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Quality Characteristics of Dairy Products Using Ohmic Heating Technology: A Review

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ABSTRACT

Milk is an emulsion of oil in water, with an emulsifier in casein. Milk is perishable because of physical, chemical, and microorganism factors, easily damaged. Methods are therefore needed to preserve the quality, prevent damage from these factors. The dairy industry is using thermal intervention to produce safe products and quality. Ohmic method of heating is an alternative to traditional heating for improving milk quality to provide longer shelf life. It necessitates the externally generated heat energy in conventional heating, which is passed to food by conduction, convection, and radiation. While ohmic heating is passed through a product that acts as an electric power resistor, in which electrical energy is converted into thermal energy. It is reducing heating time than conventional processes, also keep the nutrition and product heating more uniform. However, the formation of fouling products during milk processing can cause problems. The effectiveness of the ohmic heating technique influenced by the characteristics of the product and the process itself. Such as electrode material, frequency, the electric field strength, residence time, or electrical conductivity. Using these methods, not only fresh milk but also other dairy-based foods like whey-based drinks and whey probiotics use ohmic heating to maintain quality and increase shelf-life.

Key words: Conductivity, dairy product, milk, nutrition, ohmic heating, shelf-life

1. INTRODUCTION

Milk is a simplistic emulsion that suspends oil in the aqueous phase (o/w) [1]. In the water phase, the oil phase forms small droplets. Milk is perishable, resistant to microbial or physical and chemical damage [2]. In dairy and food industries, thermal interventions are often used to obtain secure and high-quality products. The microbiological safety of processed products is widely used for HTST (High-Temperature Short Time) pasteurization and UHT (Ultra-High Temperature) sterilization, commonly referred to as conventional thermal processes [3], [4]. The thermal process heat transfer mechanism is performed by conduction or convection. It requires a long time to allow overheating, which causes nutrient damage and degradation, and sensory changes [3], [5]. Consumer concerns related to health require products that are nutrient-rich and minimally damaged [6]–[8].

Ohmic heating is a technique to overcome conventional heating weaknesses to produce quality products [9]–[13]. It is also known as joule-, electro-, and electroconductive heating that uses electrical energy to replace thermal processes in materials [6], [14]–[16]. The ohmic mechanism doesn't involve heat transfer by conduction, convection, or radiation. Using the electrical resistance found in food, however, to generate heat [6]. The electrical energy generated from food products, due to the electrical resistance of the product, is converted into heat energy so that the heating process occurs immediately and volumetrically [16]. When electricity passes through conducting materials, atomic agitation, or charged particle movement causes temperature increases [17]. Ohmic heating provides a better uniform heat distribution, high efficiency, and faster time to achieve temperature conditions required due to infinite temperature penetration [3], [6], [13], [18].

In comparison to conventional heating, this is the advantage of ohmic heating technologies. Also, ohmic heating technology shows lower costs of capital than conventional heating. It because ohmic heating does not necessitate the installation of a boiler as heat, the lack of moving parts to make maintenance more comfortable and less expensive, and the ability to shut down the system immediately [12]. The fruitfulness of ohmic heating, however, depends on product characteristics such as frequency, electrical field strength, residence time, and electrical conductivity [12]. These factors are an essential parameter that must be controlled during the thermal process [14]. Due to the high-water content or polar compound, for example, minerals and proteins in it, ohmic heating was recommended to process various food products. For ohmic heating applications, the product should be electrically conductive. It is a constraint in food processing, especially in materials with low ionic and water content. Materials with high water content, ionic components, and electrical conductivity in the range 4.0 to 5.5 mS/ cm have demonstrated the suitability of the milk composition, making it the ideal candidate for ohmic heating [17], [19]. It reviews will, therefore, discuss the quality characteristics of pasteurized and sterilized milk products using ohmic heat.

2.OHMIC HEATING EFFECT ON THE QUALITY OF DAIRY PRODUCTS

2.1 Physicochemical Properties

The physicochemical and organoleptic properties of dairy products are essential for quality evaluation. These characteristics are impacted by the type and intensity of treatment used [20], [21]. The intensity of the ohmic heating process can also be determined using indicators of thermal methods commonly used in conventional heating [22]. Several indicators are used, including lactulose, furosine, and hydroxymethylfurfural (HMF), the fluorescence of advanced Maillard products, and soluble tryptophan (FAST) index, carboxymethyl-lysine (CML), glycosidation products, denaturation and aggregation of proteins (β-lactoglobulin), and free fatty acids (FFAs) [23]. Various studies use these damage markers to dairy products due to thermal interventions and evaluate the quality influence of the product generated [24]. Table 1 presents a summary of ohmic heating on quality attributes aspects of dairy products in different study results.

Table 1: Ohmic Heating Effects on Quality Parameters of Dairy Products

Material	Purpose	Parameter	Result	Ref.
Infant formula	Comparing ohmic heating and steam injection techniques to the functional aspects of infant milk	FAST index, furosine, CML, protein denaturation, vitamin C, and color	The FAST index, furosine, CML indicate an equivalent level of Maillard reaction throughout sterilization using the ohmic heating and steam injection. Compared with steam injection, ohmic heating can maintain color. The denaturation of the protein by both ways is equivalent; however, ohmic heating can preserve the content of vitamin C.	[24]
Milk of cow and buffalo	Evaluate ohmic heating effects on milk quality parameters	pH, FFAs, HMF, color, Rheology	Ohmic heating causes the HMF and total acid content to increase significantly. While the pH decreased significantly compared with conventional heating. Maillard reaction product formation decreases the value of L *; increases the value of a * and b *. FFA increases during ohmic heating but does not change organoleptic properties significantly.	[17]
Raspberry-flavored whey drink	Evaluate the pasteurization of whey drink with ohmic and conventional heating on other rheological and physical properties. In ohmic heating systems, variations in frequency (10, 100, 1000 Hz-25 V) and voltage (45, 60, 80 V-60 Hz) are used; the conventional temperature is 65 ^{o}C for 30 minutes	Color, rheology, particle size distribution, differential scanning calorimetry (DSC)	In the first 30 minutes, both methods increase the color consisting of chroma, hue, and total color difference parameters. Viscosity increased significantly at frequencies of 10 Hz and 1000 Hz with a voltage of 25 V, hence an increase in particle size distribution. For the DSC parameter, the same behavior is obtained. The author recommends the use of ohmic heating under 10 Hz-25 V and 1000 Hz-25 V to preserve industrial raspberry-flavored whey drink.	[7]
Normal milk and lactose-free milk	Identify opportunities for ohmic heating for lactose-free pasteurization; investigate fouling products with various electrode materials on pasteurized milk using ohmic technology	Electrical conductivity, pH, protein content	Lactose-free milk's electrical conductivity ranges from 0.6-1.3 S/ m, which shows that the sample can be heated efficiently using the ohmic method. Normal, lactose-free milk has no significant difference in protein value. The pH of ohmic-pasteurized milk using titanium electrodes was not significantly different, but HTST conventional pasteurization showed significant pH changes compared to raw milk. Ohmic-pasteurized milk with titanium electrodes significantly protein contains higher on than the conventional method. It indicates the number of fouling products, milk pasteurized by ohmic with titanium	[16]

Material	Purpose	Parameter	Result	Ref.
			electrodes, is fairly lower than the stainless-steel material used in conventional heating. Titanium electrodes better to prevent milk fouling than stainless steel. Furthermore, pasteurization using titanium electrodes is safer, as the content of post-milk chromium is lower (within safe limits) than that of stainless steel. While iron also isn't found with titanium electrodes in ohmic-pasteurized milk.	
Whey raspberry-flavored beverage	Study of ohmic heating effects on quality attributes of whey raspberry-flavored beverages under different conditions. These conditions (10, 100, and 1000 Hz at 25 V; 45, 60, and 80 V at 60 Hz)	Total phenolic and anthocyanin, antioxidant activity, angiotensin-converting I (ACE) inhibition, α-glucosidase and α-amylase, and volatile compounds	The enzymes α-glucosidase (> 99%) and α-amylase (>70%) increase by 10% due to ohmic heating, and the inhibition of ACE also increase. The anthocyanin content, however, is below conventional treatments. Mild-intermediate (10, 100 Hz at 25 V and 45, 60 V at 60 Hz) ohmic heating conditions showed the highest antioxidant activity. In all voltage treatments, furfural and 5-hydroxymethylfurfural compounds that the main intermediate products in the Maillard reaction, are found. Ohmic heating can be used for whey-raspberry processing.	[25]
Infant formula	Researching the influence of voltage gradients on physicochemical properties and volatile compound profiles in infant formula	HMF, whey protein nitrogen index, color, volatile compounds	Ohmic heating helps to reduce the formation of HMF and the sub-product of Maillard reactions in infant formula. Applying an electric field of more than 24 V/ cm can generate a time reduction of 83%, improve color, and form volatile compounds which are essential for the aroma of infant formula. Ohmic heating retains whey protein integrity.	[26]

Whey protein production ohmic heating could reduce thermal loads, alter the pathway for the aggregation of whey proteins, or interact with other molecules (such as Maillard's reaction) and affect protein-allergy response [23]. It also has an impact on functional characteristics such as hydrogel or emulsifier capability [15], [27]. Still, it maintains the bioactive component of whey protein [18]. The main milk-protein is β-lactoglobulin, which is easily denatured due to heating at a temperature of 70 to 100 ^{o}C [28]. Ohmic heating influences protein denaturation and provides lower β-lactoglobulin denaturation than conventional heating [29]. During the ohmic heating process, the electroporation effect results in low fouling and damage due to changes in temperature [16].

Milk pasteurization using ohmic and conventional heating affects the pH value. Conventional milk heating requires the flow of water, which increases pH. Ohmic heating requires electrical current only so that pH is not increased [16]. Similarly, the ohmic heating technique did not show any critical changes in pH for whey processing [18]. While Parmar et al. [17], the pH value of cow and buffalo milk samples decreased significantly after ohmic heating. It is due to lactose degradation into organic acids (particularly formic acid), conversion into colloidal calcium phosphate of soluble calcium phosphate, and casein dephosphorylation [17], [30].

Ohmic heating can cause changes in chemical components, reducing the quality of milk because of fat oxidation. The contributing factors are oxygen, minerals, and metal ions [31]–[33]. According to Suebsiri et al. [16], the metal ion content of approximately 0.1-5.0 ppm in food may encourage a fat-oxidation reaction. Therefore, electrodes that cause increased fat oxidation and milk fouling products should be avoided. Parmar et al. [17] state that the content of FFAs and HMF in milk ohmic heating increases significantly. The use of high temperatures in milk heating causes damage to the milk fat membrane components, particularly of proteins and phospholipids, which leads to the free fat formation [34], [35].

The ohmic heating method affects the rheological properties of milk products and their color. According to Marcus Vinicius S. Ferreira et al. [7], ohmic heating contributes to the increasing viscosity of raspberry-flavored whey drinks. The reason is ohmic heating electrodes, which keep the temperature stable and prevent evaporation because of the closed heating system [6], [18]. Moreover, the content of casein and whey in the ingredients also affects those characteristics [7].

In milk, casein micelles contribute to milk color. Denaturation and aggregation of whey protein cause a decrease in white milk color by thermal intervention in casein micelles [17]. Furthermore, with the start and further development of the Maillard reaction, the intensity increases. Ohmic heating decreases the L * value and increases the * and b * values [36]. Maillard reactions during milk heat lead to an increase in hydroxymethyl-furfural (HMF) in the main intermediate product [7]. The HMF values are in line with milk product color formation, the higher the HMF value, the brightness of milk decreases [17]. The use of inert electrodes may reduce color-damaging electrochemical reactions [18]. It is a concern during pasteurization or sterilization using ohmic heating systems because the decrease in color causes a deterioration in organoleptic characteristics, which are not acceptable to consumers [7].

2.2 Microbiological Properties

Besides dairy products and whey, ohmic heating can be used for fermented milk products like whey probiotics. Probiotic whey is whey protein given the cultivation of probiotic bacteria [37]. It aims to improve the benefits of digestion to the health of everyone who consumes it [38]. Probiotics can enhance intestinal microflora and improve intestinal resistance to pathogenic microorganisms [39]. Probiotic bacteria are generally *Lactobacillus* and *Bifidobacterium* species. The strains of the probiotic bacteria species *Lactobacillus* consist of *Lactobacillus acidophilus*, *Lactobacillus crispatus*, and *Lactobacillus amylovorus*; while the probiotic bacterial *Bifidobacterium* strains are *Bifidobacterium bifidum* and *Bifidobacterium longum* [7], [39]. Ohmic heating was used to extend the shelf-life of fermented dairy [36].

Ohmic heating on probiotic whey accelerates probiotic bacteria-produced enzyme inactivation. It was due to the flow of electrical energy in the material affecting enzyme-prosthetic groups such as lipoxidase and polyphenol oxidase [7], [33]. With ohmic heating, bacteria present in dairy products, such as *Streptococcus thermophilus*, can also be inactivated [40]. Ohmic heating is having a significant impact on the microorganisms' membrane structure. Ohmic heating, due to electroporation and interactions between enzymes and substrates, can cause enzyme inactivation [15]. The same thing happened to the bacterial inactivation mechanism using the ohmic heating method. Electroporation causes the process of electrical induction from the external electric field, creating an attraction between opposite charges on the external and internal cell membranes. It will form holes that cause breakage or change in the permeability of the cell membrane [15], [36], [40]. Microorganisms being treated with ohmic heating will be in a sub-lethal state. This method can thus affect microorganisms' metabolic processes [15], [41].

3.FOULING IN DAIRY PRODUCTS

Fouling is impurity contamination, the main issue in conventional heating because it can reduce the product's heat transfer coefficient [40]. Based on Minz and Subramani's research [6], conventional milk thermal interventions produce high fouling products, particularly at the bottom of a heating container. It's due to the low rate of the heater to reach the desired temperature so that it takes a long time. Impurity is also caused by denaturation and aggregation of protein [42]. Bansal and Chen [43] also found that significant amounts of denatured protein may affect impurity levels. In the milk industry, the risk of fouling may decrease productivity, require additional energy, labor costs, chemical substances, and risk of microbial contamination [44]. Milk fouling is rapidly accumulating so that heat-exchanger is cleaned regularly to achieve the targeted production amount and improve hygiene [43]. The fouling is influenced by factors: milk composition, heat exchanger operating conditions, heat-exchanger type and characteristics, microbes existence, and the fouling area [43].

If the product's electric conductivity is high enough, the use of ohmic heating has more advantages than conventional aspects related to the rate and uniformity of adequate heating [45]. It can reduce fouling product formation [46]. Ohmic heating is mainly constrained by suitable materials used as electrodes to prevent product fouling. The fundamental problems in applying ohmic heating to food products are electrode hydrolysis and corrosion that can shorten shelf-life and contaminate ohmic heating products [47], [48]. Metals may also affect the antioxidant activity and product retention by catalyzing oxygen-involving degradation [16], [49]. Using inert electrodes such as titanium can overcome weaknesses related to fouling in dairy products [15].

Milk pasteurized applying titanium electrodes by an ohmic way contains higher protein than the conventional method. It demonstrates the titanium electrodes fouling levels are lesser than the conventional heat exchangers' contact surfaces [16]. Ohmic heating is dependent on internal heat in the sample, whereas conventional heating is dependent mainly on heat convection and conduction [12], [45]. Therefore, the heat exchanger surface contact in the conventional method is greater than the product. Meanwhile, ohmic heating electrodes show temperatures proportional to the product and function to provide electric power to the food system. In conventional heating, a more fouling outcome occurs [16]. Bansal and Chen [46] state that ohmic heating pasteurized milk using titanium electrodes can retain nutrients higher than conventional heat exchangers using stainless steel.

In the health aspect, using stainless steel electrodes with the ohmic heating method for pasteurizing milk is at risk. The Federation of Drugs and Administration (FDA) has determined that the chromium intake limit is 130 μg/ kg of sample and iron <15 mg/ kg of the sample [50]. Pasteurized milk using Low-Temperature Long Time (LTST) and ohmic methods with titanium electrodes, containing chromium below 50 µg/ kg sample and iron-free. Milk heated by the ohmic way using stainless steel electrodes contains 290 mg/ kg chromium and 4.855 mg/ kg iron [16]. These metal ions can accelerate lipid oxidation, which can reduce product quality [16], [31]. Therefore, pasteurized milk with ohmic heating by stainless steel electrodes, due to chromium and iron contamination above a threshold is dangerous for consumption [42], [51]. These are demonstrated by the oxidation-reduction process reaction [52]:

a. Titanium electrode reaction

$$TiO_{2\,(s)} + 4H^{+}_{(aq)} + 2e^{-} \leftrightarrow Ti^{2+}_{(aq)} + 2H_2O_{(liq)} \quad (E^{o} = -0.502\ V)$$

$$TiO_{2\,(s)} + 4H^{+}_{(aq)} + e^{-} \leftrightarrow Ti^{3+}_{(aq)} + 2H_2O_{(liq)} \quad (E^{o} = -0.666\ V)$$

b. Stainless steel electrode reaction

$$M_{(s)} + 2H^{+}_{(aq)} \leftrightarrow M^{2+} + H_{2(g)} \text{ (Where, M=Fe, Cr, Ni, Mo); } (E^{o} = 0.44\ V)$$

Reduction-oxidation (redox) reactions on titanium electrodes couldn't occur on their own because the electro-potential of the redox reaction produced is negative, so it does not show the corrosive possibility. Conversely, the electro potential of the stainless-steel electrodes redox reaction is positive, which means that stainless steel electrodes can be corrosion and distributed electrons [10], [53]. As a result, electrodes made from stainless steel may become metal ions and contaminate the sample [51], [53]. It can be avoided by reducing electric field strength and increasing frequency [54]. A low electric field strength, however, will extend the heating time and frequency that is too high to reduce the efficacy of non-thermal, which is useful in inactivating microorganisms and enzymes [7], [54].

4. CONCLUSION

Ohmic heating is an appropriate method for pasteurizing or sterilizing milk products. These thermal interventions are successful in inactivating enzymes and microbes to maintain quality parameters as well as extended the shelf-life of dairy products. Furthermore, ohmic heating is more time-efficient and can maintain its protein content and pH in milk in comparison with conventional methods. Although, there are still weaknesses such as the formation of fouling products when using stainless-steel electrodes and the loss of color in milk. It can, however, even be minimized by replacing inert electrodes such as titanium and applying a suitable electrical current.

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