THE PASTEURIZATION OF MILK APPLYING OHMIC HEATING IN COMPARISON WITH CONVENTIONAL METHOD AND THE QUALITY ATTRIBUTES OF LACTOSE-FREE MILK

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ABSTRACT

So far, there has been an increasing number of people with lactose intolerance reported in Thailand. The main objective was to determine the potential of applying ohmic method in the pasteurization of both normal and lactose-free milks. The lactose-free milk was prepared from the cow milk using lactase enzyme. The electrical conductivities of both normal and lactose-free milks obtained from various conditions were measured applying ohmic heating apparatus. Furthermore, the chemical and physical properties of milk samples pasteurized at 63 °C for 30 min by conventional method and ohmic method were compared. It appeared that the electrical conductivities of milk samples were in the range of 0.635-1.230 $S \cdot m^{-1}$ indicating that they could be efficiently heated by ohmic method. Moreover, the electrical conductivities of normal and lactose-free milks were insignificant different. There was no significant difference in aspects of protein content, total acidity and specific gravity between the milk samples pasteurized by conventional and ohmic methods. In summary, the ohmic method showed its potential for the milk pasteurization.

Keywords: free lactose milk, ohmic heating, electrical conductivity

Introduction

Ohmic heating is an innovative thermal processing method that does not rely on heat conduction, convection and radiation mechanisms. The electrical energy conducted through the food is converted into thermal energy owing to the electrical resistance of food (Joule's Law) leading to the volumetric and instantaneous heating. The heat power generation during ohmic heating is directly proportional to the square of applied electrical field strength and the electrical conductivity of food (Cappato et al., 2017). The main mechanism of microbial inactivation caused by ohmic heating is the thermal effect on membrane and enzyme of microorganism (Sun et al., 2008). On the other hand, Previous studies reported that microbial inactivation caused by ohmic heating was due to the electroporation of cell membranes by electric current (non-thermal effect) (Yoon et al., 2002). Palaniappan et al., (1992) reported that no difference between effects of ohmic heating and conventional under same thermal history conditions on the death kinetic of yeast cell. Otherwise, Pereira et al. (2008) investigated effect on microbial inactive in dairy product by using ohmic method in comparison with conventional method under same temperature profile (63 and 65 ^{o}c), and reported that D and Z value by ohmic method are lower than those by conventional method under same condition. The electrical conductivity of food usually depends on temperature, ionic mobility and the percentage of non-conductive components, such as fat, sugar and gases (Cappato et al.,2017). The effect of fat content on the electrical conductivity of ice cream was investigated and found that the Maras type ice cream (fat content of 3.3%) had higher electrical conductivity and consequently the faster heating rates than those of traditional ice cream in Turkey (fat content of 9.8%) (Kim and Kang, 2005). Moreover, they found that the increase in fat content led to a non-homogeneous heat distribution within the samples. Shivmurti et al. (2014) compared the chemical properties of milk heated by conventional and ohmic methods. They found that the ohmically heated milk had total acidity, fat, solid-non fat, protein, total solids contents of 0.063, 6.003, 5.840, 2.777, and 11.840% respectively that were not significantly different from those of conventionally heated sample.

The application of ohmic heating technology has several advantages over the conventional process due to the possibility to promote fast and even heating in the product if the electrical conductivity of product is sufficiently high and uniform.

Therefore, this technique has the potential to reduce the impact of the heat treatment on food product quality. The range of electrical conductivity of food that is suitable for ohmic heating is 0.01 to 10 S•m^{-1} (Shivmurti et al., 2014). Moreover, the other advantages of ohmic heating consist of the ease of process control, higher energy efficiency, fouling reduction at the heating surface and no steam boiler requirement (Cappato et al., 2017).

Person with lactose intolerance are unable to digest lactose due to a genetically deficient amount of the enzyme lactase. Common symptoms include abdominal pain and bloating, excessive flatus, and watery stool following in the digestion of foods containing lactose. Lactose deficiency is present in up to 15 percent of people in northern European, up to 80 percent of blacks and Latinos (Daniel et al., 2002) and between 65-85% of adults in East Asian and African (Heaney, 2013). Treatment usually consists of avoiding lactose-containing foods and taking lactase enzyme supplements (Daniel et al., 2002). The degree of lactose malabsorption greatly varies among patients with lactose intolerance; however, most of them can consume up to 12 oz. of milk daily without symptoms (Daniel et al., 2002). In this study, the lactose-free milk was prepared from the cow milk using lactase enzyme. The electrical conductivities of both normal and lactose-free milks were measured in order to realize the effect of lactose digestion on the electrical conductivity of milk and subsequently the ohmic heating applicability. Furthermore, the properties of milk samples pasteurized by conventional and ohmic methods were compared. The key objective was to determine the potential of applying ohmic method in the pasteurization of both normal and lactose-free milks.

Methods

Milk sample preparation

The raw cow milk was purchased from KU Dairy Center, Kasetsart University, Bangkok, Thailand. Raw milk was preheated at 50 °C using a double jacket kettle (Cleveland, model KET-6-T, USA) and then holding for 5 min prior to homogenization by a two stage homogenizer (APV, model 15MR-8TA, UK) at the 1st/2nd stage pressures of 2,500/500 psi. The homogenized milk was divided into 2 portions. The 1st part was pasteurized by conventional method using double jacket kettle whereas the ohmic method was applied for pasteurizing the 2nd portion. The schematic diagram of the ohmic heating apparatus for milk pasteurization is shown in Fig. 1. The ohmic cell was made of glass with the inside diameter of 195 mm and height of 300 mm. The two curved rectangular electrodes placed inside the cell were made of titanium plate Gr-2 with their width and height of 70 and 240 mm, correspondingly. The distance between the centers of the electrodes was 95 mm. The sample temperature was measured using Type-T thermocouple located at the center of ohmic cell and recorded by a data logger (Yokogawa, model DX 1012, Japan). The electrical voltage and current were measured by a digital multimeter (Fluke, model 8808 A, USA). The pasteurization condition for both method was specified at temperature of 63°C and holding for 30 min. It must be noted that the temperature profile of sample during heated by ohmic method was controlled to be similar to that of conventional heating method by regulating the variable transformer (AC power supply) along the ohmic heating process. After pasteurization, the milk samples were immediately cooled down to around 4 °C using ice water before cold storage.

A portion of the pasteurized milk samples obtained from both conventional and ohmic methods were also processed to be lactose-free milk using lactase enzyme supplied by Institute of Nutrition, Mahidol University at Salaya, Thailand. For the lactose-free milk processing, the lactase enzyme was added into the pasteurized milk at the specified amount (1 mL per 1 L of milk) and then storing the samples at the temperature range of 0-4 °C for 18 h for the enzymatic reaction.

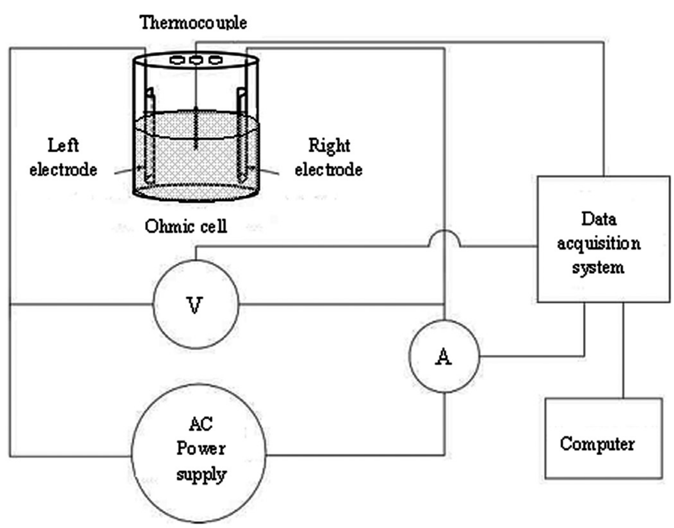

Figure 1 Schematic diagram of the ohmic heating device for pasteurization

Pasteurized milk measurement

Milk samples pasteurized by conventional and ohmic methods were checked their pasteurization completeness via the detection of alkaline phosphatase in the pasteurized milk products. The Macherey-Nagel™ Phosphatesmo MI Qualitative Test Paper (Macherey-Nagel™, model Macherey-Nagel™ 90612, Germany) was used. This test strip allows the specific detection of alkaline phosphatase in milk and commonly applied in dairy industry. The strips were dipped into the milk and incubated at 36 °C for 10 min. If the paper remained white, it indicated that the milk was completely pasteurized.

Electrical conductivity measurement

The milk samples including (1) raw milk, (2) milk pasteurized by conventional method, (3) lactose-free milk pasteurized by conventional method and (4) lactose-free milk pasteurized by ohmic method (Milk pasteurized by ohmic method was not measured electrical conductivity. Because the main purpose was to determine the factors that effect to the electrical conductivity. The factors are both type of milk (raw milk, milk pasteurized by conventional method, lactose-free milk) and pasteurized method (ohmic method and conventional method). The study investigated the result of lactose free milk pasteurized by ohmic and conventional method) were measured their electrical conductivities using a static ohmic heating device that was built at the Department of Food Science and Technology, Kasetsart University, Thailand (Tumpanuvatr et al., 2015). The schematic diagram of the apparatus is presented in Fig. 2. The cylindrical ohmic cell was made from acrylic pipe and the electrodes were stainless steel grade 316. The diameter of electrode was 0.0215 m while the distance between electrodes was 0.085 m. The electrical field strength applied in this measurement was in the range between 11-13 $V \cdot cm^{-1}$. The sample temperature was measured using Type-T thermocouple located at the center of ohmic cell and recorded by a data logger. The electrical voltage and current were measured by a digital multimeter. The experiment was conducted in triplicate for each type of sample. The electrical conductivity of sample was calculated applying Equation (1).

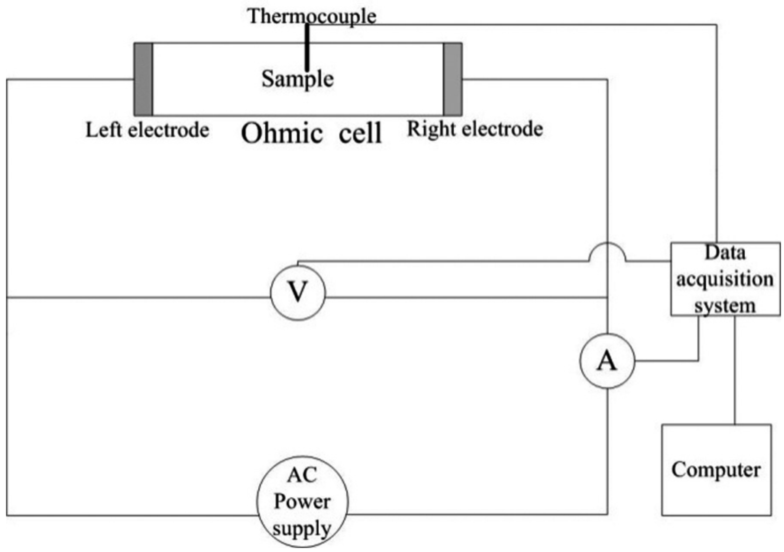

Figure 2 Schematic diagram of the ohmic heating device for electrical conductivity measurement

$$\sigma = IL/AV \quad (1)$$

where σ = Electrical conductivity ($S \cdot m^{-1}$), A = Cross sectional area of electrode (m^2), I = Electrical current (Ampere), L = Distance between the electrodes (m), V = Applied voltage (Volt).

Determination of chemical and physical properties of milk samples

The protein contents of milk samples including (1) raw milk, (2) milk pasteurized by conventional method, (3) milk pasteurized by ohmic method, (4) lactose-free milk pasteurized by conventional method and (5) lactose-free milk pasteurized by ohmic method were determined following the Manual Method of Analysis of AOAC International Official Methods 2012 (Laporte and Paquin, 1999). Furthermore, these samples were measured their color values using a colorimeter (MiniScan XE, HunterLab, USA) in the L*, a*, b* scale. L* represents lightness ($0 \leq L^* \leq 100$, while a*(+), a*(-), b*(+) and b*(-) represent redness, greenness, yellowness, and blueness correspondingly (Thoh et al., 2017). The total acidity values of all pasteurized *milk* samples were determined following the Official Methods of Analysis of AOAC International Official Methods 2012 (Laporte and Paquin, 1999). Also, their specific gravity values were measured applying a hydrometer. All the measurements were conducted in triplicate.

Milk samples pasteurized by conventional and ohmic methods were checked their pasteurization completeness via the detection of alkaline phosphatase in the pasteurized milk products. The Macherey-Nagel™ Phosphatesmo MI Qualitative Test Paper (Macherey-Nagel™, model Macherey-Nagel™ 90612, Germany) was used. This test strip allows the specific detection of alkaline phosphatase in milk and commonly applied in dairy industry. The strips were dipped into the milk and incubated at 36 °C for 10 min. If the paper remained white, it indicated that the milk was completely pasteurized.

Results and Discussion

The photograph of the test strips after testing the alkaline phosphatase in the milk pasteurized by conventional and ohmic methods are illustrated in Fig. 3. The white color of both strips indicated that both milk samples were completely pasteurized. The alkaline phosphatase in the pasteurized milk samples was inactivated. This result confirmed that the application of ohmic method in milk pasteurization provided the comparable effect to that of conventional heating method. Similarly result has been reported for yeast cell (Palaniappan et al., 1992).

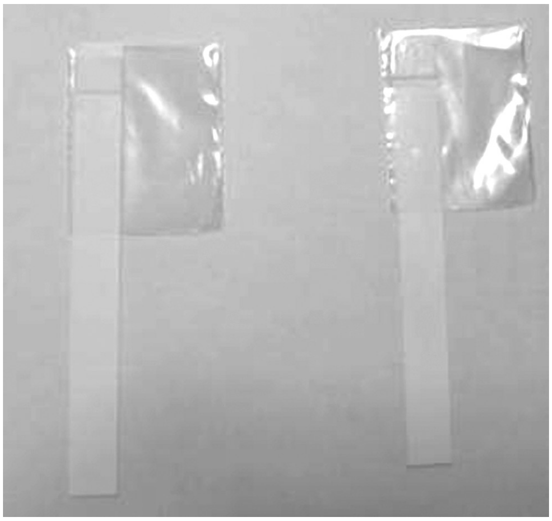

Figure 3 The test strips after the detection of alkaline phosphatase for the milk pasteurized by conventional and ohmic methods

The results of the electrical conductivity measurement of milk samples at the temperatures between 30 and 80 °C were illustrated in Fig. 4. It appeared that the electrical conductivities of samples ranged between 0.635-1.230 S•m^{-1}. No difference was found in the result of the electrical conductivity on 3 type of milk and no difference was found in term of pasteurization method between lactose-free milk pasteurized by conventional method and lactose-free milk pasteurized by ohmic method. Referring to Lyng and McKenna (2006), the food materials with electrical conductivities in the range of 0.01-10 S•m^{-1} are suitable for ohmic heating. Obviously, the electrical conductivity values increased along the rising temperature. It is unsurprising because the electrical conductivity of sample depended on the ionic mobility within the sample. At the higher temperature, the ions could move more rapid due to its high potential energy causing the increase of electrical conductivity. Moreover, it appeared that the electrical conductivities of all samples were similar implying that the degradation of lactose by lactase enzyme did not apparently affect the electrical conductivity of milk.

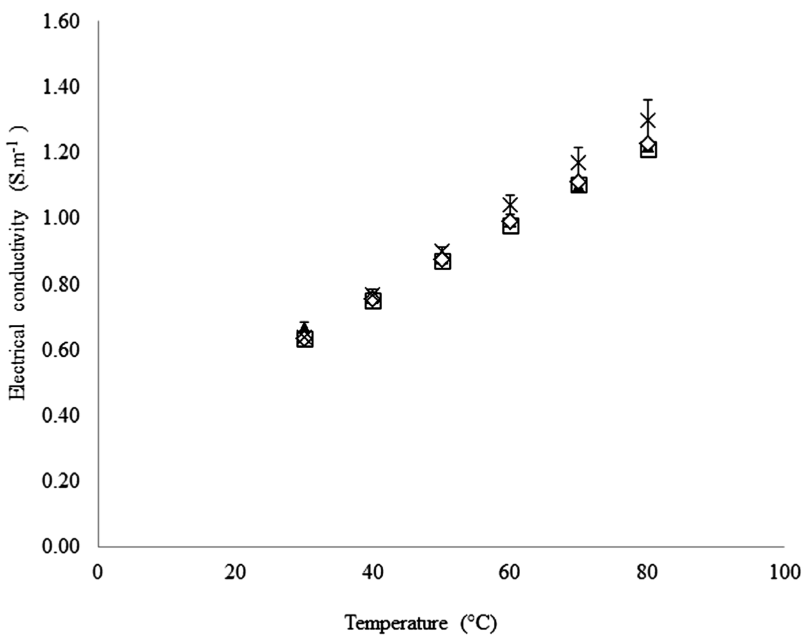

Figure 4 Electrical conductivity values of milk samples.
(×= Raw milk, ◇ = Milk pasteurized by conventional method,
□ = Lactose-free milk pasteurized by conventional method,
▲= Lactose-free milk pasteurized by ohmic method)

The protein contents and color values of milk samples are presented in Table 1. It appeared that the protein contents of samples were insignificantly different. Although the enzyme used for the lactose digestion can be categorized as protein, it did not result in the increase of protein content in the lactose-free milk samples because only the little amount of enzyme was used. In addition, this result implied that the protein lose as the fouling on the surface of electrodes in the ohmic heating was comparable to that on the heating contact surface in the conventional heating. The lightness values of pasteurized samples were significantly lower than that of raw milk while the a* and b* values of raw milk were significantly different from those of pasteurized milk specimens. It can be explained that the heat treatment during pasteurization caused the browning reactions such as Maillard reaction leading to the more intense color. However, the color values of samples pasteurized by different heating methods were similar.

The total acidity and specific gravity values of all pasteurized milk samples are shown in Table 2. It is clear that their total acidity and specific gravity values were insignificantly different. This result demonstrated that the applications of lactase enzyme and different heating methods did not influence to the total acidity and specific gravity values of milk samples.

Table 1 The protein contents and color values of milk samples

Sample	Protein content (%)	Color		
		L*	a*	b*
Raw milk*	3.01	$93.96^{a} \pm 0.05$	$0.38^{d} \pm 0.05$	$13.59^{e} \pm 0.19$
Milk pasteurized by conventional method	$2.92^{ns} \pm 0.18$	$95.09^{b} \pm 0.83$	$-1.57^{ab} \pm 0.02$	$9.91^{a} \pm 0.15$
Milk pasteurized by ohmic method	$2.93^{ns} \pm 0.01$	$95.09^{bc} \pm 0.83$	$-1.44^{c} \pm 0.03$	$10.39^{bc} \pm 0.10$
Lactose-free milk pasteurized by conventional method	$2.99^{ns} \pm 0.02$	$96.27^{d} \pm 0.48$	$-1.61^{a} \pm 0.06$	$10.47^{c} \pm 0.17$
Lactose-free milk pasteurized by ohmic method	$2.90^{ns} \pm 0.02$	$95.66^{bcd} \pm 0.17$	$-1.43^{c} \pm 0.04$	$10.44^{bc} \pm 0.13$

Remark: The superscript "ns" means not significantly different ($p \geq 0.05$).
*Raw milk sample was determined its protein content using Lactostar (Funke gerber, Lactostar model 3510, Germany) at KU Dairy Center, Kasetsart University.

Table 2 The total acidity and specific gravity values of all pasteurized milk samples

Sample	Total acidity (%)	Specific gravity (%)
Milk pasteurized by conventional method	$0.17^{ns} \pm 0.01$	$1.03^{ns} \pm 0.00$
Milk pasteurized by ohmic method	$0.17^{ns} \pm 0.01$	$1.03^{ns} \pm 0.00$
Lactose-free milk pasteurized by conventional method	$0.17^{ns} \pm 0.01$	$1.04^{ns} \pm 0.00$
Lactose-free milk pasteurized by ohmic method	$0.17^{ns} \pm 0.00$	$1.03^{ns} \pm 0.00$

Remark: The superscript "ns" means not significantly different ($p \geq 0.05$)

Conclusion

The normal and lactose-free milk samples can be heated by ohmic method due to their suitable electrical conductivities. The electrical conductivities of normal and lactose-free milk samples were not significantly different. The protein contents of all pasteurized samples were insignificantly different implying that the protein lose as the fouling on the surface of electrodes in the ohmic heating was comparable to that on the heating contact surface in the conventional heating. The applications of lactase enzyme and different heating methods did not influence to the total acidity and specific gravity values of milk samples. The result of alkaline phosphatase test showed that both conventionally and ohmically heated milk samples were completely pasteurized confirming that the application of ohmic method provided the comparable effect to that of conventional heating method. The ohmic method has the potential for applying in the lactose free milk pasteurization.

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