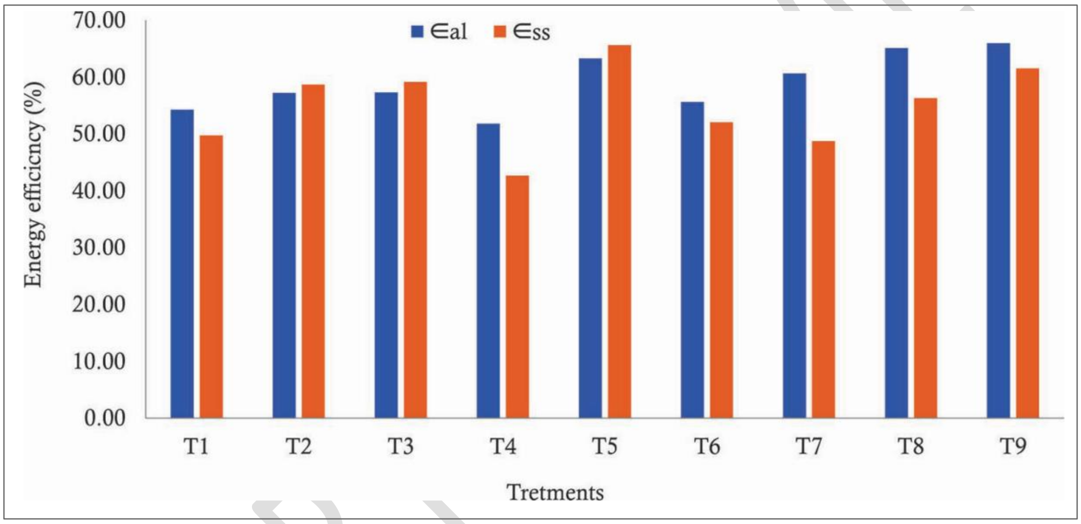


Figure 2. Effect of applied voltages (100 V) and different electrodes material on heat conversion efficiency

Conclusion

Ohmic heating is one of the rapidly emerging technologies in India's food processing sectors. Throughout the studies, the designed ohmic heating setup on a laboratory size performed admirably. The system is capable of efficiently converting a maximum of 62.50% of energy. With this system, a 80 V applied voltage could heat the liquid particle meal from 24°C to 50°C in about one minute. For the most part, the heating was volumetrically uniform. With this method, new high-value products with exceptional quality retention might be produced in large quantities while maintaining shelf stability.

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