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Ohmic Heating and its applications in food processing

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Abstract
The terms joule heating, electrical resistance heating, direct electrical resistance heating, electro heating, and electro conductive heating are additional terms for ohmic heating. The ohmic heating method heats food components based on their natural electrical resistance characteristics by transforming them into the component parts of an electrical circuit through which an alternating current (AC) flows. The square of the local electric field strength and the product's electrical conductivity determines how much energy is produced. Quick and uniform heating provided by ohmic heating shortens treatment periods and thermally deteriorates vitamins, pigments, and other components less. Producing particulate matter at temperatures exceeding liquid with conventional heating is not achievable without running the danger of blocking the heat transmission surface or burning the food product. Ohmic heating has a wide range of possible uses, according to recent worldwide study. In the military or on extended space missions, this can involve blanching, evaporation, fermentation, extraction, sterilization, pasteurization, and heating food to serving temperature. Prior to being utilized commercially, the majority of applications are still in the waiting stage. It has been demonstrated that ohmic heating works well for a range of food items, including milk, fruit, vegetables, and their products, meat, fish, flours, and starches. Ohmic heating can be used to make food that is secure and of the highest quality, validating any industrial process. Technologies like ohmic heating and dielectric heating, which are incredibly powerful and effective since the heat is generated directly inside the food, have been introduced, and they represent tremendous developments in heating technology.

Keywords: Intrinsic properties, electric heating, electric conductivity, blanching

Introduction
Ohmic heating is a method that involves passing electrical current through the food's components, according to Cappato *et al*. (2017) [3]. This method swiftly and uniformly elevates the inner temperature of the meal by transforming electrical energy into thermal energy. The dissipation of electrical energy into heat is the fundamental idea behind ohmic heating or the joule effect. In 2014, Kumar *et al* [15]. It is therefore a method of heating food goods where the material itself produces heat when an electric current is passed through it due to electrical resistance. A cutting-edge method called ohmic heating minimizes thermal harm to the food product while delivering speedy and even heating. OH is also referred to as internal thermal energy generating technology since heating is brought on by internal heat creation as a result of resistance to the flow of electric current. Kirsch (2009) [24] and others. In the food business, a variety of food products are processed using this cutting-edge heating technique, most notably plant-based meals, more particularly, processed fruits and vegetables (Cho *et al*., 2017) [5]. Ohmic heating is regarded as having a low entry barrier, excellent energy efficiency, and technological simplicity, according to Kaur *et al*. (2016) [13]. It is also known as electro-conductive heating, electrical resistance heating, and joule heating. Since milk was pasteurized in the 19th century, the idea of ohmic heating has been used to prepare foods Cappato *et al*. 2017 [3]. Energy cannot be generated or destroyed, according to the First Law of Thermodynamics, and can only be changed from one form to another. One of the best ways to put this theory into effect is ohmic heating, which transforms electrical energy into thermal energy.

History
Electric pasteurization of milk was accomplished in the early 20th century, and commercial pasteurizers were available in 6 US states. Researchers concentrated on using ohmic heating for the thawing and blanching processes between the 1950s and the 1970s. The Electricity Council of Great Britain licensed the technology to APV Baker in 1988 after patenting a continuous-flow ohmic heater.

Ohmic heating has recently been made possible by the development of new and better ohmic heating materials and designs.

Principle

According to Ohm's law, the voltage across two points is exactly proportional to the current flowing through a conductor between them. One arrives at the typical mathematical equation that characterizes the relationship by include the resistance as the proportionality constant:

V=IR

Where,

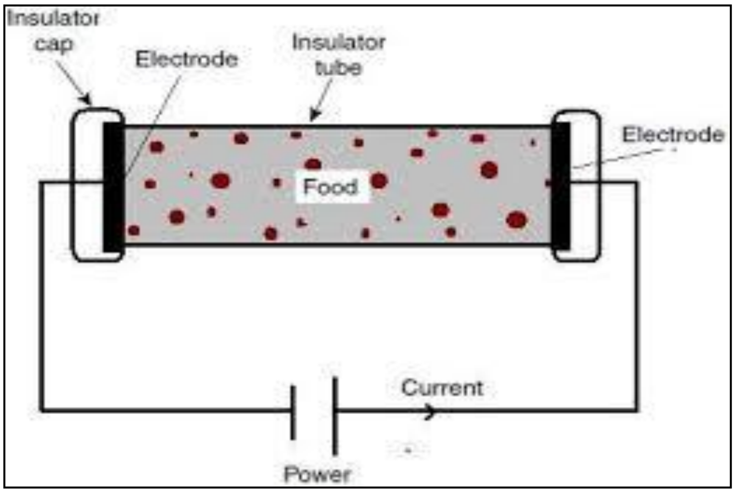
V is the voltage measured across the conductor in units of ohms.
I is the current through the conductor in units of volts,
R is the resistance of the units of ohms.

Process/Working of Ohmic heating: In order to generate electrical current, a power source or generator is required. Electric current flows through the matrix through electrodes that come into touch with the food. To get the ideal electric field strength, the distance between the electrodes can be changed. Electricity generated by the generator travels to the first electrode, where it passes through the food product positioned in the electrode gap. Internal heating results from the food product's resistance to the current flow. The current flows to the second electrode and then back to the power source to complete the circuit. The insulator cap that covers the electrodes controls the environment inside the apparatus. The two main process variables that influence heat generation are the electric field strength and the residence period.

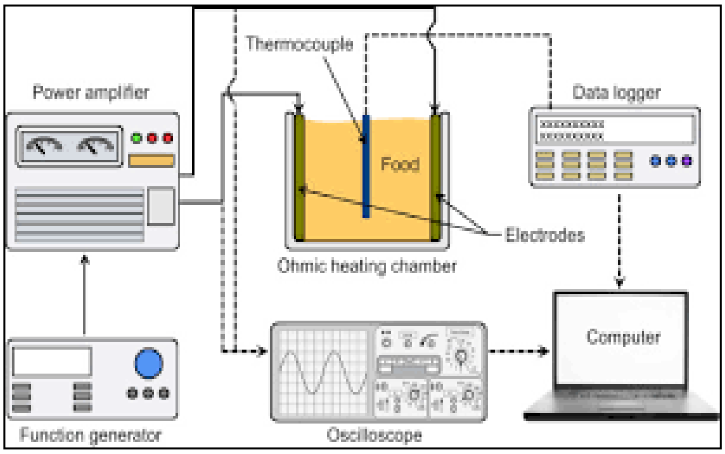
Main Parts of Ohmic Heating System

Contains mainly 3 parts:

1. Power Supply
2. Heater Assembly
3. Control Panel



Ohmic Heating Process Diagram



Effect on Microorganisms

In ohmic heating, cellular damage from the electric field causes both thermal and non-thermal microbial inactivation. This technique kills bacteria by electroporation cell membranes, rupturing membranes, and lysing cells. Cell death occurs during electroporation as a result of excessive ion and intramolecular component leakage. Cells swell as a result of increased moisture transport across the cell membrane in membrane rupture. Cells lyse as a result of pronounced destruction and breakdown of their cytoplasmic and cell wall membranes.

Importance of Ohmic heating

Food products are frequently processed and preserved via heat treatment. The most popular way for heating meals is conventional heating (Kaur *et al*. 2016) [13]. Convectional or conductional heat transfer processes are used in conventional thermal processing (Cappato *et al*., 2017) [3]. Using thermal conduction and convection between the food and the heating medium, heating methods produce heat inside the food. Food is made up of a complex matrix of different substances, such as carbohydrates, proteins, fats, vitamins, minerals, water, molecules that give it color and flavor, etc. The conventional heating of food can occasionally cause the aforementioned components to degrade, lowering the food's nutritional content and hence its overall value. According to Cappato *et al*. (2017) [3], conventional heating has drawbacks including overheating, nutritional compound loss, and sensory alterations. Slow conduction or convection heat transfer during conventional thermal processing in cans or aseptic processing systems for particle foods results in significant product quality disability (Kaur *et al*. 2016) [13].

The heating medium also relies on natural resources like fossil fuels, whose burning results in pollution issues as well as some financial and energy losses. By using cutting-edge methods like ohmic heating, these drawbacks can be avoided. Due to the straightforward internal heat generation method and usage of electrical energy, there is efficient heating without any energy loss occurring during processing. Its benefits over conventional heating also include faster and more consistent heating, higher yields, and better food nutritional value retention. This is primarily because it can heat materials quickly and evenly, which results in a less severe thermal treatment (Darvishi *et al*. 2013) [8].

Factors That Influence Ohmic Heating

- According to Joule's First Law, a food material's ability to produce heat is inversely correlated with its electrical conductivity and electric field intensity (Kumar *et al*., 2014) [15]. The consideration of electrical conductivity is consequently essential for ohmic heating. The electrical conductivity of a material determines whether current can flow through it when subjected to an electric field.
- The relative conductivities and volumes of the system's phases have a major impact on how quickly particles in a fluid heat up. Poor concentrations of poor conductivity solid particles in relation to the volume of the fluid usually cause them to lag behind the fluid. Although the same low conductivity particles may heat up more quickly than the fluid around them in circumstances where the particle concentration is large.
- The relevance of particle resistance to the total circuit resistance determines whether the phenomenon of particle-lagging or particle-leading occurs. The reason for this phenomena is that as the concentration of the particles rises, the path of the electric current through the fluid gets more complicated requiring a higher proportion of the current to pass through the particles. According to Kirsch *et al*. (2010), this may lead to increased particle energy generation rates and, as a result, a higher relative particle heating rate.

Factors affecting electrical conductivity

- **Temperature:** It is crucial to take into account because it is the primary factor that influences electrical conductivity. Electrical conductivities should be measured at temperatures other than room temperature because, as numerous studies have discovered, EC rises with temperature (Darvishi *et al*., 2013) [8]. According to Kumar *et al*. (2014) [15], the electrical conductivity of only liquid meals rises linearly with temperature.
- **Voltage Gradient:** According to Kumar *et al*. (2014) [15], temperature and voltage gradients are the key determinants of electrical conductivity variation. According to Kaur *et al*. (2016) [13], a rise in field strength causes the fluid velocity through the capillaries to increase, which is exactly proportional to EC. Thus, voltage gradients also affect the ohmic heating times. Time slows down when the voltage gradient grows (Darvishi *et al*., 2012) [7].
- **Frequency:** The total ohmic heating process is significantly impacted by the applied frequency as well. The majority of the time, a rise in electrical conductivity with increased frequency causes the heating rate to increase. However, this doesn't always happen. According to studies, the majority of the time (such as with turnips and Japanese white radish) there is a rise in temperature with a decrease in frequency. According to Kaur *et al*. (2016) [13], the sample reached high temperatures more quickly the lower the frequency.
- **Electrolytic concentration:** The amount of electrolytes present in a dietary material directly relates to its electrical conductivity. The charged molecules or ions found in meals in the form of salts are what are known as electrolytes. Changing a food's ionic content can change its electrical conductivity (Kumar *et al*., 2014) [15]. The rate of heating increases as ionic concentration does. The conductivity of the product will increase with the concentration of ionic ingredients (Kaur *et al*., 2016) [13].
- **Moisture content:** The amount of free water that is contained in a food is indicated by its moisture content. The food's free water serves as a conductor of electricity. Therefore, the EC will be higher the higher the moisture content.
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Comparision with Conventional Heating

- To transfer heat from the food product to the heating medium, such as air, water, or oil. Typical food industry heating systems use conductive, convective, or radiative mechanisms. It could take a while to conduct enough heat into the product core to reach a temperature that is safe, depending on the shape of the product. The quality of the product could suffer as a result of some product components being overdone or undercooked (Kumar *et al*., 2014) [15]. In contrast to traditional heating (CH), which transfers heat from a heated surface into the food's interior, OH evenly distributes heat throughout the food's mass (Cho *et al*., 2017) [5]. In addition to being more efficient and quicker than conventional heating, it is also cleaner, more ecologically friendly, produces more food, and retains more of the food's nutritional worth. This is primarily because it can thermally treat materials less aggressively thanks to its capacity to heat materials quickly and uniformly (Darvishi *et al*., 2013) [8]. Unlike other heating methods, ohmic heating is less affected by changes in the thermal characteristics of food. On the other hand, because of the extremely high conversion ratio of electrical energy to heat energy, ohmic heating, particularly for fruit juices, often has a high efficiency. When the current is passed uniformly, a homogeneous temperature distribution can be easily obtained. According to Cokgezme *et al*. (2017) [6], ohmic heating systems do not require the use of steam or hot water and do not generate any waste. One of the benefits of OH over CH is that it provides uniform heating without a temperature gradient, which makes it feasible to quickly heat a complete sample because there are no cold patches. In a two phase food material, OH enables extraordinarily quick and homogeneous heating of both the solid and liquid phases. A high-quality product is produced quickly with little to no structural, nutritional, or organoleptic change in OH since there isn't a hot surface there to cause fouling issues and thermal degradation to the product (Cho *et al*., 2017) [5].

- Collectively, OH has advantages over conventional heating are:
- **Uniformity in heating:** The OH approach, in contrast to conventional heating, allows for simultaneous heating of the solid and liquid phases. food with a particle content, food with a higher viscosity, and liquid particle combinations. The quick switching on and off makes the process simple to manage. Greater energy efficiency: The OH process converts 90% of the electrical energy it uses into heat energy as a result of internal energy generation. The energy efficiency of this new technology is substantially better than other new technologies.
- **Fouling Reduction:** Due to the absence of hot surfaces for heat transfer, the OH method reduces fouling and the possibility of food layers burning. Because of this, cleaning costs are lower and the processing time is shortened. Effects of electroporation, a non-thermal addition in general, electroporation causes cellular damage in microorganisms, which reduces their ability to withstand heat during treatment.

Applications

- Pasteurization, evaporation, dehydration, fermentation, extraction, and blanching are just a few of the processes that can be carried out using ohmic heating. In the military and on lengthy space missions, ohmic heating is also utilized to heat food to the serving temperature for the crew.
- **Extraction:** Ohmic heating can be used in conjunction with conventional extraction techniques. It has been discovered that sugar beets may extract sucrose more effectively than before.
- **Enzyme Inactivation:** Food processing requires the deactivation of enzymes in order to preserve food for a long time. Ohmic heating can be used to inactivate food enzymes because research has shown that it is more effective than conventional heating at reducing deactivation times and maintaining product quality.
- **Blanching:** Studies have shown that ohmic blanching retains color quality better and inactivates enzyme activity more quickly than typical water blanching. So, blanching can be accomplished using ohmic heating.
- **Waste water treatment:** There is usually a high biological oxygen demand (BOD) in waste water. The process of reducing the BOD of waste water with a high protein concentration involves boiling the protein and then separating it.
- **Starch gelatinization:** One of the most crucial variables during the gelatinization of starch is the gelatinization temperature. According to Kumar *et al*. (2014) [15], Wang and Sastry (1997) suggested that ohmic heating is the most efficient way to measure starch gelatinization when compared to other techniques.
- **Pasteurization and sterilization:** Industries have recognized ohmic heating as a method of treating liquids and solid-liquid combinations. According to a recent study, guava juice is sterilized using ohmic heating. Food products are frequently pasteurized or sterilized using ohmic heating, which produces food of great quality. According to a study, the ohmic heating method was employed to pasteurize milk in the early 20th century.
- **Ohmic Thawing:** When food is sandwiched between two electrodes and exposed to an alternating current, ohmic heating can be utilized to thaw frozen items. The benefits of this procedure are the lack of water use and waste water production, the potential for a reasonably uniform thawing due to volume heating, and the ease of controllability. However, ohmic thawing's drawbacks have also been researched (Varghese *et al*., 2014) [23].

Conclusion

By passing an alternating electrical current through food products, ohmic heating creates interior heat as a result of electrical resistance. It is a cutting-edge method that offers speedy and consistent heating, minimizing thermal harm to the food product. It is thought to be technically simple, has a high energy efficiency, and is environmentally friendly. The heat produced by conventional heating techniques inside the meal has drawbacks such overheating, loss of nutritious components, and sensory alterations. Ohmic heating is therefore applied to foods where heating is obtained as a result of internal heat generation in order to eliminate these losses. Additionally, compared to other heating techniques, it is less affected by changes in the thermal characteristics of the meal. Ohmic Heating doesn't have a hot surface, which decreases fouling issues and thermal damage to the product. As a result, a high-quality product is produced quickly with little structural, nutritional, or organoleptic modifications. Ohmic heating alters the nutritional value and quality of food in a number of ways, including the inactivation of enzymes and microorganisms, the breakdown of heat-sensitive substances, the alteration of cell membranes, viscosity, pH, and color. When compared to conventional heating, processes like enzyme inactivation and blanching can be completed in a lot less time while yet retaining the maximum amount of color and flavor. It can be used in a wide range of industrial processes, including extraction, enzyme inactivation, blanching, waste water treatment, starch gelatinization, pasteurization, and sterilization, among others.So, whenever possible, ohmic heating should be employed as a substitute for conventional heating.

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