

Review Article

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Ohmic Heating as an Alternative to Conventional Heating for Shelf Life Enhancement of Fruit Juices

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ABSTRACT

India, being a leading producer of fruits and vegetables, novel thermal technologies should gain popularity from the point of enhancing the shelf life with minimal degradation of nutritional and organoleptic parameters of food materials. Ohmic heating, also known as electrical resistance heating, Joule heating, and direct electrical resistance heating in which the conversion of electrical energy into volumetric heating takes place without any environmental hazards. Ohmic heating is a recent advancement for different applications in food processing sectors, especially for inactivation of enzymes in fruit juices. The present review work briefly emphasizes on factors to be considered during ohmic heating for fruit juices as well as optimization of the factors to minimize the undesirable physico-chemical changes occurring during the treatment period. Different configurations of ohmic heating set up have been demonstrated in various research institutes of India. From the point of commercialization, ohmic heating can be acceptable for treating the fruits and vegetables for preventing the spoilage due to enzymatic browning. Thus the shelf life of fruits and vegetables can be extended to some more weeks so that it will meet the demand of consumers to get higher qualitative foods.

Keywords

Ohmic heating,
Fruit juice, Shelf
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Introduction

Development of new products and process technologies is necessary from the point of increasing demand of consumers for high quality foods. Heating methodologies have advanced remarkably with the new era of novel technologies such as ohmic heating,

dielectric heating (including microwave heating and radio frequency heating) etc. These processing methods are effective because of volumetric heating of foods. Ohmic heating, also known as Joule heating, electrical resistance heating, and direct electrical resistance heating in which electric current is passed through the object that acts

as an electric resistance. Then electrical energy generates volumetric heating in the food material. Uniform distribution of temperature as well as uniform heating are the salient features of ohmic heating.

India is the second leading country in the world producing 90.2 million metric tons of fruits and 169.1 million metric tons of vegetables during 2015-16 (NHB 2015-16). The production of pulp and fruit juice production increased from 150.8 to 158 thousand metric tons during 2015-18 (Statista 2018). Enzymatic browning leads to spoilage in quality parameters in fruits and vegetables is a common phenomenon due to mechanical damage and many unit operations including cutting, slicing, dicing, pulping etc. Heating treatment is often applied for deactivation of the appropriate enzymes (Yemenicioglu and Cemeroglu, 1998). The conventional heating methods apply high temperature which shows greater degradation of sensory and nutritional qualities of food material. In ohmic heating, food components are placed in electric circuit, behaving as an element, through which an alternating current (AC) passed, resulting in volumetric heating of food without causing any transmission losses (Sarang *et al.*, 2008; Morgan, 2009). Shortening the treatment period and internal heat generation with minimal degradation of heat sensitive compounds are the attractive features of ohmic heating without causing any environmental hazards (Machado *et al.*, 2010). The present review paper summarizes the parameters influencing the design of ohmic heating chamber as well as the heating process and the physico-chemical changes of fruit juices exposed to ohmic heating.

Factors to be considered during ohmic heating of fruit juices

Numerous variables are affecting ohmic heating of food material such as electrical

conductivity, strength of electric field, ionic concentration, particle orientation, and electrodes.

Electrical conductivity

Electric conductivity of food samples is the most deciding parameter from the point of designing of an efficient ohmic heater (Sarang *et al.*, 2008). The rate of electrical resistance heating varies as second power of the electrical conductivity and electrical field strength (Sastry *et al.*, 1992). Castro *et al.*, (2003) did research work on fresh strawberry and selected the range of temperature of 25-100⁰C to measure electrical conductivity which showed increasing trend in electrical conductivity but the reverse conditions identified for strawberry pulp. Sarang *et al.*, (2008) quantified electrical conductivity of peach and pear over a wide range of temperature 25–140⁰C. Singh *et al.*, (2008) measured the electrical conductivity for apple juice over a temperature range of 25-70⁰C during the exposure to ohmic heating. Qihua *et al.*, (1993) investigated that electrical conductivity showed nonlinear relationship with temperature in orange juice. Icier *et al.*, (2004) investigated that there was increasing the electrical conductivity values of sourcherry and apple juice concentrates with temperature irrespective of all voltage gradients. Darvishi *et al.*, (2013) observed the decreasing trend of electrical conductivities with temperature rise.

Electrical field strength

Increasing in the ohmic heating rate occurs due to increment in the electrical field intensity and electrical conductivity. Vikram *et al.*, (2005) used electrical field strength of 42 V/cm and analyzed the deterioration kinetics of ascorbic acid in orange juice. Similar work was done by Lima (1996), in which orange juice was treated at temperature

of 90°C for the exposure time of 30 min with the application of electrical field strength of 18.2 V/cm. Castro *et al.*, (2004) conducted experiment on inactivation kinetics of enzymes exposing to joule heating of apple juice by taking combinations of electrical field strength and frequency range 20 V cm⁻¹ and 50 Hz respectively. Icier *et al.*, (2005) had taken the combinations of electrical field strength and frequency (60 V/cm and 50 Hz to 1 MHz) for evaluating the rate of ohmic heating of peaches. Similarly, inactivation of polyphenoloxidase enzyme, physical properties of apple juice was studied by Moreno *et al.*, (2013) at 13 V/cm of voltage gradient.

Ionic concentration

The rate of ohmic heating was greatly affected by increasing rate of concentration of ions. Icier *et al.*, (2005) observed that the rate of joule heating was higher in peach puree due to higher acidic in nature.

Particle orientation

Particle orientation plays a major role in the ohmic heating system. Zareifard *et al.*, (2003) investigated that higher rate of joule heating occurred in the liquid phase as compared to the solid phase for the parallel condition, while the opposite conditions were revealed in the series condition.

Selection of electrodes

Losses due to heat are caused by the electrodes during ohmic heating (De Alwis *et al.*, 1990). There is a variation while measuring the temperature by using thermocouple positioned at the center and positioned closely to the electrodes (Marcotte *et al.*, (1998). Zell *et al.*, (2011) used various metals as electrode material such as titanium, Stainless steel, aluminum and platinized

titanium. Tzedakis *et al.*, (1999) concluded that platinized titanium showed insignificant electrocatalytic effects upon the food materials and recommended as the most suitable electrode material for giving a satisfactory heating rate.

Ohmic heating setup for treatment of fruit juices

Heating cell, data logger system, AC power source, electrodes, voltage control unit and thermocouples are the major parts of ohmic heating system unit. Many researchers had tested several configurations for designing the treatment chamber. Jakob *et al.*, (2010) analyzed inactivation kinetics of food enzymes in fresh apple juice during joule heating. The research works were conducted in a cylindrical glass reactor of inner diameter and length of 2.4 cm and 6.0 cm respectively attached with stainless steel electrodes. The temperature was measured by using resistance thermometer, made up of platinum. Moreno *et al.*, (2013) exposed apple juice to ohmic heating by immersing the sample in concentric cylindrical tanks (3.7 cm and 19 cm in diameter) made of stainless steel positioned with two electrodes which was connected to a generator. The alternating current with frequency and voltage of 60 Hz and 100 V was supplied to the control panel which had the capacity of generating a voltage gradient of 13 V/cm. To detect the temperature, voltage and current continuously, OM-420 data logger was connected. Castro *et al.*, (2004) conducted experiment by taking apple juice in the ohmic treatment chamber which consisted of a cylindrical glass tube of length of 30 cm and 2.3 cm inside dia and temperature was measured by using three nos. of thermocouple placed centrally. Two electrodes were made up of titanium. The control system was operated with an alternating current with the combinations of electrical field strength and frequency (20 V cm⁻¹ and 50 Hz).

Table.1 Effect of ohmic heating on viability of microorganisms in different food materials

Food	Microorganism	Processing parameters	Findings	References
Goat milk	<i>Escherichia coli</i> ATCC 25922	Electrical field – 20-54 V/cm Electrode gap- 2 cm Frequency- 50 Hz	D-value for OH sample less than conventional heating.	Pereira <i>et al.</i> , (2007)
Milk	<i>Streptococcus thermophilus</i> 2646	Voltage- 70-12 V Current- 7.3-2 A Electrode gap- 3 cm	D ₇₀ = 6.59 D ₇₅ =3.09 D ₈₀ =0.16	Sun <i>et al.</i> , (2008)
	Viable aerobes		D ₅₇ = 8.64 D ₆₀ =6.18 D ₇₂ =0.38	
Buffalo milk	Total visible colonies, yeasts and molds, coliforms, <i>E.coli</i> , <i>Salmonella</i>	Voltage varied to match the thermal conditions of conventional heating. Temperature- 72°C Electrode gap-2.9 cm	Higher reductions of total visible colonies, yeasts and molds, <i>E.coli</i> and coliforms (6.04, 6.52, 5.78, and 6.26 log CFU/mL, respectively) than conventional heating; <i>Salmonella</i> - N.D.	Kumar and Hausain (2014)
Orange juice	Bacteria, yeasts and molds	Frequency- 50 Hz Temperature- 90, 120, and 150 °C Time- 1.13, 0.85, and 0.68 s	Complete inactivation of bacteria, yeasts and molds; Flavor remained intact; Pectin esterase activity and Vitamin C reduced by 98 and 15%, respectively & Sensory qualities conserved.	Leizeron and Shimoni (2005)
Orange juice	<i>E.coli</i> O157:H7, <i>Salmonella typhimurium</i> , <i>Listeria monocytogenes</i>	Electric field- 10-20V/cm Frequency- 60Hz Time – 120-540s	E. coli O157:H7 reduced by >5 log CFU/ml after three treatments; Similar results for <i>Salmonella typhimurium</i> , <i>Listeria monocytogenes</i>	Sagong <i>et al.</i> , (2011)
Tomato juice		Electric field- 10-20V/cm Frequency- 60Hz Time – 90-480 s		
Apple juice	<i>E.coli</i> O157:H7,	Electric field- 30, 60 V/cm	5-log reduction of all three	Park <i>et al.</i> , (2017)

	<i>Salmonella Typhimurium, Listeria monocytogenes</i>	TSS- 36, 48 °Brix Time- 20, 60 s	pathogens.	
Gochujang	<i>Bacillus</i> vegetative cells	Electric field- 30 V/cm Frequency- 60 Hz Temperature- 100 °C Time- 150 s	<i>Bacillus</i> cells were reduced by 99.7% after ohmic heating. Taste, flavor, color and texture of OH samples were similar to those of conventionally treated samples.	Cho <i>et al.</i> , (2016)
Beef meatballs	Total mesophilic aerobic bacteria, molds, yeasts, <i>Staphylococcus aureus</i> , <i>Salmonella</i> spp., <i>Listeria monocytogenes</i>	Electric field- 15.26 V/cm Frequency- 50 Hz Temperature- 75 °C Holding time- 0 s	Total mesophilic aerobic bacteria - 2.47 log reduction, Molds and yeasts- N.D., <i>Staphylococcus aureus</i> – N.D., <i>Salmonella</i> spp., <i>Listeria monocytogenes</i> cells not inactivated efficiently.	Sengun <i>et al.</i> , (2014)
Meat	<i>L. innocua</i>	LTLT: Electric field: 8.33 V/cm Frequency- 50 Hz Temperature- 95 °C Time- 7 min HTST: Electric field: 8.33 V/cm Frequency- 50 Hz Temperature- 72 °C Time- 15 min	Bacteria reduced to N.D. LTLT samples has less cook loss (29.3%) than conventional method; HTST sample had better color	Zell <i>et al.</i> , (2010)
Apple juice	<i>Alicyclobacillus acidoterrestris</i>	Electric field= 26.7 V/cm Frequency- 25 kHz Temperature- 100 °C Time- 30 s	Total inactivation of cells. No significant change in TSS and color	Kim <i>et al.</i> , (2017)
Cloudberry jam	<i>Bacillus licheniformis</i>	Voltage varied to simulate thermal conditions.	D-value for OH sample less than conventional heating.	Pereira <i>et al.</i> , (2007)

D_T: Decimal reduction time at T °C temperature; N.D. : Not detected; LTLT: low temperature long time; HTST: High temperature short time; TSS: Total soluble solid

Leizeron *et al.*, (2005) used the electro heating unit for citrus juice comprised of two sets of contiguous graphite anodes, with a 20 cm hole between each match of anodes. The framework used an exchanging current at a recurrence of 50 Hz and at greatest voltage of 8 kV. The current and voltage were measured automatically by control system and thermocouple was inserted at the exit end of the heating chamber to detect the predetermined heating temperature.

Physico-chemical changes of fruit juices exposed to ohmic heating

Effect on inactivation of enzymes

There have been limited research works on enzyme inactivation of fruit juices. Castro *et al.*, (2004) found that ohmic heating caused the faster deactivation of lipoxygenase and polyphenoloxidase than the common heating methods. Leizeron *et al.*, (2005) concluded that the activity of pectin methyl esterase was reduced by 98% in orange juice exposed to ohmic heating. The deactivation of pepsin activity in grape juice was greatly influenced by pH, electrical field strength, electrical conductivity (Yang *et al.*, 2004). Margot *et al.*, (1997) observed the inactivation of trypsin activity for the ohmic treated fruit juice within 55 to 70°C range of temperatures. Jakob *et al.*, (2010) studied the mechanism of deactivation of pectin methylesterase in fresh apple juice during ohmic heating and concluded that kinetic parameters were significantly changed as compared to the conventional heating method. Wilinska *et al.*, (2008) revealed that the deactivation of pectin methyl esterase in apple juice followed first-order kinetics by exposing to ohmic treatment. Moreno *et al.*, (2013) postulated that polyphenoloxidase was completely inactivated by ohmic heating assisted with vacuum impregnation at a temperature of 50 °C for which shelf life of apple juice was enhanced to more than 4 weeks. The

microbiological study of ohmic heated food materials has been illustrated in table 1.

Changes in the heat sensitive compounds

Sarkis *et al.*, (2013) studied the degradation of anthocyanin compound in blueberry pulp by comparing in both ohmic and common heating methods. Degradation was found to be higher in ohmic heating at higher electric field. Assiry *et al.*, (2003) observed the impact of ohmic heating which was found to be more effective in vitamin C degradation as compared to common heating methods. Mercali *et al.*, (2012) observed that ascorbic acid in acerola pulp was degraded in the similar trend by exposing to both ohmic and common heating methods. Vikram *et al.*, (2005) found that the ascorbic acid in orange juice was degraded to approximately 35% after 3 minutes of ohmic heating at a temperature of 90⁰C with 42 V/cm of applied electrical field strength. Castro *et al.*, (2004) revealed that the deterioration of ascorbic acid was following the first order kinetics in both ohmic and conventional heating methods and was independent of presence of electric field.

Changes in pH and viscosity

Singh *et al.*, (2008) observed the variations of viscosity and electrical conductivity of apple, pineapple, tomato, and orange juices exposed to ohmic treatment and showed that with increasing the temperature, viscosity was decreasing.

Darvishi *et al.*, (2013) found that there was a significant effect of voltage change on the pH of pomegranate juice samples and showed a nonlinear relationship during the treatment period.

Changes in color

Mercali *et al.*, (2014) observed the higher change in the color parameters L*, a*, b* at

low electric field frequency of 10 Hz which was due to electrochemical reactions. Icier *et al.*, (2006) showed that the variation in colors followed the first order kinetics in pea puree during ohmic blanching with the electrical field strength of 20V/cm.

In conclusion, development of new products and process technologies is necessary from the point of increasing demand of consumers for high quality foods. In ohmic heating, the conversion of electrical energy absorbed by the material into volumetric heating takes place without any surfacial heat loss. Uniform distribution of temperature as well as uniform heating is the main advantages of ohmic heating. Enzymatic browning causes color and quality degradation in fruit juices. So ohmic heating can be applicable as an alternative to conventional heating to enhance the shelf life of fruit juices with minimal degradation of nutritional and organoleptic qualities.

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