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Ohmic Heating for Food Products- A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Author AP designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author MS managed the analyses of the study. Author MS managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Ohmic heating is a novel technology for food processing. This review paper summarizes the research progress and application in ohmic heating technology used in food processing. Ohmic heating is an electrical resistance heating method for the heat treatment of food products. When electric current passes through the food, the food heats up because of its internal electrical resistance. In this process heating rate depends upon the electrical conductivity and field strength. By this method a product undergoes a minimum structural damage, retain its nutritional value. This technique gives excellent processed quality products in minimum operating time. In this method electrical energy is converted into thermal energy. This is a uniform and rapid heating method. Electrical conductivity of food plays an important role in the ohmic heating process. Ohmic heating is good for liquid products, milk desserts, yoghurts, eggs, fruit juices, condiments, gelatine, wine, and hydrocolloids, etc which have electrical conductivity greater than 0.05 S/m. This method can be used in several sectors of food processing such as thawing process, blanching, sterilization, pasteurization, enzyme inactivation, expression, extraction, desalination and waste water treatment, rice bran stabilization, tofu making process, semi meat ball cooking and drying process etc.

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1. INTRODUCTION

In 1827, Georg Ohm, was the first to outline which is known as Ohm's law but recognition of the thermal effects of electricity within a conductor was the first elucidated by James Prescott Joule in 1840. The technology was once again revived in the 1980 and some industrial applications have resulted, including pasteurization of liquid eggs and processing of fruit products, among others. Ohmic heating concept was used in the early 20th century where electric pasteurization of milk and other food materials were achieved by pumping the fluid between plates with a voltage difference between them [1].

Ohmic heating is a resistance heating technique for liquids and pumpable particles [2]. It consists of equipment for passing alternative current through the fluid between electrodes [3]. Ohmic heating is used in a wide range of applications such as pasteurization, sterilization, preheating, blanching [4].

This is one of the excellent alternative methods of heating, this technique shows much promise especially in food industry over the last few decades, because there is an increasing shift from batch thermal operation towards continuous high temperature and short time processing of foods [5].

2. PRINCIPLES

An ohmic heater is an electrical heating device that uses a liquid's own electrical resistance to generate the heat [6]. Ohmic heating works on

the principle of Ohm's law of electricity. The passage of electric current through an electricity conductive food material obeys Ohm's law and heat is generated due to electrical resistance of food.

$$V \propto I$$

$$V = IR$$

Where

V = Voltage (volt), I = Current (ampere),
R = Resistance (Ohm)

2.1 Electrical Conductivity

It is quantity of electrical energy transferred through a unit area, per unit potential gradient and per unit time. The electrical conductivities of samples were calculated from the voltage and current data using the following equation,

$$\sigma = L / A \times I / V$$

Where,

σ is the electrical conductivity (S/cm)
L is the distance between electrodes (cm)
A is the area (cm²)
I is an alternating current passing through the sample (Amp)
V is the voltage across the sample (V) [7].

Electrical conductivity is an important parameter for ohmic treatment of food products. Rate of ohmic heating depends on the electrical conductivity of the food products during process.

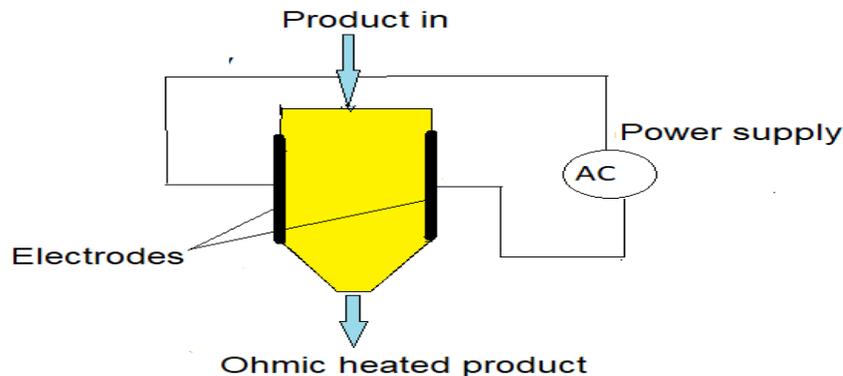


Fig. 1. The principle of ohmic heating

Electrical conductivity of food products should be greater than 0.05 S/m for good behaviour of ohmic heating. Examples:- milk desserts, yoghurts, eggs, fruit juices, condiments, gelatine, wine and hydrocolloids, etc.

Electrical conductivity of margarine, marmalade and powder type products are 0.005 to 0.05 S/m which behave like low ohmic heating and which food products have less than 0.005 S/m electrical conductivity behave poor ohmic heating examples:- fat, frozen foods, foam, liquor and syrup etc. [8]

Jae et al. [9] proposed the modelling of the thermal behaviour of multiphase food products with various electrical conductivities under ohmic heating system. Distortion of electric field due to heterogeneous food properties. They developed ohmic heating pattern of solid-liquid food complex that contained three different solid particles with substantially different electrical conductivities and 3% NaCl solution. The solid food samples used in the experiment were potato, meat and carrot, which were less conductive to carrier medium Hot spots existed on the continuous phase in zones which perpendicular to the solid cubes and cold spots were in between the particles where the lack of current density. Resulted the starch cellular structures of carrot and potato were collapsed down by thermal gelatinization [9].

Kumar et al. [10] reported that the electrical conductivity of food products usually increases with temperature and water content. They suggested that knowledge of electrical conductivity of food products is important for the designing of ohmic heating system [10].

Srivastav and Roy [11] prepared an ohmic heating system for heating of tomato juice (temperature 32°C to 80°C) at different voltage gradient in the range of 50 to 70 V/cm. It was found that the voltage gradient had significant impact on conductivity and system performance coefficient. It was concluded that the electrical conductivity values linearly increased with temperature. The electrical conductivity of tomato juice was strongly dependent on temperature. The rate of change of the electrical conductivity of tomato juice with temperature for 70 V/cm was higher compared to other voltage gradients applied. As the voltage gradient increased, time and performance coefficient decreased [11].

Kautkar et al. [12] revealed that the electrical conductivity of ginger paste was dependent on

temperature and ionic concentration. The electrical conductivity of the ginger paste linearly increased with temperature and it measured in terms of point and bulk electrical conductivity. Point electrical conductivity was greater than bulk electrical conductivity. The rate of change of temperature and electrical conductivity was higher for higher salt addition at all voltage gradients applied [12].

Palaniappan and Sastry [13] investigated that the heating rate of particle liquid mixture depends on conductivity of mixture and the volume of each phase. The reason of that, as particle content increased, the path of current through the fluid, forcing the total current to flow through particles. This will be caused in more energy generation within the particles and a greater particle heating rates. It was also concluded that the range of electrical conductivity of the food products should be in the range from 0.01 – 10 S/m. Food products which are used should have pH more than 4.6 and solid particulates food is solid to liquid ratio 40:60 [13].

2.2 Effects of Ohmic Heating on Physiochemical Property of Foods

Pereira et al. [14] studied the effect of ohmic and conventional heat processing of different food products on their chemical and physical parameters. Parameters such as pH, total solid, ash, titratable acidity, ascorbic acid, total sugar, total fatty acids, total phenolic compounds and anthocyanins content were determined before and after ohmic heating and conventional pasteurization techniques. Goat milk samples were treated by ohmic heating technology the pH was 6.58 and total fatty acid was 86.5 %. Ohmic treated samples show a lower content of lactic acid 0.13%. Chemical analysis of food products indicated similar chemical properties treated by both ohmic heating treatment and conventional treatment [14].

Samaranayake [15] determined the minimization of electrochemical reactions during ohmic heating. Ohmic heating is capable of reducing the electrochemical reaction of stainless steel, titanium and platinized- titanium electrodes compared with conventional 60 Hz ohmic heating. In general, except at the highest frequency low duty-cycle heating, pulsed ohmic heating was less successful in suppressing the electrochemical reaction of graphite electrodes compared with conventional ohmic heating. Ohmic heating provides its best result for

graphite electrodes. It is suitable for minimization of electrochemical reaction [15].

Viscosity of milk decreased with increasing temperature because increase in temperature leads to lower milk fatty blocs which are responsible for the high viscosity of milk. The relationships between viscosity and temperature were first-order equations for all electrical fields. Milk density was reduced by increasing milk temperature. This reduction was started after the rising of milk temperature above 40°C [16].

2.3 Effect of Ohmic Heating on Microbial Activity

Kumar et al. [17] studied the inactivation effects of ohmic and conventional heating on total plate count, molds and yeast, E. coli, coliforms and salmonella in buffalo milk under identical temperature conditions. Resulted the microbial counts from ohmic heating were lower than conventional heated milk. Salmonella were completely killed by ohmic heating treatment. Microbial destruction was higher in ohmic heat treated samples as compared to conventional heat-treated samples. Soft paneer was obtained by ohmic treated milk samples and sensory paneer list of this soft paneer was superior to paneer obtained from traditional method [17].

Kim et al. [18] investigated the lethality within foods particles undergoing 5 kW ohmic heating system used microbiological and chemical marker measurements. Meatball contains spores of B. stearo thermophilus and precursors of chemical markers were thermally processed in the solution of starch with 30 to 40 % solids content. Higher lethality was observed, microbiologically and chemically, at the centre of the meatballs rather than near the surface. They concluded that ohmic heating had a high potential for providing high quality of food products, shelf stable foods that were not achieved by conventional thermal processing [18].

2.4 Electroporation Effect during Ohmic Heating

Lebovka NI [19] studied the effect of temperature on electroporation of plant tissues during the pulsed electric field or alternative current. He was determined the effectiveness of the electroporation effect in plant tissues damage for

potatoes tissues in the range of electric field strengths 40-500 V/cm, at temperatures 22°C and 49°C in pulsed electric field treatment. Ohmic heating of potato and apple tissues were evidence of the importance of the electroporation mechanism of tissues damage at moderate electric fields under 100 V/cm and effectiveness of this mechanism increased with temperature increased. He observed the importance of the electroporation mechanism in plant tissues damage was induced by ohmic heating which is controlled by temperature induced changed in the cell membrane structure [19].

Cho et al. [20], (USA-FDA, 2000) investigated the incidence of electric field in the fermentative process may cause membrane electroporation provoking faster and efficient nutrient transport to the interior of the cell, thus reducing the lag phase of the fermentation. Ohmic heating has demonstrated to cause productivity decrease. This decrease may also be related to the electroporation effect which possibly allows the transport of metabolites to the interior of the cell and consequently inhibits the fermentative process [20].

3. APPLICATIONS OF OHMIC HEATING

3.1 Thawing

To increase the shelf life of meat products frozen storage is important. Meat thawing by ohmic heating is fast and less weight loss was observed in the sample. The fast thawing process gives better quality of meat products because of decrease unwanted microbial activity during thawing [21].

3.2 Meat Ball Cooking and Poultry Products

Ohmic cooking procedure was found to be safe in terms of PAH formation and mutagenic activity. Sensory evaluation showed that overall acceptance of the semi cooked meat ball samples was good. High cooking yield, moisture retention and fat retention values in samples were obtained with ohmic cooking [22]. The quality of the ohmic heated chicken breast samples was similar or superior to that of the retort- heated samples based on the measurement of water content and glutamic acid in the treated sample. The sample quality did not deteriorate or degrade during storage [23].

3.3 Extraction

Model of ohmic heating showed good performance when used for ohmic and enzyme assisted aqueous extraction of rapeseed oil [12]. Improve the extraction of soymilk from soybeans by ohmic heating [24]. Diffusion of beet dye from beetroot into a carrier fluid was increased in ohmic heating and the amount of dye extracted was proportional to the electrical field strength used [25].

3.4 Blanching

Blanching by ohmic heating permits the effective damage of food product's cells by combination of thermal and electrical effects. By ohmic heating osmotic dehydration of strawberries enhances the water and sugar transfer [26]. Ohmic heating is popular due to its volumetric heating rates, rapid process and the enhancement of mass transfer even at relatively low temperatures [27].

3.5 Pasteurization

Leizeron and Shimoni, [28] measured higher concentration of ohmic heated pasteurized orange juice during storage and the storage period was 105 days, resulted the particle size was lower in ohmic heated orange juice also prevented the growth of micro-organism, and the shelf life of ohmic treated orange juice was > 100 days. It was second time longer than these of conventionally pasteurized juice [28].

3.6 Expression

Enhancement of carrot juice recovery using 2-stage pressing with ohmic heating. Mathematical analysis for multi stage pressing applied to second stage expression process. The total carrot juice recovery increased in the duration of first pressing. Maximum enhancement in carrot juice recovery in second stage expression with ohmic heating over control was 13.76 %, resulted that the ohmic heating did not cause much change in the colour of carrot juice. In the first pressing, maximum carrot juice recovery was 98.9 % in 2.72 minutes, in the second pressing ohmic heating temperature was 65.6°C, voltage gradient was 15 V/cm for the time duration of 10 minutes [29].

3.7 Stabilization of Raw Rice Bran

10 Kg rice bran was hydrated and heated by flow of electric current through ohmic heating system. The treated sample was observed to be stable even after 75 days of storage in the comparison of raw rice bran sample. The free fatty acid (FFA) percent in ohmic heated rice bran was observed to be 4.77% after 75 days of storage whereas it was 41.84% in case of raw rice bran. The FFA concentration of the ohmic heated samples increased very slowly in comparison to raw rice bran samples during 75 days of storage [30].

3.8 Drying

In the vacuum dryer ohmic heated sample take less time for drying compared to raw samples. The maximum reduction of time was 24% [31]. Ohmic treatment helps in a significant decrease in time required for vacuum drying and positively effects the economic and product quality.

4. ADVANTAGES OF OHMIC HEATING TECHNOLOGY

In this technology high temperature for UHT processing can be achieved, surface fouling is not created, during the heating of the product and this method is very useful for pre-heating of the products before canning process [32]. Ohmic heating is used for continuous processing of food products. Capital investment is low compared to conventional and microwave heating method [5]. In this technology there is no need of boiler for parboiling of paddy, this is rapid and uniform heat treatment method for solid and liquid food products, there is less heat damage of the products, less nutrient loss and less color change of the products through this method [33]. Temperature of the system can be raised very quickly, instant shutdown system is provided and there is no extra heat transfer after switching off the current and there are no any moving parts in the ohmic heating system so it saves the maintenance cost of the system [27].

5. DISADVANTAGES OF OHMIC HEATING

Ohmic heating system is difficult to monitor and to control, lack of generalized information, complex coupling between the temperature and the electrical field distribution [5]. Electrochemical

reactions and electrode corrosion increase because of low frequencies [34].

6. CONCLUSIONS

Ohmic heating is a novel technology for food processing. It is an electrical resistance heating technique, in which heat is produced by electrical resistance of food materials. Electrical conductivity of food products should be greater than 0.05 S/m for good behaviour of ohmic heating. Electrical conductivity of food products usually increases with temperature and water content. Ohmic heating is rapid and uniform heating method. In this method electrical energy is converted into thermal energy. This method can be used in several sectors of food processing such as thawing process, blanching, sterilization, pasteurization, enzyme inactivation, expression, extraction, desalination and waste water treatment, rice bran stabilization, tofu making process, semi meat ball cooking and drying process. It gives high and good quality products, it takes less cooking time and decrease microbial activities from the food and increases the shelf life of food products during storage period.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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