Ohmic heating in food preservation

Ohmic heating is also known as joule heating, electric resistance heating, direct electric heating, electro heating and electro conductive heating. It is a process in which alternating electric current is passed through food material to heat them. Heat is internally generated within the material owing to the applied electrical current. In conventional heating, heat transfer occurs from a heated surface to the product interior by the means of convection and conduction and is time consuming especially with longer conduction or convection paths that may exist in the heating process. Elecroresistive or ohmic heating is volumetric in nature and thus has the potential to reduce over processing by virtue of its inside-outside heat transfer pattern. Ohmic heating is distinguished from other electrical heating method by the presence of electrodes contacting the food by frequency or by waveform.

Ohmic heating is not a new technology; it was used as a commercial process in the early twentieth century for the pasteurization of milk. However, the electro pure process was discontinued between the late 1930s and 1960s ostensibly because of the prohibitive cost of the electricity and a lack of suitable electrode material.

Interest in ohmic heating was rekindled in the 1980s, when investigators were searching for viable methods to effectively sterilize liquid- large particle mixtures, a scenario for which aseptic processing alone was unsatisfactory. (Rahman, 1999)

Ohmic heating is one of the newest methods of heating foods. It is often desirable to heat foods in a continuous system such as heat exchanger rather than in batches as in a kettle or after sealing in a can. Continuous systems have the advantage that they produce less heat damage in the product, are more efficient, and they can be coupled to aseptic packaging systems. Continuous heating systems for fluid foods that contain small particles have been available for many years. However, it is much more difficult to safely heat liquids containing larger particles of food. This is because it is very difficult to determine if a given particle of food has received sufficient heat to be commercially sterile. This is especially critical for low acid foods such as Beef stew which might cause fatal food poisoning if under heated. Products tend to become over processed if conventional heat exchangers are used to add sufficient heat to particulate foods. This concern has hindered the development of aseptic packaging for foods containing particulates. Ohmic heating may over come some of these difficulties and limitations.

Considerable heat is generated when an alternating electric current is passed through a conducting solution such as a salt brine. In ohmic heating a low-frequency alternating current of 50 or 60 Hz is combined with special electrodes. Products in a conducting solution (nearly all polar food liquids are conductors) are continuously passed between these electrodes. In most cases the product is passed between several sets of electrodes, each of which raise the temperature. After heating, products can be cooled in a continuous heat exchanger and then aseptically filled into presterlized containers in a manner similar to conventional aseptic packaging. Both high and low- acid products can be processed by this method. (Potter et al, 2006)

An advancement in the thermal processing is ohmic heating. In principle, electricenegy is transformed into thermal energy uniformly throughout the product. Rapid heating results, and better nutritional and organoleptic qualities are possible when compared with conventional in -can sterilization. “ Ohmic heating employs electrodes immersed on pipe,” Quass says. ” Product is pumped through the pipe as current flows between the electrodes.” Depth of penetration is not limited. The extent of heating is determined by the electrical conductivity through the product, plus residence time in the electric field. “ ohmic heating is useful for foods thus burn-on or have particulates that plug up heat exchangers,” continues Quass. “ Instead of using a scraped surface heat exchanger for stew, for example, ohmic heating can reduce the come-up time, and improve product quality.’

Ohmic heating is defined as a process wherein (primarily alternating) electric currents are passed through foods or other materials with the primary purpose of heating them. The heating occurs in the form of internal energy generation within the material. Ohmic heating is distinguished from other electrical heating methods either by the presence of electrodes contacting the food (as opposed to microwave and inductive heating, where electrodes are absent), frequency (unrestricted, except for the specially assigned radio or microwave frequency range), and waveform (also unrestricted, although typically sinusoidal). In inductive heating, electric coils placed near the food product generate oscillating electromagnetic fields that send electric currents through the food, again primarily to heat it. Such fields may be generated in various ways, including the use of the flowing food material as the secondary coil of a transformer. Inductive heating may be distinguished from microwave heating by the frequency (specifically assigned in the case of microwaves), and the nature of the source (the need for coils and magnets for generation of the field, in the case of inductive heating, and a magnetron for microwave heating). Information on inductive heating is extremely limited.

A project was conducted in the mid-1990s at the Technical University of Munich (Rosenbauer 1997), under sponsorship from the Electric Power Research Institute. No data about microbial death kinetics under inductive heating were published. Thus, the succeeding discussion focuses on ohmic heating. A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation, and extraction. The present discussion, however, concerns primarily its application as a heat treatment for microbial control. In this sense, the main advantages claimed for ohmic heating are rapid and relatively uniform heating. Ohmic heating is currently being used for processing of whole fruits in Japan and the United Kingdom. One commercial facility in the United States uses ohmic heating for the processing of liquid egg. The principal advantage claimed for ohmic heating is its ability to heat materials rapidly and uniformly, including products containing particulates. This is expected to reduce the total thermal abuse to the product in comparison to conventional heating, where time must be allowed for heat penetration to occur to the center of a material and particulates heat slower than the fluid phase of a food. In ohmic heating, particles can be made to heat faster than fluids by appropriately formulating the ionic contents of the fluid and particulate phase to ensure the appropriate levels of electrical conductivity.

Principle of ohmic heating:

Joule heating is also referred to as ohmic heating or resistive heating because of its relationship to OhmHYPERLINK “ http://en. wikipedia. org/wiki/Ohm’s_law”‘ HYPERLINK “ http://en. wikipedia. org/wiki/Ohm’s_law” s Law.

Ohm’s law states that, at constant temperature in an electrical circuit, the current passing through a conductor between two points is directly proportional to the potential difference (i. e. voltage drop or voltage) across the two points, and inversely proportional to the resistance between them.

The mathematical equation that describes this relationship is:

$$I= v/R$$

Where,

I is the current in amperes, V is the potential difference between two points of interest in volts, and R is a circuit parameter, measured in ohms (which is equivalent to volts per ampere), and is called the resistance. The potential difference is also known as the voltage drop, and is sometimes denoted by U, E or emf (electromotive force) instead of V.

The law was named after the physicist Georg Ohm, who, in a treatise published in 1827, described measurements of applied voltage and current passing through simple electrical circuits containing various lengths of wire. He presented a slightly more complex equation than the one above to explain his experimental results (the above equation is the modern form of Ohm’s law; it could not exist until the ohm itself was defined (1861, 1864)).

Well before Georg Ohm's work, Henry Cavendish found experimentally (January 1781) that current varies in direct proportion to applied voltage, but he did not communicate his results to other scientists at the time.

The resistance of most resistive devices (resistors) is constant over a large range of values of current and voltage. When a resistor is used under these conditions, the resistor is referred to as an ohmic device because a single value for the resistance suffices to describe the resistive behavior of the device over the range. When sufficiently high voltages are applied to a resistor, forcing a high current to flow through it, the device is no longer ohmic because its resistance, when measured under such electrically stressed conditions, is different (typically greater) from the value measured under standard conditions (see temperature effects, below).

Ohm's law, in the form above, is an extremely useful equation in the field of electrical/electronic engineering because it describes how voltage, current and resisitance are interrelated on a macroscopic level, that is, commonly, as circuit elements in an electrical circuit.

Advantages of ohmic heating:

Ohmic heating exhibits several advantages with respect to conventional food processing technologies as follows.

Particulate foods upto 1 in are suitable for ohmic heating; the flow of a liquid particle mixture approaches plug flow when the solids content is considerable (20-70%).

Liquid particle mixtures can heat uniformly under some circumstances (for example, if liquids and particles posses similar electrical conductivities or if properties such as solids concentration, viscosity, conductivity, specific heat and flow rate are manipulated appropriately).

Temperatures sufficient for ultra high temperature (UHT) processing can be rapidly achieved.

There are no heat surfaces for heat transfer, resulting in a low risk of product damage from burning or over processing.

Energy conversion efficiencies.

Relatively low capital cost. (Biss et al 1989)

Parameters of importance in ohmic heating:

Product properties:

The most important parameter of interest in ohmic heating is the electrical conductivity of the food and food mixture. Substantial research was conducted on this property in the early 1990s because of the importance of electrical conductivity with regard to heat transfer rate and temperature distribution. The electrical conductivity is determined using the following equation:

Đ‘= L / AR

Where Đ‘ is the specific electrical conductivity (S/m), A the area of cross section of the sample (m2), L the length of the sample (m), and R the resistance of the sample (ohm). General findings of numerous electrical conductivity studies are as follows.

The electrical conductivity is a function of food components; ionic components (salt), acid, and moisture mobility increase electrical conductivity, while fats, lipids, alcohol decrease it. Electrical conductivity is linearly correlated with temperature when the electrical field is sufficiently high (at least 60 V/cm).

Nonlinearities (sigmoid curves) are observed with lower electrical field strength.

Electrical conductivity increases as the temperature and applied voltage increases and decreases as solids content increases.

Lowering the frequency of AC during ohmic heating increases the electrical conductivity.

The waveform can influence the electrical conductivity; through AC is usually delivered in sine waves, sawtooth waves increased the electrical conductivity in the some cases, while square waves decreased it.

Electrical conductivity as opposed to raw sample showed increased electrical conductivity as opposed to raw samples when both were subsequently subjected to ohmic heating.

The electrical conductivity of solids and liquids during ohmic heating of multiphase mixtures is also critically important. In an ideal situation, liquid and solid phases posses essentially equal electrical conductivities and would thus (generally) heat at the same rate. When there are differences in the electrical conductivity between a fluid and solid particles, the particles heat more slowly then a fluid when the electrical conductivity of the solid is higher than that of the fluid. Fluid motion (convective heat transfer) is also an important consideration when there are electrical conductivity differences between fluids and particles.

Other product properties that may affect temperature distribution include the density and specific heat of the food product. When solid particles and a fluid medium have similar electrical conductivities, the component with the lower heat capacity will tend to heat faster. Heat densities and specific heats are conductive to slower heating. Fluid viscosity also influences ohmic heating; higher viscosity fluids tend to result in faster ohmic heating than lower viscosity fluids.

Texture Analysis:

Sensory evaluation is critically important to any viable food processes. Numerous publications have cited the superior product quality that can be obtained through decreased process time, though few published studies specifically quantify sensory and texture issues. Six stew formulations sterilized using ohmic heating before and after 3 years of storage were analyzed; the color, appearance, flavor, texture, and overall food quality ratings were excellent. ‘ Indicating that ohmic heating technology has the potential to provide shelf-stable foods mechanical properties of hamburgers cooked with a combination of conventional and ohmic heating were not different from hamburgers cooked with conventional heating.

Microbial Death Kinetics:

In terms of microbial death kinetics, considerable attention has been paid to the following question: does electricity result in microbial death, or is microbial death caused solely by heat treatment? The challenge in modeling microbial death kinetics is precise matching of time-temperature histories between ohmic heating and conventional process. The FDA has published a comprehensive review of microbial death kinetics data regarding ohmic heating.

Initial studies in this area showed mixed results, though the experimental details were judged insufficient to draw meaningful conclusions. Researches compared death kinetics of yeast cells under ohmic heating. More recent work in this area has indicated those decimal reduction times of Bacillus Subtiles spores were significantly reduced when using ohmic heating at identical temperatures. These investigators also used a two-step treatment process involving ohmic heating, followed by holding and heat treatment, which accelerated microbial death kinetics. The inactivation of yeast cells in phosphate buffer by low-amperage direct current (DC) electrical treatment and conventional heating at isothermal temperature was examined. These researchers concluded that a synergistic effect of temperature and electrolysis was observed when the temperature became lethal for yeast.

Future research regarding microbial death kinetics, survivor counts subsequent to treatment, and the influence of electricity on cell death kinetics are necessary to address regulatory issues. At the present time, assuming that microbial death is only a function of temperature (heat) results in an appropriately conservative design assumption.

Vitamin Degradation Kinetics:

Limited information exists regarding product degradation kinetics during ohmic heating. Researchers measured vitamin C degradation in orange juice during ohmic and conventional heating under nearly identical time-temperature histories and concluded that electricity did not influence vitamin C degradation kinetics. This study was conducted at one electrical field strength (E= 23. 9 V/cm). Others found that the ascorbic acid degradation rate in buffer solution during ohmic heating was a function of power, temperature, NaCl concentration, and products of electrolysis. Further research in this area could include the influence of electrical field strength, end point temperature and frequency of AC on the degradation of food components during ohmic heating. The characterization of electrolysis is also critical need in this area.

Mechanisms of Microbial Inactivation

The principal mechanisms of microbial inactivation in ohmic heating are thermal in nature. Occasionally, one may wish to reduce the process requirement or to use ohmic heating for a mild process, such as pasteurization. It may then be advantageous to identify additional non-thermal mechanisms. Early literature is inconclusive, since temperature had not been completely eliminated as a variable. Recent literature that has eliminated thermal differences, however, indicates that a mild electroporation mechanism may occur during ohmic heating. The principal reason for the additional effect of ohmic treatment may be its low frequency (50 – 60 Hz), which allows cell walls to build up charges and form pores. This is in contrast to high-frequency methods such as radio or microwave frequency heating, where the electric field is essentially reversed before sufficient charge buildup occurs at the cell walls.

Applications of ohmic heating in food industries:

Ohmic heating can be applied to wide variety of foods, including liquids, solids and fluid-solid mixture.

Ohmic heating is being used commercially to produce liquid egg products in United States.

It is being used in the United Kingdom and Japan for the processing of whole fruits such as Strawberries.

Additionally, ohmic heating has been successfully applied to wide variety of foods in lab including Fruits and Vegetables, juices, sauces, stew, meats, seafood, pasta and soups.

Widespread commercial adoption of ohmic heating in the United states is dependent on regulatory approval by the FDA, a scenario that requires full understanding of the ohmic heating process with regard to heat transfer (temperature distribution), mass transfer (concentration distribution, which are influenced by electricity), momentum transfer (fluid flow) and kinetic phenomena (thermal and possibly electro thermal death kinetics and nutrient degradation)

Research Related To Effect Of Ohmic Heating On Food Products:

1. Ohmic heating could up juice quality:

Israeli scientists say that ohmic heating of orange juice has proved to be good way of improving the flavor quality of orange juice while extending sensory shelf life.

The scientists were observed that sensory shelf life of orange juice could be extended to more than 100 days, doubling expectancy compared to pasteurization methods. Ohmic heating uses electricity to rapidly and uniformly heat food and drink, resulting in less thermal damage to the product. The technology has been around since the early 1900s, but it was not until the 1980s that food processing researchers began investigating the possible benefits to the industry.

The scientists compared pasteurized orange juice, which had been heated at 9oËšc for 50 sec, with orange that was treated at 90, 120 and 150Ëšc for 1. 13, 0. 85 and 0. 68 sec in an ohmic heating system. The experiment found that for all examples retention of both pectin and vit. C was reported similar. Likewise both treatments prevented the growth of micro-organisms for 105 days, compared to fresh orange juice. However, where the ohmic heated samples proved much stronger was in the preservation of flavors and the general taste quality over a period of time. The scientists tested five representative flavor compounds- decanal, octanol, limonene, pinene and mycrene. Testing showed that levels of these compounds were significantly higher in the ohmic treated samples after storage than in the pasteurized examples.

The scientists’ results found that only adverse reaction that the ohmic treated orange juice had that it increased browning in the juice, although this was not reported to be visible, until after 100 days. Conversely the appearance of the ohmic heated samples was said to be visibly less cloudy. The implications of the findings to the juice industry could be wide reaching as quality is a major driving force for a product that is often marketed in the premium category. If the cost of implementation proves competitive then this could become a serious contender to pasteurized methods. (Siman et al 2005)

2. Ohmic heating behavior of hydrocolloid solutions:

Aqueous solutions of five hydrocolloids (Carrageenan, 1-3%; xanthan, 1-3%; pectin, 1-5%; gelatin, 2-4% and starch, 4-6%) were heated in a static ohmic heating call at a voltage gradient of 7. 24V cm-1. Time and temperaturedata, recorded at selected time intervals, were used to study the effect of concentration and temperature on the ohmic heating behavior of hydrocolloid solutions. Of the test samples examined, carrageenan gave the shortest time to raise the temperature from 20 to 100Ëšc: 4200, 1600 and 1100s at 1, 2 and 3% concentraton respectively. For the same temperature raise, xanthan samples required 5500, 2300 and 1400s at 1, 2 and 3% concentration levels. Pectin and gelatin samples were found to exhibit even lower, but similar heating profiles. At highest concentration (5%), pectin took 7300s to reach 100 from 20Ëšc, and at all other concentrations, the time limit of 10, 000s was exceeded before it reached 100Ëšc. The temperature of starch solutions never exceeded 62Ëšc within the specified time limit. Heating was found to be uniform throughout samples for carrageenan, pectin

(1-3%) and gelatin samples. For xanthan and starch solutions, some non-uniformity in temperature profiles was observed. The observed ohmic heating behavior of hydrocolloid solutions corresponded well with their electrical conductivity values. The homogenesity of heating was related to rheological properties of hydrocolloid solutions and values. The homogenesity of heating was related to rheological properties of hydrocolloid solutions and their behavior at high temperature. (Marcotte et al 1998)

3. Design and performance evaluation of an ohmic heating unit for liquid foods:

An experimental ohmic heating unit was designed and fabricated for continuous thermal processing of liquid foods. The unit was supported by a data acquisition system for sensing the liquid temperature distribution, line voltage and current with time. A separate small ohmic heating unit was also used for batch heating tests. The data acquisition system performed well and could record temperatures, voltage and current at intervals of two seconds. The performance of the ohmic heating unit was evaluated based on batch and steady state continuous flow experiments. Tests with 0. 1 M aqueous sodium chloride solution showed the ohmic heating to be fast and uniform. In batch heating tests, the electrical conductivity of the liquid could be determined easily as a function of temperature using instantaneous values of the voltage gradient and current density. In continuous flow heating experiments, other physical properties, applied voltage gradient and dimensions of unit the heating. (Jindal et al, 1993)

4. Determination of starch gelatinization temperature by ohmic heating:

A method for measuring starch gelatinization temperature (T), determined from a change in electrical conductivity (Ð±), was developed. Suspension of native starches with different starch/ water mass ratios and pre-gelatinized starches were prepared, and ohmicallly heated with agitation to 90Ëšc using 100V by AC power at 50 Hz, and a voltage gradient of 10 V/cm. the results showed that Ð± of native starch suspensions was linear with temperature (R2> 0. 999) expect for the gelatinization range, but the linear relationship was always present for the pre-gelatinized starch-water system. It was seen that the shape of dÐ±/dT versus T curve was essentially similar to the endothermic peak on a DSC thermo gram, and the gelatinization temperature could be conveniently determined from this curve. Thus, the segment profile on this curve was called the “ block peak”. The reason for the decrease in Ð± of native starch suspension in the gelatinization range was probably that the area foe motion of the charged particles was reduced by the swelling of stearch granules during gelatinization. (Tatsumi et al 2003)

5. Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics

The effect of field strength and multiple thermal treatments on electrical conductivity of strawberry products were investigated. Electrical conductivity increase with temperature for all the products and conditions tested following linear relations. Electrical conductivity was found to depend on the strawberry- based product., an increase of electrical conductivity with field strength was obvious for two strawberry pulps and strawberry filling but not for strawberry-apple sauce. Thermal treatments caused visible changes (a decrease) in electrical conductivity values of both strawberry pulps tested, but the use of a conventional or ohmic pre-treatment induces a different behavior of the pulps’ conductivity values. Ascorbic acid degradation followed first order kinetics for both conventional and ohmic heating treatments and the kinetic constants obtained were in the range of the values reported in the literature for other food systems. The presence of an electric field does not affect ascorbic acid degradation. (Castro et al, 2003)

6. Polyphenoloxidase deactivation kinetics during ohmic heating of grape juice

The heating method affects the temperature distribution inside a food and directly modifies the time-temperature relationship for enzyme deactivation. Fresh grape juice was ohmically heated at different voltage gradient (20, 30 and 40 V/cm) from 20ËšC to temperatures of 60, 70, 80 or 90Ëšc and the change in the activity of polyphenoloxidase enzyme (PPO) was measured. The critical deactivation temperatures were found to be 60Ëšc or lower for 40V/cm were fitted to the experimental data. The simplest kinetic model involving one step first-order deactivation was better than more complex models. The activation energy of the PPO deactivation for the temperature range of 70-90Ëšc was found to be 83. 5 kJ/mol. (Baysal et al, 2006)

7. Processing and stabilization of cauliflower by ohmic heating technology:

Cauliflower is a brittle product which does not resist conventional thermal treatments by heat. The feasibility of processing cauliflower by ohmic heating was investigated. Cauliflower florates were sterilized in 10 kW APV continuous ohmic heating pilot plant with various configurations of pre-treatments and processing conditions. The stability of final products was examined and textural qualities were evaluated by mechanical measurements. Ohmic heating treatments gave a product of attractive appearance, with interesting firmness properties and proportion of particles > 1cm. stabilities at 25Ëšc and 37Ëšc were verified and in one case, the product was even stable at 55Ëšc. Low temperature precooking of cauliflower, high rate and sufficient electrical conductivity of florates seem to be optimal conditions. The interest of using this electrical technology to process brittle products such as ready meals containing cauliflower was high lightened. (Sandrine et al, 2006)

The commercial development of ohmic heating processes

The authors discuss the problems of heat transfer techniques in cook-chill food processing. These include destruction of flavours and nutrients, and particle damage arising from high shear often employed to improve heat transfer rates. These heat transfer problems have now been overcome with the development of ohmic heating technology. The ohmic heating effect occurs when an electric current is passed through an electrically conducting product. In practice, low frequency alternating current (50 or 60 Hz) from the public mains supply is used to eliminate the possibility of adverse electro-chemical reactions and minimise power supply complexity and cost. Electrical energy is transformed into thermal energy. The depth of penetration is virtually unlimited and the extent of heating is governed only by the spacial uniformity of electrical conductivity throughout the product and its residence time in the heater. The authors briefly discuss the design features, temperature control and market acceptance of ohmic heating. (Skudder et al 1992)

8. Electrical conductivity of apple and sour cherry juice concentrates during ohmic heating

Ohmic heating is based on the passage of electrical current through a food product that serves as an electrical resistance. In this study, apple and sourcherry concentrates having 20-60% soluble solids were ohmically heated by applying five different voltage gradients (20-60 V/cm). The electrical conductivity relations depending on temperature, voltage gradient and concentration were obtained. It was observed that the electrical conductivities of apple and sourcherry juices were significantly affected by temperature and concentration (P < 0. 05). The ohmic heating system performance coefficients (SPCs) were defined by using the energies given to the system and taken up by the juice samples. The SPCs were in the range of 0. 47-0. 92. The unsteady-state heat conduction equation for negligible internal resistance was solved with an ohmic heating generation term by the finite difference technique. The mathematical model results considering system performance coefficients were compared with experimental ones. The predictions of the mathematical model using obtained electrical conductivity equations were found to be very accurate. (Coskan et al 1999)

CONCLUSION:

The studies discuss the problems of heat transfer techniques in cook-chill food processing. These include destruction of flavours and nutrients, and particle damage arising from high shear often employed to improve heat transfer rates. These heat transfer problems have now been overcome with the development of ohmic heating technology.

The Energy efficiency is more and also the cost of preservation is also low so, it is beneficial to use the this technique.