Basics of Ohmic Heating - A Novel Food Preservation Technique

Review Paper

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***Abstract*—Ohmic Heating is a process in which an alternating electric current is passed through food materials for heating where heat is internally generated in the material due to electrical resistance when electric current is passed through it. It is a novel technique which provides quick and consonant heating, resulting in less thermal damage to the food product. Most of the times, foods are thermally processed by conventional methods which has several disadvantages like overheating, degradation of colouring and/or flavouring compounds, loss of nutritional compounds and sensory changes, etc. This results in lowering of the ultimate nutritive and thus, overall value of that food. Hence, in order to overcome these drawbacks, ohmic heating is the most suitable alternative thermal process. This paper deals with the basic information of ohmic heating and its need along with the comparison with traditional conventional heating methods. This paper also presents the effect of ohmic heating on the quality of foods with respect to enzymes, pH, colour and heat-sensitive compounds, and the practical applications of the same.**

***Index Terms*- OH - Ohmic heating, CH - Conventional heating, EC - Electrical conductivity, Enzymes, pH, Applications.**

I. Introduction

Any kind of food is a complex matrix of several compounds, most of which are commonly known as carbohydrates, proteins, lipids, vitamins, minerals, water, colour and flavour compounds in variable amount. When these food materials contain sufficient water and electrolytes (mainly present as mineral salts), they acts as charge carriers and allows the passage of electric current through them (i.e. food) thus generating internal heat as the result of electrical resistance. This technique was originally developed at the Electricity Research Council, Caphenhurst, United Kingdom. The basic principle of ohmic heating or joule effect is the dissipation of electrical energy in the form of heat (Kumar *et al.*, 2014). It is also referred to as Joule heating, electrical resistance heating and electro-conductive heating. The concept of ohmic heating was applied to foods since 19th century where it is first being applied to milk pasteurization (Cappato *et al.*, 2017).

Ohmic Heating is defined as a process wherein electric current is passed through food materials with primary purpose of heating by the conversion of electrical energy into thermal energy, resulting in rapid and uniform temperature increase within the food. (Cappato *et al.*, 2017). Thus it is a process in which an alternating electric current is passed through food materials for heating where heat is internally generated in the material due to electrical resistance when electric current is passed through it. OH is a novel technique which provides quick and consonant heating, resulting in less thermal damage to the food product. Since the heating occurs as a result of internal heat generation due to resistance to the passage of electric current, OH is also referred as internal thermal energy generation technology (Knirsch *et al.*, 2010).

This innovative heating method is used in the food industry for processing a broad range of food products (Cho *et al.*, 2017), especially plant based foods; fruits and vegetable processed products to be more precisely. Ohmic heating has high energetic efficiency, low investment costs and is considered technically simple (Kaur *et al.*, 2016).

As per the 1st Law of Thermodynamics, energy can neither be created nor destroyed; it can only be converted from one form to another form. OH is the one of the best application of this law wherein, the electrical energy is converted into thermal energy.

II. Necessity

Heat treatment is often used for the processing and preservation of food products. Conventional heating is the most common method in the heating of foodstuffs (Kaur *et al.*, 2016). The conventional thermal processing includes heat transfer mechanisms either conduction or convection (Cappato *et al.*, 2017). Heating methods generate heat inside the food depending on thermal conduction and convection in between the food and heating medium. Food is a complex matrix of several compounds like carbohydrates, proteins, lipids, vitamins, minerals, water, colour and flavour compounds, etc. This conventional heating of food sometimes results in the degradation of the said compounds which ultimately lowers the nutritive and hence overall value of that food.

Conventional heating has disadvantages like overheating, loss of nutritional compounds and sensory changes (Cappato *et al.*, 2017). During conventional thermal processing in cans or aseptic processing systems for particulate foods, significant product quality damage occurs due to slow conduction or convection heat transfer (Kaur *et al.*, 2016). Also, the heating media is dependent on natural sources like fossil fuels of which combustion creates pollution complications and some economic and energy losses too.

These drawbacks can be avoided by advanced techniques like ohmic heating. Since it includes the use of electrical energy with simple mechanism of internal heat generation, there is efficient heating with no any energy loss occurs during processing. As compared to conventional heating, its advantages also include the more uniform and faster heating, higher yield and higher retention of nutritional value of food. This is mainly due to its ability to heat materials rapidly and uniformly leading to a less aggressive thermal treatment (Darvishi *et al.*, 2013).

III. FACTORS INFLUENCING OH

The According to Joule's 1st Law, the heat energy generated in the food is proportional to the square of the electric field strength and the electrical conductivity of that food material (Kumar *et al.*, 2014). Thus, Electrical conductivity is the important parameter in ohmic heating to be considered. Electrical conductivity is the ability of a material that allows the current to pass through it when subjected to an electric field.

The heating rate of particles in a fluid mainly depends on the relative conductivities of the system's phases and the relative volume of those phases. Low conductivity solid particles, comparatively to the fluid conductivity, tend to lag behind the fluid at low concentrations related to the volume of the fluid. However, in condition where the concentration of the particles is high, those same low conductivity particles may heat faster than the surrounding fluid. So, the phenomenon of particle-lagging or particle-leading depends on the significance of particle resistance to the overall circuit resistance. This phenomenon occurs because, with the increase of the particles' concentration, the electric current path through the fluid becomes more tortuous, forcing a greater percentage of the current to flow through the particles. This can result in higher energy generation rates within the particles and consequently in a greater relative particle heating rate (Knirsch *et al.*, 2010).

Factors affecting electrical conductivity

There are several factors that affect electrical conductivity. Those are as follows –

1. Temperature

It is the main factor that affects the electrical conductivity and hence important to be considered. It is important to quantify electrical conductivities not only at room temperature as many researchers found that EC increases with temperature (Darvishi *et al.*, 2013). For purely liquid foods, the electrical conductivity increases linearly with temperature (Kumar *et al.*, 2014).

2. Voltage Gradient

Electrical conductivity varies mainly depending on voltage gradients used along with the temperature (Kumar *et al.*, 2014). The increase in field strength results in increasing fluid motion through the capillaries, which is directly proportional to EC (Kaur *et al.*, 2016). Ohmic heating times are thus also dependent on the voltage gradients. As the voltage gradient increases, time decreases (Darvishi *et al.*, 2012).

3. Frequency

The applied frequency also has significant effect on overall ohmic heating process. Most of the times, the heating rate increases due to increase in electrical conductivity with increasing frequency. However this does not occur all the time. Studies had found that in most of the cases (e.g. turnip, Japanese white radish, etc.) there is increase in temperature with decrease in frequency. The lower the frequency, the faster the sample reached elevated temperatures (Kaur *et al.*, 2016).

4. Electrolytic concentration

Electrical conductivity of a food material is directly proportional to the electrolytes present in it. The electrolytes are nothing but the charged molecules or ions that are present in the foods in the form of salts. The electrical conductivity of foods may be manipulated by altering its ionic concentration (Kumar *et al.*, 2014).

Greater the ionic concentration faster is the heating rate. Higher the concentration of ionic constituents, higher will be the conductivity of the product (Kaur *et al.*, 2016).

5. Moisture content

Moisture content of food represents the amount of free water present in it. The free water present in the food acts as electrical conductor. Thus higher the moisture content, higher will be the EC.

6. Nature of food

It is also related with the concentration of electrolytes and amount of free water present in food. Generally, solid vegetable particles have lower EC than liquids (Kaur *et al.*, 2016). Also, intermolecular bonds have a little effect on EC.

7. Particle size

It is also an important factor. Increase in particle size, the heating time to achieve the same temperature rise also increased. Particle concentration is a critical factor in determining the heating rate of the two phases. During the study of ohmic heating behavior of two-phase food systems, it was found that as particle concentration increased, values of EC decreased uniformly solids having lower EC than the fluid would lag behind the fluid if they were in low concentration, but in high concentrations, the particles may heat faster than the fluid. The position of the particle with respect to electric field can be significant in electric heating de- pending on relative EC of the solid and liquid ohmic heating behavior of a mass of particles as affected by their location with respect to electrodes. It was observed that for the parallel condition, the liquid phase heated faster than the solid phase while in the series condition, reverse was observed. For the parallel condition, the current that passed through the liquid was greater than the current through the solid; hence more heat was generated in liquid phase. For series condition, the solid phase heated faster than the liquid phase. The amount of current passing through food system was same. Since the resistance of solid was greater than that of the liquid, the amount of heat generated in solid phase was greater (Kaur *et al.*, 2016).

8. Biochemical cellular changes

Amongst the other factors of electrical conductivity changes in foods during OH, the destabilization of cellular membranes is pointed to be the main responsible effect for the reduction of the system's impedance, but it is also affected by cell rupture, cell electroporation, tissue shrinkage, phase change, dehydration, starch gelatinization, salt concentration and mobility, moist mobility, pH value and the presence of fat or other non-conducting substances among other factors (Knirsch *et al.*, 2010).

IV. Comparison with conventional heating

Conventional heating methods used in the food industry rely on conductive, convective or radiative mechanisms from the heating medium (air, water, oil, etc.) to the food product. Depending on the product geometry, it may take considerable time to conduct sufficient heat into the product core to reach a safe end-point temperature. This may cause some parts of the product to be overcooked, or undercooked, and adversely affect the quality (Kumar *et al.*, 2014).

In contrast to conventional heating (CH), where the heat of a hot surface is conducted from the outside of the food to its inside, OH induces heat within the entire mass of the food uniformly (Cho *et al.*, 2017). Its advantages compared to conventional heating also include the more and faster heating, cleaner and more environmentally friendly, higher yield and higher retention of nutritional value of food. This is mainly due to its ability to heat materials rapidly and uniformly leading to a less aggressive thermal treatment (Darvishi *et al.*, 2013).

Ohmic heating is less influenced by change of thermal properties of foodstuff compared to other heating methods. On the other hand, the efficiency of ohmic heating especially for fruit juices is generally high since the conversion ratio of the electrical energy to heat energy is very high. The homogenous temperature distribution can be easily obtained when the current is passed homogenously. Ohmic heating system does not require the usage of steam or hot water and does not produce any waste (Cokgezme *et al.*, 2017).

OH has several advantages over CH, one of which is providing uniform heating without a temperature gradient, with the absence of a cold spots making it possible to rapidly heat an entire sample. OH makes it possible to heat both the solid particles and the liquid in a two phase food material extremely rapidly and uniformly. In addition, the absence of a hot surface in OH reduces fouling problems and thermal damage to the product and results in the rapid production of a high-quality product with minimal structural, nutritional or organoleptic changes (Cho *et al.*, 2017).

Collectively, OH has advantages over conventional heating are:

i. Uniformity in heating : OH process can promote the heating of both phases (solid and liquid) at the same time, which is impossible in the conventional heating.

ii. Heating of particulate foods, liquid particle mixtures and higher viscosity foods.

iii. It makes the control of the process easier with instant switch-on and shut-down.

iv. Higher energy efficiency : Due to the internal energy generation, in OH

process, 90% of the electrical energy is converted into heat energy. The energy efficiency is even better compared to other emerging technologies.

v. Fouling Reduction : The OH process reduces fouling and the risk of burning food layers, because there are no hot surfaces for heat transfer. This fact also reduces the cost in cleaning process, thus reducing processing time.

vi. Non-thermal addition effects (electroporation) : The overall effect of electroporation on the microbial cell promotes cellular damage, thus reducing the thermal resistance of the micro-organism in the treatment. The reduction of kinetic parameters (D and z value) allows the accomplishment of a treatment with lower thermal intensity guaranteeing the same effectiveness for food safety (Cappato *et al.*, 2017).

V. Effect on overall quality of foods

Kaur *et al.*, (2016) reviewed the nutritional impact of ohmic heating on fruits and vegetables. The ohmic heating causes various changes in quality and nutritional parameters which include inactivation of enzymes and micro-organisms, degradation of heat-sensitive compounds, changes in cell membranes, viscosity, pH, colour, and rheology. It has been observed that electrical field applied during ohmic heating enhances faster deactivation of enzymes and micro-organisms. Also, the degradation of heat sensitive compounds (anthocyanins, ascorbic acid and vitamin C) increases with both increasing voltage and solid contents during ohmic heating.

Shivmurti *et al.*, (2014) reviewed ohmic heating is an alternative preservation technique. It was observed that the results of chemical analysis indicate that ohmic heating and conventional heating technology gives products with similar chemical properties. This is important because it allows the producers to replace the methods without major changes in their final products. Various other parameter of milk was tested and that was found that at 40°C electrical conductivity was increased and viscosity was decreased with increasing temperature. Viscosity of milk decreased with increasing temperature and this because the increase in temperature leads to lower milk fatty blocs responsible for the high viscosity of milk. Milk density was reduced with increasing milk temperature.

Cappato *et al.*, (2017) reviewed ohmic heating in dairy processing. It was studied that in the goat milk processing, the FFA after the OH did not show any change compared to the conventional process, which indicated that the ohmic treatment did not affect the product quality. Gomathy *et al.*, (2015) studied the effect of ohmic heating on the electrical conductivity, biochemical and rheological properties of papaya pulp. It was observed that for papaya pulp, the lycopene, β-carotene and ascorbic acid content of 100 g fresh papaya pulp were found decreased when the pulp is subjected to ohmic heating. The decrease in the contents during thermal process might be due to the isomerization of lycopene and β-carotene leading to the conversion of trans- isomers to sis-isomers reducing the nutritive value upon heating.

Effect on enzymes

Castro *et al.*, (2004) studied the effect of electric field on important food processing enzymes. There are several enzymes that are used in the food industry for improving food quality (for example, texture and flavour), for the recovery of by-products and for achieving higher rates of extraction. On the other hand, enzymes may also have negative effects on food quality such as production of off odors and tastes and altering textural properties. Therefore, control of enzymatic activity is required in many food processing steps to promote/inhibit enzymatic activity during processing. There is only limited information available concerning the effects of ohmic heating on enzyme activity. The studied enzymes were lipoxygenase (LOX), pectinase (PEC), polyphenol oxidase (PPO), alkaline phosphatase (ALP), Pectin Methyl Esterase (PME) and Peroxidase.

i. Lipoxygenase (LOX)

It is widely distributed in vegetables and its involvement is in off-flavour development and colour loss. However, LOX is also important in the bakery industry because it interacts with the gluten side chain, making the gluten more hydrophobic and, subsequently, stronger. With stronger gluten, the dough will have better gas retention properties and increased tolerance to mixing. The electric field has an additional effect on the LOX inactivation. It has been found that there is considerable reduction in the inactivation time when the food is subjected to the ohmic heating.

ii. Pectinase (PEC)

It functions in foods are to clarify juices and wines, to reduce viscosity by hydrolyzing the pectin, to accelerate the rate of filtration, to prevent pectin gel formation, and to improve colour extraction from grape skin. The electric field does not have any influence in the inactivation of pectinase.

iii. Polyphenol oxidase (PPO)

The official name of the enzyme responsible for enzymatic browning is ortho-diphenol oxygen oxidoreductase, also known as catecholase, tyrosinase, phenolase, and polyphenol oxidase which is responsible for browning. Browning occurs only when the tissues are disrupted or destroyed and the compounds come into contact with air and with each other. The electric field has an additional effect on the PPO inactivation just like LOX. It has been found that there is considerable reduction in the inactivation time when the food is subjected to the ohmic heating.

iv. Alkaline phosphatase (ALP)

It is involved in several physiological processes. It is an enzyme used as an indicator of the effectiveness of the milk thermal processing. The activity of ALP does not seem to be more affected by ohmic heating than by conventional heating.

v. Pectin Methyl Esterase (PME)

It is an enzyme that has been found in essentially every plant tissue, several fungi, and bacteria. It catalyzes de-esterification of galactosyluronate methyl esters of pectins. A study conducted on orange juice showed that ohmic heating reduces PME activity by 98% (Kaur *et al.*, 2016).

vi. Peroxidase

Peroxidases are known to be the most heat stable enzymes in vegetables, and their inactivation is usually used to indicate the adequacy of blanching. A study in which ohmic blanching of pea puree at four different voltage gradients (20–50 V/cm) was carried out. It has been found that the inactivation time of peroxidase enzyme during ohmic blanching was less than water blanching at 30 V/cm and above voltage gradient. As the voltage gradient increases the critical inactivation time decreases during ohmic blanching. (Kaur *et al.*, 2016).

Also, enzyme denaturation is caused by rearrangement and/or destruction of non-covalent bonds such as hydrogen bonds, hydrophobic interactions, and ionic bonds of the tertiary protein structure. The presence of an electric field can influence biochemical reactions by changing molecular spacing and increasing interchain reactions. The time required for thermal treatment (for example, blanching of vegetables) is much lower when ohmic heating process is applied, thus reducing negative thermal effects in the other food components. Thus, the use of ohmic heating as an alternative to conventional heating is beneficial in terms of enzyme inactivation when compared with conventional heating.

Effect on colour

Boldaji *et al.*, (2015) investigated the process of producing tomato paste by ohmic heating method. It was found that the voltage gradient had a significant effect on the colour parameters of tomato samples during ohmic cooking. The luminance of the samples was improved and heating process preserves or enhances slightly the green colour of the tomato samples. It was also found that the pH was decreased with increased the voltage gradient. The maximum increase in the pH was 8.39% at 6 V/cm.

Kaur *et al.*, (2016) reviewed nutritional impact of ohmic heating on fruits and vegetables. Acerola has a good amount of anthocyanins and carotenoid pigments. Their gradual degradation results in colour changes in the final product. At low electric field frequency (10 Hz), higher colour change was probably due to occurrence of electrochemical reactions. Icier *et al.*, (2006) studied peroxidase inactivation and colour changes during ohmic blanching of pea puree and it was observed that first-order kinetics described the changes in colour values during ohmic blanching. Several researchers have also reported that colour degradation kinetics follows first-order reaction kinetics.

Effect on pH

Shivmurti *et al.*, (2014) reviewed ohmic heating is an alternative preservation technique. It was found that pasteurized milk chemical composition and its pH were not influenced in electrical field (Assad *et al.*, 2013)

Boldaji *et al.*, (2015) investigated the process of producing tomato paste by ohmic heating method. It was found that the pH was decreased with increased the voltage gradient. The maximum increase in the pH was 8.39% at 6 V/cm.

Darvishi *et al.*, (2012) studied the ohmic heating behaviour and electrical conductivity of tomato paste. It was observed that there was a slight change in the pH of the tomato samples based on the applied voltage gradient. The range of the tomato samples pH after ohmic treatments was 4.20 to 4.51. The pH was decrease with increased the voltage gradient.

Darvishi *et al.*, (2013) studied Electrical conductivity and pH change in pomegranate juice due to ohmic heating. It was found that there was a slight change in the pH of the pomegranate juice based on the applied voltage gradient. The voltage gradient had significant effect on the pH change of pomegranate juice samples during ohmic treatment. The range of the pomegranate juice pH after ohmic treatments was 3.22 to 3.35. The change in the pH at voltage gradients of 30–45 V/cm decreased and then as the voltage gradient increased the change increased. This behaviour was probably due to the residence time of different reactions such as hydrolysis of the pomegranate juice and corrosion of electrodes that might occur during the ohmic heating.

Effect on heat-sensitive compounds

i. Anthocyanin

Kaur *et al.*, (2016) reviewed the anthocyanin degradation of various fruits. Several studies showed that its stability is influenced by inherent properties of the product and the process characteristics. Anthocyanin degradation in blueberry pulp was evaluated after thermal treatment using ohmic and conventional heating. The results showed that degradation was increased with both increasing voltage and solids content. The comparison between ohmic and conventional heating showed that when lower voltages were used, the percentage of degradation was lower to those obtained during conventional heating. The pulp processed during ohmic heating exhibited higher anthocyanin degradation with high electric fields. It has been found that in case of strawberries and sour cherries, there is increase in anthocyanin degradation with an increase in solid content. Volden *et al.*, (2008) found a considerably higher level of anthocyanin degradation of 59% in red cabbage. However, the level of degradation reached 55% in blueberry jam in some other studies when anthocyanins were exposed to high temperatures for longer periods of time.

ii. Ascorbic acid & vitamin C

Kaur *et al.*, (2016) reviewed the ascorbic acid & vitamin C degradation. It has been found that there is much more degradation of vitamin C occurred in case of ohmic heating using high voltages as compared to conventional heating. This study was done by Assiry *et al.* (2003). They concluded that during ohmic heating, in addition to the degradation caused by heat, there is also electrochemical degradation due to number of several reactions, including electrode reactions, electrolysis of the solution and reactions in between the electrode materials and the electrolysis products also. These reactions may influence the degradation reaction mechanisms and the kinetic parameters. Another study showed the effects of voltage and solid contents on vitamin C and ascorbic acid degradation in acerola pulp. In that, a comparative study in between the conventional and the ohmic heating processes showed similar results of degradation of both the ascorbic acid and the total vitamin C when ohmic heating was performed with low voltage gradients. It also has been found that as voltage

gradient increases, ascorbic acid degradation increases. It is mainly because of electrochemical reactions. Also, the use of low electric field frequency (≤10 Hz) led to greater ascorbic acid degradation and higher colour changes probably due to electrochemical reactions. On the other hand, at higher frequency both ohmic and conventional heating processes showed similar degradation rates of ascorbic acid and colour changes. Thus, it can be stated that high electric field frequency does not affect the degradation kinetics of ascorbic acid. Vikram *et al.*, (2005) studied the kinetics of ascorbic acid degradation during ohmic heating of orange juice. The results showed that the degradation was approximately 35% after 3 min of heating at 90°C when electric field strength of 42 V/cm was applied.

VI. APPLICATIONS

Ohmic heating possesses wide applications, including blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization. Ohmic heating is also used for heating of foods to serving temperature for the people in the military field or long-duration space missions.

i. Extraction

The application of ohmic heating can be applied in combination with traditional extraction processes. It has been found that there is increase in extraction efficiency of sucrose from sugar beets.

ii. Enzyme Inactivation

Enzyme inactivation is an important step in the food processing for preservation of foods for long time. Since several studies showed that ohmic heating is quite efficient than conventional heating in case of lowering of deactivation time and product quality retention, it can be applied for inactivation of enzymes that are found in foods.

iii. Blanching

Studies showed that the ohmic blanching inactivates enzyme activity at lesser time than the traditional water blanching with better retention of colour quality. Thus, ohmic heating can be applied for blanching.

iv. Waste water treatment

Waste water always has high Biological Oxygen Demand (BOD). Protein coagulation by heating and subsequent separation is the method to reduce the BOD of waste water having high protein concentration. Ohmic heating is an efficient heating method that heats the fluid in much less time. Thus ohmic heating can be an alternative for waste water treatment (Sastry 1994, Huang *et al.*, 1997).

v. Starch gelatinization

Gelatinization temperature is one of the most important parameters during gelatinization of starch. Wang and Sastry (1997) proposed that the determination of starch gelatinization by ohmic heating is effective as compared to other methods (Kumar *et al.*, 2014).

vi. Pasteurization and sterilization

Ohmic heating has been accepted by the industries for processing liquids and solid-liquid mixtures. A recent study had found that ohmic heating is used for the sterilization of guava juice. Ohmic heating is very often used in pasteurization/sterilization of food products resulting in excellent quality. A study showed that the ohmic heating technique was used for milk pasteurization in the early 20th century. Ohmic heating can be used for ultra-high temperature (UHT) sterilization of foods, and especially those that contain large particles (up to 2.5 cm) that are difficult to sterilize by other means.

vii. Ohmic thawing

Ohmic heating can be used to thaw frozen foods placed between two electrodes and applying an alternating current to it. The advantages of this process include, water and waste water is not generated, thawing can be relatively uniform due to volume heating and the process can be easy to control. However, limitations of ohmic thawing are also been studied (Varghese *et al.*, 2014).

VII. CONCLUSION

Ohmic heating of food products involves the passage of alternating electrical current through them, thus generating internal heat as the result of electrical resistance. It is a novel technique which provides quick and consonant heating, resulting in less thermal damage to the food product. It has high energetic efficiency, environment friendly, low investment costs and is considered technically simple. Conventional heating methods generate heat inside the food which has disadvantages like overheating, loss of nutritional compounds and sensory changes. Thus, to avoid these losses, ohmic heating is employed to foods where heating is achieved as a result of internal heat generation. Also, it is less influenced by change of thermal properties of foodstuff compared to other heating methods. The absence of a hot surface in OH reduces fouling problems and thermal damage to the product and resulting in the rapid production of a high-quality product with minimal structural, nutritional, or organoleptic changes.

Ohmic heating causes various changes in quality and nutritional parameters of foods which include inactivation of enzymes and micro-organisms, degradation of heat-sensitive compounds, changes in cell membranes, viscosity, pH, colour, and rheology. Processes like enzyme inactivation, blanching can be carried out in much lesser time as compared to conventional heating with maximum retention of colour and flavour which was not possible by conventional heating. Also, degradation of heat sensitive enzymes is found minimum in case of ohmic heating when lower voltages are applied. It has wide practical industrial applications like extraction, enzyme inactivation, blanching, waste water treatment, starch gelatinization, pasteurization, sterilization etc. Therefore, ohmic heating should be used as an alternative to conventional heating in all maximum possible areas.

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