A Review On Ohmic Heating And Its Use In Food

Rossi Indiarto, Bayu Rezaharsamto

Abstract: Ohmic heating, known as joule heating, can produce heat by flowing electric current through materials that can resist the flow of electricity. The volumetric properties resulting from ohmic heating cause heat to be spread evenly on the material. This method is best for foods containing suspended particulate matter in media containing weak salt. The advantage of ohmic heating in food is demonstrated by its ability to deactivate pathogenic microbes, prevent the decline in functional properties of food, nutritional, and sensory values so that food shelf life increases. However, related to viscosity, electrical conductivity, and fouling deposits are the limitations of ohmic heating. In addition to the inhibition of the microbial and enzyme activity, ohmic heat was also used for the extraction of essential compounds, including various specific processes such as starch gelatinization. This review discusses the ohmic heating, the principles and design of ohmic heating, the factors that influence it, and its use in food.

Index Terms: Ohmic heating, conductivity, frequency, electrodes, enzyme inactivation, microbes

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1. INTRODUCTION

The thermal method is one of the most crucial food processing and preservation procedures. It's used to eliminate pathogenic bacteria, improve texture, digestibility, and detoxify various food products [1]. The use of thermal processes in food generally uses pasteurization and sterilization methods [2]. Nevertheless, the use of high temperatures in these processes causes a decrease in the quality of the final product, such as reduced nutritional content [3] and organoleptic characteristics [4]. An alternative to this thermal method is using electric energy [5]. Ohmic is an electric-based heating method. Its effects are equivalent to pasteurization and sterilization processes with much higher efficiency [6]. Ohmic heating produces heat directly from inside the material and ignores restrictions such as low heat transfer coefficient, as well as the difficulty of heat penetrating the material's surface wall [7]. This volumetric heating property makes the ohmic process more efficient in processing time and heating rate [5], [8]. The ohmic system in the industry has been investigated and implemented for heating dairy around 1920 since the late 19th century [9]. In other products like sausages and vegetables, the ohmic heating method also used [10]. Due to high energy costs, electrode corrosion, and the difficulty of finding inert material and development of ultra-high temperature (UHT), ohmic heating was abandoned [11]. However, as ohmic related research develops, this method has once again become an alternative method that is very important to its use in food, such as blanching [12],[13], evaporation [14], dehydration [15], baking [16], extraction [17], thawing [18], sterilization [19], pasteurization [20] and gelatinization of starch [21]. Ohmic heating is seldom used due to high electricity costs, degradation of the electrode, difficulty in finding inert material, and the development of the Ultra High Temperature (UHT) process [11]. However, this method is widely used in foods such as blanching [12],[13], evaporation [14], dehydration [15], baking [16], extraction [17], thawing [18], sterilization [19], pasteurization [20] and gelatinization of starch [21]. This work aims at reviewing the influence of ohmic heating and its application in foodstuffs based on principles and mechanisms.

2. OHMIC HEATING PRINCIPLES AND DESIGNS

2.1. The ohmic heating principle

The principle of ohm heating is that electrical energy in the form of heat is dispersed by an electrical conductor [11]. Electrical energy flowed into food is converted into thermal energy. The electrical resistance of food, known as the Joule effect, causes volumetric heating [2]. This heating has very high efficiencies (> 90%). Because it can ignore the principle of conventional thermal transfer, i.e., heat transfer via temperature gradients or hot surfaces from the environment to medium [22]. It results in uniform and rapid heating due to the reactor fluctuation of electrical fields, thus increasing the dynamic motion of charged species and solution dipole moments [22]. The generated energy is directly proportional to the electric quadratic area used and the conductivity of the heating material [2].

An essential distinction between ohmic and other methods of heating is the use of electrodes that directly affect the heated media [22]. Ohmic heater electrodes may be considered as electric current connecting with heated medium, and electrodes are also uniformly distributed to the medium by the electric current [23]. The frequency used in ohmic heating is lower than microwave and radio, and the sinusoidal waveform is used [22].Ohmic methods can be used for heating foods between 0.1 and 10 S/m conductivity. Ohmic technology may be performed in batches or continuously. Electric field intensity, electrode configuration, and conductivity of heating material generate current flows. The current flow causes a high-power density and fast heating input of heat energy. The voltage is 400 to 4000 V; the power of the field is between 20 and 400 V/cm, and the gap between 10 and 50 cm for the electrode. The heating rate is determined by the efficiency of the energy source, the design of equipment, and the character of the thermal medium, such as conductivity, viscosity, and heat-specific capacity [10].

2.2. Design

Ohmic heating systems have different designs, but several key elements are necessary [6]. The ohmic heating system consists of a heating chamber, a pair of electrodes, and an alternating current generator that supplies electrical energy to the system [24]. The electrodes used must consist of highly conductive, low cost, and non-corrosive materials to prevent metal ion migration to foods such as Cr, Fe, Ni, Mn, and Mo [25]. The electrodes connected to the power station must be in direct contact with the material so that the electrical current

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can be connected. The distance between the electrodes may vary depending on the system size used. The electrode gap changes the number of formed electric fields [6]. The heating design ohmic, as stated by Goullieux and Pain [11]:

a) Batch configuration

The flow of the heated medium is ignored in the batch configuration so that the medium becomes static. This configuration makes it easy to calculate fundamental parameters such as electric conductance, heating time, and process homogeneity. This batch configuration can be used to identify an optimum initial product composition, and to monitor the processing effect on final product quality. This design is ideal for lab use, as it is useful for testing new product development. The application is simple and can easily find the best condition control during storage. However, to scale up the product, the industry should use a continuous system.

b) Transverse configuration

This configuration uses a continuous system, parallel product flow with electrodes, and perpendicular to the electrical field. Electrodes are used as flat or coaxial [6]. The design of this configuration is straightforward. However, there are two electrical problems, namely 1) Possible leakage of current through the material leaving the system due to active electrodes adjacent to the inlet and outlet pipes, 2) The density of the electrical current which leads to the flow of the product may be very uneven around the edge of the electrode.

c) Colinear configuration

In this configuration, the product is flowing from one electrode to another with the fluid flow parallel with the electric field. Compared to the two previous designs, the layout of the two electrodes is relatively more spaced.

3. OHMIC HEATING FACTORS INFLUENCE

Several factors, such as conductivity of electrical materials, frequency and wave shape, particle size, heat capacity, and material viscosity, as well as used electrodes, can influence the food process ohmic heating [24].

3.1. Electricity conductivity

The heating efficiency of ohmic depends on the material's conductivity [6]. The main factor of the ohmic heating rate is the electrical conductivity of the food. When the alternative current (AC) passes through the material, the electrical conducting indicates that electricity is converted to heat [26]. The unit used for electric conductivity measurement is Siemens per meter (S/m) and can be calculated by using the Sakr and Liu formulation [8]:

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

Where: σ= Electricity conductivity; L= Spaces of 2 electrodes (m); A= Cross-sectional heat cell material surface (m^2); I= alternating current flow through the materials (A); V = material voltage (V). The electrical conductivity of the materials depends on various parameters, including the power of ions, the water-free content, and the material's microstructure [27]. Ion compounds such as acids and bases can improve electrical conductivity but reduce non-polar compounds such as fats and lipids [28], [29]. The material's electrical conductivity value is not constant. Increasing material temperature can increase the conductivity of electricity [8]. Preheating with conventional methods is one method for streamlining ohmic heating to increase the electrical conductivity of materials [27]. The ohmic process can not effectively heat the food at electrically conductive values less than 0.01 S/m and above 10 S/m. It caused the desired heat to require huge voltages or currents [30].

3.2. Frequency and waveform

The frequency used for food ohmic heating applications is classified by 50 Hz-60 Hz as low frequency [30]. The electroporation of the quick cell membrane results from too low a frequency. As a result, electric conductivity suddenly increases, affecting the finished product's texture. The use of high frequencies can reduce the electroporation of the cell membrane, but can considerably increase the time needed to reach the temperature required [31]. Electricity is also significantly increased in wavelengths when the waveforms used are sinusoidal (sine waves) and triangular (like saws) in comparison to 4 Hz quadratic waves [22].

3.3. Size, heat capacity, and material viscosity

With an increased particle size of the material, the electric conductivity of the material will decrease [24]. Materials of less than 5 mm particle size can have an impact on the conductivity of the material. However, the particle size has a significant effect on the electrical conductivity of large particle (15 to 25 mm) material, which affects the process heating rate [32]. When solid particles are suspended into a liquid medium of the same power conductivity, the material component with a lower heat capacitance is heated more rapidly [6]. Materials with high specific gravity and heat tend to require more time to reach the desired temperature [22]. Liquid materials of higher viscosity tend to heat more quickly than materials of lower viscosity [33]. Materials with higher solid particulate concentrations usually have a faster heating rate. This is because more particles flow through the electrical current so that the heat energy produced in the particles gets faster [6].

3.4. Electrode

Electrodes are one possible cause of heat loss during ohmic heating and can lead to too high a product temperature gradient [34]. The thicker the electrodes are, the lower the temperature rates. This is because of the higher mass, lower electrical resistance [35]. The material used as an electrode can also influence the ohmic heating process. Titanium electrodes have a higher temperature in heating than the Stainless-Steel electrodes of the same thickness on the surface of the electrodes. Aluminum electrodes tend to be electrolyzed so that there is likely to be contamination in the material [34]. Titanium electrodes are the best materials and are electrolysis resistant and offer an optimum heating rate [34].

4. OHMIC HEATING ON FOOD

Ohmic heating has enormous potential for use in the food industry. Food ohmic heat is used for microbial inactivation, pasteurization, extraction, blanching, thawing, starch gelatinization, and evaporation. This method can be applied to various food products. However, some food products should be prepared for ionic content improvement and solid-phase conductivity [11]. The lower the conductivity difference of the material in the liquid and solid phase, the more the electric current flow is uniformly distributed so that the generated heating is more equally distributed [36]. Before the ohmic heating process, other pre-treatments can be made to reduce the reduction of texture value and to equalize the electric conductivity of the material to achieve a uniform drying rate at all stages within the material [11].

4.1. Pathogenic microbes' inactivation

There are various drawbacks to microbial inactivation by using conventional heating methods, namely reduced organoleptic quality and nutrient content in the material, especially in materials that are not heat resistant [37]. The ohmic heating process is the lethal result of conventional heating for pathogenic microbes to be inactivated. Ohmic heating can, however, be more effective in keeping quality ingredients with shorter heating times [30]. Several studies have shown that ohmic heating can cause non-thermal damage to microbial cells due to exposure to electric fields. So that the value of D or the time needed to kill microorganisms as much as 1 log cycle during ohmic heating becomes smaller when compared to conventional heating [30], [38]. The inactivation of the microorganisms has significant impacts on the temperature and electrical current. A 1% increase in the temperature can decrease over 9% of the population of the first microorganisms, and a 1% rise in the current of the electricity used can decrease over 20% of the Zygosaccharomyces rouxii population in orange juice [37]. The inactivation of Alicyclobacillus acidoterrestris spores using ohmic heating also proved to be more effective than the conventional heating of orange juice. Ohmic heating with an electric field of 30 V/m in orange juice at 90 °C for 30 minutes is sufficient to reduce 5 log spores in the material [39]. According to Shao et al. [40], there is a positive correlation between Escherichia coli bacteria or the phase of adaptation with the voltage gradient in ohmic heat. When the lag phase is longer than conventional heat. This phenomenon can lead to non-thermal effects of ohmic heat. Some other ohmic heating-inactivated microorganisms include Listeria monocytogenes [41], Salmonella typhimurium [42], Bacillus coagulans spores [43], and Geobacillus stearothermophillus [44].

4.2. Enzyme inactivation

In the ohmic heating method, the mechanism of inactivation of the enzyme is the same as conventional heating, although some kinetics of parameters change [45]. Various types of enzymes found in food can cause adverse effects, such as odors and deforested taste and texture changes, so that inactivation is necessary [46]. The pectin methylesterase is an enzyme which in the ripening process can degrade pectin in fresh fruits like oranges and purify the juice by forming a Ca^{2+} pectate gel [46], [47]. It is necessary to inactivate this enzyme to avoid excessive pectin degradation and cause extreme changes in texture. The method of inactivating this enzyme with both ohmic and conventional heating also follows the kinetics of the first-order inactivation. Still, the cost of the reduction of ohmic heat shows a level of efficiency that is better than conventional orange juice heating, which is 96% compared to 88,3% [45], [46]. Some enzymes can cause undesirable color changes, such as sugar cane juice browning due to the peroxidase enzyme [48]. But in the second stage, peroxidase enzymes are inactivated more rapidly by ohmic heat, although the first phase did not change significantly compared to conventional heat [45]. The presence of an electric field combined with a heat of 80 °C influences the biochemical reaction to peroxidase inactivation in sugarcane juice samples. However, no significant non-thermal effect was found during the inactivation process due to ohmic heating [48], [49]. Tyrosinase is an enzyme that, in the case of oxygen, can catalyze the oxidation reaction of phenolic compounds into quinone, forming dark-brown pigments [50]. Inactivation of tyrosinase using ohmic heating has shown that the time needed for inactivation is reduced compared to conventional heating [51]. Polyphenol oxidase and lipoxygenase are other enzymes whose activation is more productive using the ohmic heating method. Nevertheless, the inactivity of certain enzymes such as alkaline phosphatase, pectinase, and β-galactosidase is not affected by all heated ohmic treatments [52].

4.3. Extraction

Ohmic heating can induce cell membrane electro-permeability. The temperature and membrane damage can increase as electric current flows through the medium, resulting in fluid diffusion into the cellular structure [53]. The application of ohmic heating to bulb samples for inulin extraction in Jerusalem has proven that the extraction yields are significantly higher than conventional heating [17]. The reason is that the electrical field is higher, and the more solids are extracted into the solution. According to Aamir and Jittanit [54], the extraction of tepurang (Momordica cochinchinensis) fruit oil using ohmic heating showed an extraction efficiency, color characteristics, β-carotene, and lycopene content higher than conventional heating. This is due to the more easily damaged skin cell walls during the ohmic heating process. Further, it has been proven that phytochemical extractions such as anthocyanins and phenolic compounds from colored potatoes lead to more extraction results with shorter treatment times, less consumption of energy, and no use of organic solvents using ohmic heating methods [55].

4.4. Thawing

The process of thawing with ohmic heating is more efficient. The heat generated throughout the material is faster and more uniform. This affects the time needed to prevent significant freezing [56]. Increasing the frequency of frozen thawing will increase the heating rate. The higher beef fat content results in lower electrical conductivity and longer cycle times [56]. Ohmic heating also decreased weight loss and frozen beef thawing period [18]. An increase in gradient voltage will minimize thawing time without increasing the loss of weight in the final frozen beef product in the form of blocks and cubes [57].

5. CONCLUSION

Ohmic is an alternative method of heating, which uses electrodes to convert electric energy into heat. The electrode is directly in contact with the heated material. The ohmic heating process allows for a higher quality of the end products, faster cooking time, and efficient use of energy. The electrical conductivity of the heating material is one of the factors that determine the effectiveness of the ohmic heating system. Ohmic heat from materials with electrical conductivity of between 0.01 and 10 S/m can be effectively and efficiently generated. There is already extensive use of ohmic heating potential in the food sector. Ohmic heat is most widely used in foods, including inactivation of pathogens and enzymes, as well as the removal of compounds in food.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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