Minireview Paper

Comprehensive Review on Ohmic Heating of Muscle Food

ABSTRACT

The aim of the present study is to know about the effects of ohmic heating (OH) on fish and meat and compare it with other thermal methods of food processing. Food quality, food safety, convenience, freshness, healthy food, natural flavor and taste with extended shelf-life are the main criteria for the demand made by today's consumers. Ohmic heating is an alternative fast heating method for food products. Compared to conventional heating methods, this process can achieve shorter heating times while avoiding hot surfaces and can reduce temperature gradients. The electrical, thermophysical and rheological properties of the products play an important role in achieving uniform heating. In addition to the product parameters, process parameters such as the current frequency used, the electrode material and the geometry of the treatment chamber are also relevant. It was concluded that large number of actual and potential applications exist for OH, including heating, evaporation, dehydration, extraction, waste water treatment of different type fish and meat and its product.

Keyword: *Ohmic heating, electrical conductivity, fish and meat*

1. INTRODUCTION

Food is a nutritious substance that people or animals eat or drink or that plants absorb in order to maintain life and growth. There is a need to process food to prevent, reduce, eliminate infestation microbial growth or toxin production by microbes. Hence food production processes are mainly concerned by product quality and safety management by inactivating micro-organisms. Product deterioration like degradation of substance, quality loss like appearance change, off-odors & color deterioration and health problems like diseases or illness are caused by the presence of undesired microorganisms. So inactivation of microorganisms is important for food safety and quality management of food product [1] to prevent food-borne illness. This includes a number of routines that should be followed to avoid potentially severe health hazards [36]

Present scenario of supermarkets get changed as compare to past there is more requirement of ready to eat product in market. Apart from fruit and vegetable there is also a huge demand of fish and meat ready to product such as soup, biscuit, fish and meat ball, cutlet, nuggets, sausages, pickle etc. and its hygienic marketing for earning higher economic returns and its availability throughout the year. Through value addition cost can be enhanced and it also adds over few per cent more profit. India is lagging in fish and meat processing sectors as compare to other country. Conventional heating and cooking has many disadvantages viz low rate of heat penetration to the centre (pasteurization) which causes long cooking time and outer layer of muscle receiving a more severe heat exposure which deteriorate the quality of the product, high heat loss(conduction and convection) as it consist of heat-transfer mechanisms of conduction, convection and radiation. The internal resistance by conduction results in very heterogonous treatment and the notable loss of product quality [1, 2, 5, 7]. To overcome these problems, alternative technologies utilizing electrical energy directly in the food processing have attracted interest in the food industry in recent decades.

2. PROCESSING TECHNIQUE AND PRINCIPLE of OHMIC HEATING

2.1 What Is Ohmic Heating?

Ohmic heating is a novel thermal food processing operation in which electric currents are passed through conductive foods with the primary purpose of heating them and as food also has some resistive properties so heat is generated because of resistance [19]. It is also referred to as Joule heating, electrical resistance heating, direct electrical resistance heating, electro-heating, and electro-conductive heating where **Joule heating** is the process by which the passage of an electric current through a conductor releases heat. Its basic principle shows in Fig 1.The amount of heat released is proportional to the square of the current as shown in equation 4 [34].

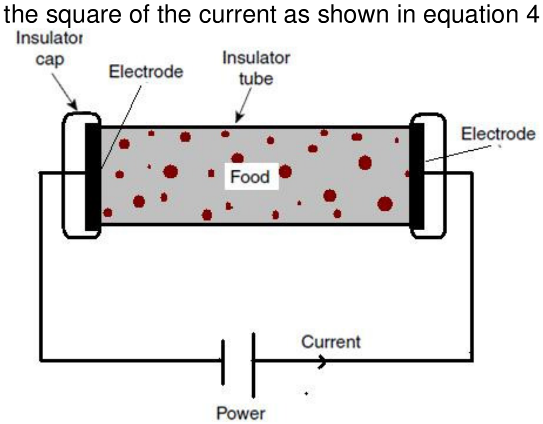

Fig1: Ohmic heater principle

2.2 How Ohmic Is Different Than Conventional Heating

In conventional method heating are applied at the coldest point of a system, which is generally the center of the largest particle. In conventional heating, the time it takes to increase the temperature at this cold point may over process the remaining particles and the surrounding liquid. This over-processing leads to a destruction of nutrients and flavor reduction. Ohmic heating processes the particles and surrounding liquid simultaneously, preventing overcooking. The absence of a hot surface in ohmic heating reduces fouling problems and thermal damage to a product [37].

2.3 How Heat Is Generated

The heating occurs in the form of internal energy generation within the material as electrical energy is directly converted or dissipated into thermal heat with negligible heat loss. This heat generation rate is **proportional to square of electric field strength and electrical conductivity** [26] which is generated due to moving ion within food collide with another molecule and these collision leads to momentum transfer to these molecules which in turn increase their kinetic energy thereby heating the product. Momentum transfer is the amount of momentum that one particle gives to another particle. Ohmic heating is distinguished from other electrical heating methods either by the presence of electrodes contacting the food, frequency, and waveform (also unrestricted, although typically sinusoidal). Generally 50-60 Hz alternating current is used for ohmic heating [3].

2.4 Working of Ohmic Heating

Foods that contain water and ionic salts are capable of conducting electricity but they also possess a resistance properties which generates heat when an electric current is passed through them as resistive material oppose the current and movement of ion. The electrical resistance of a food is the most important factor in determining how quickly it will heat. Conductivity measurements are therefore made in product formulation, process control and quality assurance for all foods that are heated electrically. The food acts as an electrical resistor.
Ohmic heating depend on the Ohm's Law which deals with the relationship between voltage and current in an ideal conductor

$$V = IR \qquad \text{.......... (1)}$$

The measured resistance is converted to conductivity using:

$$R = \frac{1}{\sigma} x L/A = \rho L/A \qquad \textbf{.....(2)}$$

So by putting R value in eq^{n} 1

$$\mathbf{V = I\,(1/\sigma)\,L/A} \qquad \textbf{.....(3)}$$

Where $\sigma = 1/\rho$

$$H = E^2 \sigma \qquad \text{.... (4)}$$

$$E = V/\ l \qquad \text{.....(5)}$$

$$H = I^2RT \qquad \text{...(6)}$$

Where

ρ = resistivity of product

σ product conductivity in (S/ m)

R Resistance in ohms (Ω), present in the conductor

V is the potential difference between two points which include a **resistance** R

I is the current flowing through the resistance which flow in conductor

L Length of the cell in m and

A Area of the cell (m^2)

L/A Cell constant

E electric field strength

V/ L Voltage gradient ie. ratio voltage applied to distance between two electrode

t is the amount of time that this happens for.

H is the amount of heat

2.5 Factors affecting ohmic heating process

The important parameter in ohmic heating of a liquid food product is its electrical conductivity behavior. It depends on temperature, applied voltage gradient, frequency, and concentration of electrolytes [13, 16, and 42]. Beside the electrical conductivity of the food it depends on the rate of heat generation in the system, the, electrical field strength, residence time so machine (system) and material both parameters affect the ohmic heating process and the method by which the food flows through the system [14, 35]. In machine variables voltage or voltage gradient, electrode distance and area of electrode while in material or product variables composition, physical and electrical properties of food influence the effectiveness of ohmic heating. Food, which contains water and ionic salts in ample, is the most suitable for ohmic heating [26]. Heating is accomplished according to Ohm's law where conductivity or resistivity of food will determine the current that will go between product and electrode. Machine and material as a independent variables which affect ohmic heating process are tabulated in Table 1**.**

Table 1: Variables affect ohmic heating process

Food variables (Material)	**Ohmic heater variables (Machine)**
Electrical properties(electrical conductivity , electric field strength)	Voltage or voltage gradient
Rheological properties(viscosity)	Distance between electrode
Physical properties (size and shape)	Area of electrode
Thermal properties (rate of heat generation)	Current

2.5.1 Food Properties Affecting Ohmic Heating

2.5.1.1 **Electrical Properties**:

2.5.1.1.1 <u>The Electrical Conductivity</u> (σ): It is a measure of how well a material accommodates the movement of an electric charge. It is the ratio of the current density to the electric field strength. Its SI derived unit is the Siemens per meter (S/m), for any material the electric conductivity can be calculated from the equation (3). It is a function mainly of food chemistry and structure and temperature. Electrical conductivity of food and food mixture which in turn depends on food components: ionic components (salt), acid amount and type of electrolyte, pH, protein and moisture content [23, 25]. For purely liquid foods, the electrical conductivity increases linearly with temperature but overall falls as the concentration of pulp in it increases [25] In solid foods, the situation is more complicated as the electrical conductivity rises linearly with temperature, especially at low voltage gradients and may be different in different directions within the solid. The electrical conductivity of foods may be manipulated by altering its ionic concentration [22]. For example moisture mobility increases electrical conductivity, while fats, lipids, and alcohol decrease it. In short temperature, voltage and salt concentration affect the EC. The conductivity of food increases with temperature due to increased ionic mobility. Structural changes in tissue like cell wall break down, softening and reduce phase viscosity enhance ionic mobility [27]. The conductivity of food increases with temperature so as to attain the high temperature it is necessary to increase the current or voltage and use longer distance between electrodes.

2.5.1.1.2 Electric Field Strength: It can be calculated by equation (5) and its unit is V/cm may be varied by changing either the applied voltage or gap between the electrodes. The electrode gap (distance between the electrodes in the system) can fluctuate depending on the size of the system.

2.5.2 **Rheological Properties:** Fluid viscosity, higher viscosity fluids shows faster ohmic heating than lower viscosity fluids.

2.5.3 **Physical Properties:** Density, size and shape of particle pieces. Electrical conductivity decreases as particle size and concentration increases [42]

2.5.4 **Thermal Properties:** The specific heat of the food product, thermal conductivity tells how material is affected by heat as electrical energy is converted into thermal energy. Specific heat capacity is the amount of energy needed to increase the temperature of a substance by a certain interval. This is can be helpful for determining temperature distribution in a substance that is to be heated ohmically. The lower heat capacity will tend to heat faster ie. high heat transfer. Heat densities and specific heats are conductive to slower heating. Thermal conductivity also gets changes as temperature changes.

2.5.4.1 . **Heating Power Supplied To Ohmic Heater:** The energy (heat, P) given to the ohmic heating system to given temperature are calculated by using the current (I) and voltage (ΔV) values during heating time [13].

Work done on resistor = Energy given to system

$$W = VI\Delta t$$

$$W/\Delta t = P = VI \quad \text{...... (7)}$$

$$W = P = VI\Delta t \quad \text{... (8)}$$

Where W= Work done

P energy given to the ohmic heating system

2.5.4.2. Rate of Heat Generation : Due to the passing electrical current through the heating sample, a sensible heat is generated causing the temperature of the sample rise from T_i to T_f, the amount of heat give to the system can be calculated from the following equation [9]:

Energy required to heat the product = $m\,C_p\,(T_f - T_i)$ ....(9)

The energy generated due to electrical resistance of the fluid causes a change in thermal energy of the product between inflow and outflow [8].

$$P = VI = m\,C_p\,(T_f - T_i) + m\,\lambda + Q_{loss} \quad \text{............ (10)}$$

Heat dissipated through product = thermal heat generated in the product

Where m = mass of the product

C_p = specific heat

T_i = initial temperature of product

T_f = final temperature of product

2.5.2 Ohmic Heater System Variables Affecting Ohmic Heating

2.5.2.1 Voltage gradient: The amount of heat generated is directly related to the current induced by the Voltage gradient in the field. It has increasing effect on electrical conductivity [25].Voltage application causes fluid motion through the capillary porous membrane of biological tissue. Applied voltage also affects the electric field strength

2.5.2.2 <u>Electrode Area and Distance Between Electrodes</u>: They affect electrical conductivity, temperature profile and heating rate during the ohmic heating process.

2.5.2 .3 <u>Electrode Material</u>

Electrode material [41] found that 1-mm-thick platinised titanium electrode proved to be the most satisfactory compromise as it was resistant to electrolysis, gave a satisfactory heating rate

2.6 HOW OHMIC HEATING AFFECT MICROBIAL INACTIVATION

The principal mechanisms of microbial inactivation in ohmic heating are thermal in nature. 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 [37]. 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. An applied electric field under OH causes electroporation of cell membranes. The cell electroporation is defined as the formation of pores in cell membranes due to the presence of an electric field and as a consequence, the permeability of the membrane is enhanced and material diffusion throughout the membrane is achieved by electro-osmosis [6, 23]. It is assumed that the electric breakdown or electroporation mechanism is dominant for the non-thermal effects of OH [21].

3. OHMIC HEATING APPLICATION IN MUSCLE FOOD

Ohmic heating is now receiving increasing attention from the food industry, once it is considered an alternative for the indirect heating methods of food processing [4, 24] such as heating liquid foods such as soups, stews, and fruits in syrup; Heat sensitive liquids processing; Juices treated to inactivate proteins (such as pineapple or papaya); blanching; thawing; starch gelatinization; sterilization; peeling of fruits (eliminating the need for lye-a harmful corrosive chemical); dehydration; extraction; fermentation and processing protein-rich foods which tend to denature and coagulate when thermally processed. Except this now days application of ohmic heating is also becoming popular for muscle food such as meat product and fish products etc. Applications related to fish and meat is discussed as below:

3.1 Fish

Fish is good sources of animal protein with low fat which is in high-quality. Beside this it contains omega-3 fatty acids, vitamins such as D and B_2 (riboflavin) and calcium and phosphorus and other minerals, such as iron, zinc, iodine, magnesium, and potassium which is essential for maintaining a good health, brain, and heart. It has high moisture content and low acid content which make it an extremely perishable after catch if not utilized within one day under normal condition , get spoiled as it provides favourable medium for the growth of microorganisms after death. Microbial action, chemical action, enzymatic action and physiological deterioration degrade the fish quality (example proteins, carbohydrates, fat and color) after death without any preservative or processing measures within 12-20 hours at tropical temperature.

3.1.1 Fish Heating

Thermal processing of fish using OH has the benefits of inactivating endogenous enzymes and stopping microbial growth. There is no clear report on the effect of OH on colour, texture and quality of fish. The present study was undertaken to investigate the effect of OH on quality parameters of fresh fish steaks [20].

Ohmic heating is also used a cooking unit-operation in the production of cooked and peeled shrimps (Pandalus Borelias). The shrimps were heated to a core temperature of 72 ℃ in a brine solution using a small batch ohmic heater. Three experiments were performed: 1) a comparative analyses of the temperature development between different sizes of shrimps and thickness (head and tail region of the shrimp) over varying salt concentrations (10 kg m^{-3} to 20 kg m^{-3}) and electric field strengths (1150 V m^{-1} to 1725 V m^{-1}) with the heating time as the response; 2) a 2 level factorial experiment for screening the impact of processing conditions using electric field strengths of 1250 V m−1 and 1580 V m−1 and salt concentrations of 13.75 kg m^{-3} and 25.75 kg m^{-3} and 3) evaluating the effect of pretreatment (maturation) of the shrimps before ohmic processing. The maturation experiment was performed with the following maturation pre-treatments: normal tap water, a 21.25 kg m^{-3} brine solution and without maturation. The measured responses for experiments 2 and 3 were: the heating time until the set temperature of the shrimps was reached, weight loss, press juice and texture profile. It was possible to fit main effects model relating process settings and the heating time, weight loss and press juice measurements. Furthermore, the results showed that over the tested process workspace no significant changes were seen in the texture measurements of the shrimps and that the shrimp achieved a comparable quality compared to the conventional heating processes reported in the literature. The findings show a promising utilization of ohmic heating as a unit operation for the shrimp [28]

Electrical conductivities of Alaska pollock surimi mixed with native and pregelled potato starch at different concentrations (0%, 3%, and 9%) were measured at different moisture contents (75% and 81%) using a multifrequency ohmic heating system. Surimi-starch paste was tested up to 80°C at frequencies from 55 Hz to 20 KHz and at alternating currents of 4.3 and 15.5 V/cm voltage gradients. Electrical conductivity increased when moisture content, applied frequency, and applied voltage increased, but decreased when starch concentration increased. Electrical conductivity was correlated linearly with temperature ((R^2) approximately 0.99). Electrical conductivity pattern (magnitude) changed when temperature increased, which was clearly seen after 55°C in the native potato starch system, especially at high concentration. This confirms that starch gelatinization that occurred during heating affects the electrical conductivity. Whiteness and texture properties decreased with an increase of starch concentration and a decrease of moisture content [30].

3.1.2 Fish Waste Water Treatment

Ohmic heating can be used to remove protein from fish mince (threadfin bream) washwater collected from a surimi production plant in order to improve water quality. The samples were heated under different electric field strengths (EFS, 20, 25, and 30 V/cm) until reaching the desired temperature (50, 60, and 70°C), and further held at that temperature for a certain time (0, 15, and 30 minutes). Heating the samples to 70°C resulted in a better protein removal when compared to 50 and 60°C. After heating to 70°C, the samples were centrifuged. The analysis of the supernatant obtained shows the reduction of protein, COD, BOD, TS, and TDS to 42%, 25%, 23%, 44%, and 61%, respectively. The electrical conductivity of the samples showed a linear relationship with temperature and the temperature demonstrated a parabolic relationship with heating time. EFS and holding time have no significant effect on protein removal [15].

3.1.3 Ohmic Thawing of Frozen Surimi or Fish Product

Ohmic thawing system can be used for a frozen saline surimi cube. The thawing rate and surimi gel strength in the ohmic thawing process were investigated, in comparison with conventional thawing technique. The electric mechanism for the ohmic thawing process was also discussed. Under the condition of the applied voltage of V and frequency of Hz, a homogeneous temperature distribution in the frozen surimi was obtained at different concentration of electrode solution. The thawing rate increased linearly with the increasing concentration of electrode solution. The changes in thawing rate and temperature distribution with the concentration of electrode solution could be explained by an equivalent electric circuit. The ohmic thawing had a higher thawing rate and resulted in stronger gels than the conventional thawing. It was concluded that the ohmic thawing system can be applied well in the thawing of frozen surimi [40].

3.2 Meat

Lean red meats are an excellent source of high biological value protein, vitamin B12, niacin, vitamin B6, iron, zinc and phosphorus, source of long-chain omega-3 polyunsaturated fats, riboflavin, pantothenic acid, selenium and possibly also vitamin D. It is mostly low in fat and sodium and sources of a range of endogenous antioxidants and other bioactive substances including taurine, carnitine, carnosine, ubiquinone, glutathione [38]

3.2.1 Meat Heating

Minced beef–fat blends having different fat level (2%, 9% and 15%) and full meat-fat samples were ohmically cooked by different voltage gradients (20, 30 and 40 V/cm). Main factors affecting the electrical conductivity were the temperature and the composition of the blends. Although the effect of initial fat content on electrical conductivity was statistically significant, voltage gradient did not affect the electrical conductivity changes during cooking treatment ($p > 0.05$). The electrical conductivity of the samples increased with increasing temperature up to the critical initial cooking temperature (60–70 °C) depending on the fat level, and then decreased due to structural changes and the increase in the bound water during cooking. The results of the nonlinear mathematical model including the effects of initial fat level and the temperature on the electrical conductivity changes had good agreement ($r = 0.952$; SEM = 0.009) with the experimental data. The determination of electrical conductivity changes being affected by process variables is crucial to characterize the ohmic cooking of meat products and design of ohmic systems. It was obtained that ohmic cooking was applicable to the minced beef lean–fat blends having different fat contents by using different voltage gradients. The initial fat content and the temperature were important factors affecting the electrical conductivity of the samples, while the applied voltage gradient during the ohmic cooking did not affect it. Electrical conductivities of the meat blends increased up to the critical temperatures (heating region) and then decreased (cooking region) during the ohmic cooking. During the ohmic cooking, as the initial fat content increased the change in the fat content during cooking increased. The moisture removal was not different for the different voltage gradients applied [10].

3.2.2 Meat Thawing

Frozen storage in the preservation of meat maintains its importance in terms of food safety. However, physical and chemical activities happening in meat thawing and thawing process may affect the qualifications of quality as much as preservation. There are some drawbacks in the conventional thawing methods such as longer thawing time, occurrence of weight loss due to the high amount of leakage, nutritional loss with the leaked fluids and unwanted microbial activity during thawing. It was concluded that an ohmic heating system can be effective and useful in thawing to use with good quality. The fastest thawing and the least weight loss were observed in the samples in which the ohmic method was employed [8].

4. CONCLUSION

Ohmic heating is an emerging novel technology; which has it a large number of industrial applications such as blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization and heating of foods and all these application are also used for fish and meat industry. It works on the dissipation of electrical energy in the form of thermal heat using an electrical conductor. The electrical conductivity of food materials play important role in ohmic heating system. It provides better product quality, less cooking time. Ohmic heating has immense potential for achieving rapid and uniform heating. But more research is required to maintain the uniform heat generation rate, especially for semi solid, and high moisture content food.

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