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EFFECT OF OHMIC HEATING TREATMENT ON DIFFERENT PROPERTIES OF WHOLE COW MILK

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ABSTRACT

Ohmic heating is a unique thermal technology in which an electrical current is passed through a food product, causing heat to be generated. This alternative heating process was investigated in terms of energy efficiency and high quality method for a batch quantity of whole cow milk. The study's major goal is to show that it is possible to develop a heater that successfully pasteurizes milk on a laboratory scale. Before and after ohmic and conventional heating procedures, chemical characteristics (such as protein, acidity as lactic acid, fat, and solid non-fat), alkaline phosphatase, and microbial counts (such as total bacteria count and E. coli) of the milk were examined. When the maximum voltage gradient (19.13 V/cm) was used, the protein content of pasteurized milk remained unaltered. The fat level remained consistent at 5.10 % across all pasteurization methods. Both conventional and ohmic heating inactivated alkaline phosphatase and microorganisms. Different voltage gradients of 6.08 V/cm, 9.56 V/cm, and 19.13 V/cm were also studied to see what effect they would have on the ohmically heated milk's electrical properties (such as electrical conductivity and current).

INTRODUCTION

Non-thermal food preservation methods offer the ability to fulfill customer demands for high-quality processed foods that are free of additives and have not been subjected to high heat treatment. Heat treatment of dairy products remains a complex procedure, despite major developments in traditional technology over the last decades. In this context, however, any novel methods that use thermal treatment, Ohmic heating, or nonthermal treatments to pasteurize or sterilize food are of enormous scientific and industrial importance. The ohmic heating technique is used for blanching, evaporation, sterilization, thawing, and pasteurization. Ohmic heating is also known as electrical resistance heating or joule heating. As electrical energy is dissipated, heat is created, resulting in rapid and uniform heating. It involves passing an electrical current directly through the medium to be treated between a pair of electrodes (Ould-El-Moctar, 1992). In contrast to conventional heating from an exchanger's heated surface, Ohmic heating is described as volume heating or direct-resistance heating (Salengke and Sastry, 2007). Before it can be employed with ohmic heating, the material must be electrically conductive, which is a limiting factor in the processing of products with low water and ionic content (Nielen *et al.*, 1992). The basis of ohmic heating is that electrical energy is turned into heat energy. When electricity passes through a conductive material, it causes atoms to agitate or charged particles to vibrating motion, raising the temperature (Sastry, 2003). Several studies have shown that the particle's center can be heated faster than the liquid in Ohmic heating (Sastry and Palaniappan, 1992). The absence of a hot wall should be a major advantage for food applications, since it prevents heat-sensitive compounds from deteriorating and reduces electrode fouling (Ayadi, 2005). The heating rate of food undergoing Ohmic heating is influenced by the electrical conductivity, specific heat, particle size, shape, and concentration, as well as particle orientation in the electric field (Skudder and Biss, 1987).

The rate of heating, on the other hand, is mostly governed by the physical characteristics of the food, particularly its electrical conductivity (De Alwis and Fryer, 1992). Enzyme and microbe inhibition, heat-sensitive chemical degradation, pH, and rheological properties are all examples of changes in food quality caused by the electric field of Ohmic heating (Kaur *et al*., 2016). As a result, a study found that improved heat treatment processes are crucial in preventing food degradation and eliminating germs including bacterial cells and spores (Mercali *et al*., 2015). Palaniappan and Sastry (1991) found no difference in the effects of Ohmic heating and conventional heating on the death kinetics of microbial cells. They discovered that a simple electrical pretreatment reduced the amount of heat required to inactivate *Escherichia coli* at particular temperatures. Yoon *et al*., (2002), on the other hand, discovered that Ohmic heating generated more intracellular component leakage in *Saccharomyces cerevisiae* than conventional heating. Although Ohmic heating looks to be a promising and successful method, there is little data on its impacts on individual food products when compared to the effects of conventional pasteurization (Leizerson and Shimoni, 2005; Vikram *et al*., 2005). The goal of this research was to look into the electrical, microbiological, and physiochemical aspects of a built model of batch Ohmic heating device used to pasteurize cow milk.

MATERIALS AND METHODS

Cow milk was obtained from a local market in Mosul, Iraq. The milk was filtered through two layers of muslin to remove any dirt that might have been present. 300 mL milk samples were treated with various voltage gradients (6.09, 9.56, and 19.13 V/cm) in the batch ohmic heating experimental setup (Fig. 1) that was devised and built in the Food Science Department, College of Agriculture and Forestry, University of Mosul, Iraq. It comprises of a domestic power supply (220V and 60Hz), an Ohmic heating tube constructed of polyvinyl chloride with two stainless steel electrodes (4 cm long, 0.5 cm diameter) at the tube's ends, a temperature sensor to monitor temperature, an ampere recording screen, and a voltage power converter. The genuine designed and built batch type Ohmic heat equipment is depicted in Figure (2).

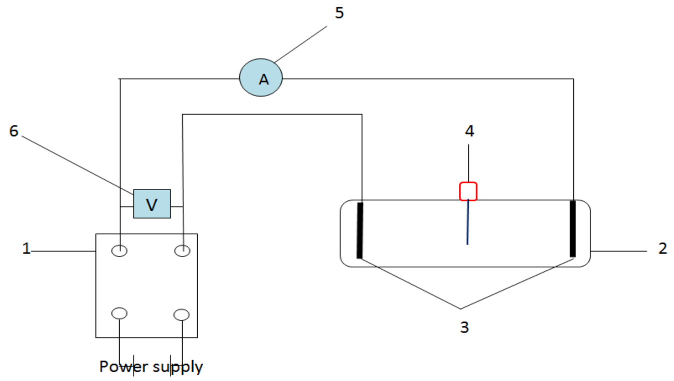

Figure (1): The ohmic heating experimental setup on a laboratory scale.1, power supply; 2, Ohmic heating tube; 3, electrodes; 4, thermometer; 5, Ampere digital monitor; 6, voltage converter.

Figure (2): batch type ohmic heating equipment

Milk is heated in a water bath at 72°C for 15 seconds in the conventional method, whereas milk is heated in an ohmic heating chamber with provided voltage gradients (6.08 V/cm, 9.56 V/cm, and 19.13 V/cm) to achieve 72°C temperature in the ohmically heating method (Sakr and Liu, 2014) . Both conventionally heated and Ohmic heated samples were examined for phosphatase presence, physio-chemical, and microbiological assays at 0 time of cold temperature storage. The electrical parameters of milk samples exposed to different voltage gradients were calculated.

Electrical conductivity:

The electrical conductivity values, according to Sakr and Liu (2014), represented the passage of electrical current through the milk being tested.

$$\sigma = \frac{L}{A} \times \frac{I}{V}$$

σ is the electrical conductivity (S/m), L is the length of ohmic heating tube (m), I is the electrical current (Amp), A is the cross sectional area of the ohmic tube (m^2), and V is the voltage value (V).

Milk analysis:

Determination of protein, fat, alkaline phosphatase enzyme, acidity, solid-not-fat.

AOAC's procedure for calculating protein as a percentage of whole milk was used (2014). The Gerber method was used to determine the proportion of fat content in milk, according to Ling (1963). The detection of alkaline phosphatase in pasteurized milk using ready-made kits supplied by Biolab SA (France) was used to measure pasteurization completion in milk samples using conventional and ohmic methods. Titratable acidity of milk samples was determined as lactic acid percentage through the application committed by Ling (1963). Solid-not-fat (SNF) content was obtained through the method explained by AOAC (2014).

Microbiological experiments:

The samples of raw and pasteurized milk were analyzed for the determination of total bacteria count and *Escherichia coli* colony forming unit (cfu/ml). Nutrient agar medium was used to determine the total bacteria count as described by APHA (1987). MacConkey agar medium was used to determine the *E. coli* count.

Statistical analysis

The data was analyzed according to Complete Randomized Design using Duncan Test among the treatments (SAS Institute Inc. 2004).

RESULTS AND DISCUSSIONS

Chemical, physical, and microbial properties of treated milk

All of the samples were tested three times, with the average of the results used as the final result. Table (1) demonstrates a comparison of the different characteristics of milk samples that were left untreated, conventionally heated, and ohmically heated. The time required to pasteurize the milk to 72°C in a water bath was (16.58) minute, but the time required to pasteurize the milk at different voltage gradients (6.08, 9.56, and 19.13 V/cm) was 19:58, 18:09, and 3:59 minute, respectively. The temperature appears to have risen ($p \leq 0.05$), as have the voltage gradients. The conventional heating method, on the other hand, takes significantly ($p \leq 0.05$) longer to attain the pasteurization temperature. According to certain research, as voltage gradients increased, temperature rose and the time to reach pasteurization temperature reduced (Hosain et al., 2011, Al-Hilphy, 2013).

Table (1): Values of different properties of untreated, conventional treated and ohmic treated whole cow milk samples.

Test	Untreated sample	ohmic heated sample			Conventionally heated sample
		Voltage gradient values			
		6.08 V/cm	9.56 V/cm	19.13 V/cm	
Protein %	3.67±0.01a	3.60±0.02c	3.63±0.01b	3.67±0.01a	3.61±0.01b
Fat %	5.10±0.05a	5.10±0.02a	5.10±0.01a	5.10±0.05a	5.10±0.01a
SNF %	8.60±0.17e	9.20±0.05b	9.40±0.01c	9.80±0.10d	9.90±0.17e
Acidity %	0.18±0.01a	0.17±0.01b	0.17±0.01b	0.16±0.01c	0.16±0.01d
ALP	+ve	-ve	-ve	-ve	-ve
TBC (cfu)	1.1×10^4	0	0	0	0
E. coli (cfu)	1.2×10^4	0	0	0	0

Values with different lathers in each raw are significant at 5%.
ALP- Alkaline phosphatase
TBC- Total Bactria count
Mean: ±SD

The thermal efficiency of Ohmic heating is said to be 90% (Minz and Subramani, 2018). At voltage gradients of 6.08, 9.56 V/cm, the protein values of both conventional and Ohmic heating at voltage gradients of milk pasteurization were less in raw milk as 3.61 %, 3.60 %, 3.63 %, and 3.67 %, respectively. In contrast, we discovered that Ohmic heating at a highest voltage gradient used (19.13 V/cm) had no effect on the protein content of pasteurized milk, which remained unchanged compared to raw milk (3.67 %). It's fairly understandable that the short period spent in this condition had no effect on the protein content of pasteurized milk. Other pasteurization conditions, which used either conventional or ohmically heated voltage gradients (6.08 and 9.56 V/cm), reduced the amount of protein that was exposed to denaturation. Protein is thought to be vulnerable to long-term exposure to an electric field. Protein loss diminishes as field intensity rises (Al–Hilphy, 2013). Throughout all pasteurization procedures, the fat level remained steady at 5.10 %. Shivmurti *et al*. (2014) discovered that conventional heating had no effect on the fat content of pasteurized milk, but Ohmic heating had a small effect. The amount of SNF in pasteurized milk increased when it was heated conventionally and ohmically. This rise in SNF could be caused by the amount of denatured protein produced during pasteurization, or it could have been caused by evaporation caused by probably untightened insulation of the Ohmic heating system and conventional heating. When compared to the acidity value in fresh samples, there was a small decrease in milk acidity throughout the various treatments used in this study. Ohmically heated samples with voltage gradients of 6.08 and 9.56 V/cm, on the other hand, showed a lower increase ($p \leq 0.05$) in acidity than Ohmic heated samples at 19.13 V/cm and conventional heated samples at 0.7, 0.7, 0.6, and 0.6 %, respectively. The alkaline phosphatase in pasteurized milk samples was inactivated by conventional and Ohmic heating. This finding revealed that using the Ohmic approach to pasteurize milk had a similar effect to using the conventional heating method. Sastry and Palaniappan (1992) have reported a similar finding. It can be observed from table (1) there is a complete inactivation of microorganisms found in pasteurized milk either conventionally or ohmically. Pereira *et al*. (2008), on the other hand, compared the influence of the Ohmic method on microbial inactivation in dairy products to the conventional method under the same temperature profile (63 and 65 °C), and discovered that the Ohmic method's D and Z values were lower under the same conditions.

Electrical properties of ohmically pasteurized milk

Electrical conductivity tests of milk samples at temperatures ranging from 15 to 72 °C are shown in Figure (1). The electrical conductivity rose ($p \leq 0.05$) as the voltage gradients increased, reaching the pasteurization temperature of the milk sample (72 °C). The electrical conductivity of the sample was between 0.4-1 S/m as the voltage gradient was raised from 6.08 V/cm to 19.13 V/cm. The electrical conductivity of the Ohmic heating at the lowest voltage gradient (6.08 V/cm) was significantly ($p \leq 0.05$) highest (1 S/m), compared to the other two voltage gradients (9.56 and 19.13 V/cm), which had electrical conductivity of 0.51 S/m and 0.40 S/m, respectively. It is shown known that when the voltage gradient increases, the electrical conductivity decreases. It was speculated that raising the voltage gradient would cause more fouling to accumulate on the heating surfaces (electrodes) that function as thermal resistance (Stancl and Zitny, 2010).

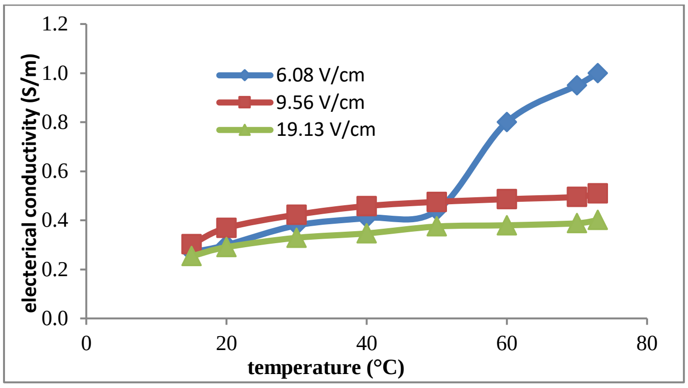

Figure (3): The effect of electrical conductivity on the temperature of pasteurized milk at different voltage gradients.

The current values grew as the voltage gradient increased, which was followed by a temperature increase (Fig. 2). Applying various voltage gradients (6.08, 9.56, and 19.13 V/cm) to reach the pasteurization temperature (72 °C) from a reference temperature of 15 °C resulted in current values of 1.25, 1.89, and 3.04 Amp respectively. The electric field strength and the electrical conductivity of the material are directly proportional to the rate of heating (Palaniappan and Sastry, 1991). While the voltage remains constant during the Ohmic heating process, the current flow fluctuates only according to the electrical conductivity of the milk. As a result, the temperature-current relationships shown in figure (2) represented the electrical conductivity change of the milk samples as a function of temperature during Ohmic heating. The current flowed through the samples that were subjected to varied voltage gradients, however, had an effect on the time used to Ohmic heat the liquid samples (Ahmed *et al.*, 2022). With some specific selected

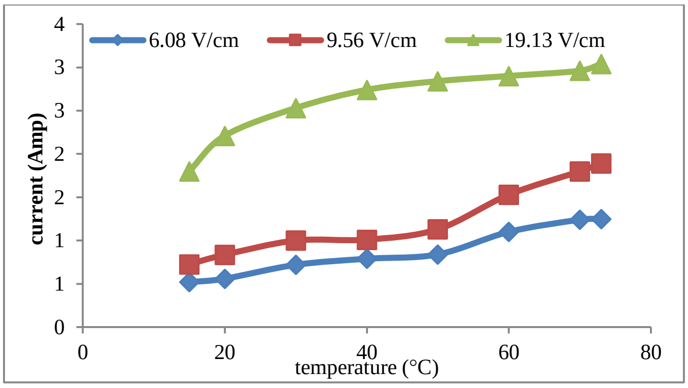

Figure (4): Temperature profile as electrical current passing through the milk at different voltage gradients.

liquid food materials undergone Ohmic heating, the changes in the current profiles were also remarkable (Kong *et al.*, 2008).

CONCLUSION

The findings of this study confirmed the feasibility of heating milk with Ohmic heating technology. According to the chemical analysis, Ohmic heating performs better in terms of operational time than conventional heating. It may be stated that Ohmic heating gives milk chemical qualities, as well as microbiological and alkaline phosphatase inactivation, that are comparable to conventional heating. Because quick heating kinetics or homogenous heat treatment are required, heat treatment through the direct Joule effect has various advantages. Electrical conductivity was discovered to be the most essential factor influencing the Ohmic heating process. The electrical characteristics tested (electrical conductivity and electrical current) rose as the voltage gradients increased, causing the temperature of milk samples to rise.

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CONFLICT TO INTEREST

Authors declare no conflict of interest regarding the publication of this study.

تأثير التسخين الاومي على الخصائص المختلفة لحليب البقر كامل الدسم

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الخلاصة

تقنية التسخين الاومي تقنية حرارية حديثة، حيث يتم فيها تمرير تيار كهربائي عبر المادة الغذائية مما يؤدي إلى رفع درجة حرارتها. تمت دراسة عملية التسخين الاومي لمعرفة درجة كفاءتها في استهلاك الطاقة الكهربائية ودرجة جودة الحليب كامل الدسم المعرض للتسخين الاومي. الهدف الرئيسي للدراسة هو تطوير معاملة حرارية تعمل على بسترة الحليب في النطاق المختبري. تم اختبار عينات الحليب قبل وبعد البسترة بالتسخين الاومي والتسخين التقليدي لمعرفة خصائص الحليب، مثل نسبة البروتين والحموضة ونسبة الدهن والمواد الصلبة غير الدهنية وانزيم الفوسفاتيز القلوي وعدد الاحياء المجهرية (العد الكلي للبكتيريا وبكتريا القولون). حافظ محتوى البروتين في الحليب المبستر بدون تغيير عند استخدام التدرج الأقصى للجهد (19.13 فولت/سم). كان مستوى الدهن ثابتًا عند النسبة 5.10٪ خلال جميع طرق البسترة المستعملة في هذه الدراسة. وجد لكلا التسخين التقليدي والأومي دور في تثبيط انزيم الفوسفاتيز القلوي والكائنات الحية الدقيقة. تم دراسة تدرجات جهد الكهربائية المختلفة (6.08 فولت / سم، و9.56 فولت/سم و19.13 فولت/سم) لمعرفة تأثيرها على الخصائص الكهربائية للحليب المبستر بالتسخين الاومي (مثل التوصيل الكهربائي والتيار الكهربائي).

الكلمات الدالة: الصفات الكهربائية، الصفات الكيميائية، التسخين الاومي، عدد الاحياء المجهرية.

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