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Electrical parameters of ohmically heated cow's milk

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ABSTRACT

Science and industry are very interested in alternative pasteurization and sterilizing methods, like the direct electrical effect. An experimental batch ohmic heating unit was built and manufactured for this study. Our goal is to design and build batch Ohmic heating equipment that ensures adequate pasteurization of whole cow's milk while also looking into the electrical phenomena that occur throughout the process. Ohmic and conventional heating technology were used to heat cow's milk from 15 to 72°C. The temperature increased when ohmic heating was applied with varying voltage gradients (6.08, 9.56, and 19.13 V/cm), resulting in a substantial decrease ($p \leq 0.05$) in the heating time for milk pasteurization. The current that flows through the sample was higher at higher voltage gradients, which led to a quicker accumulation of heat. The change in electric current during ohmic heating of the milk is only dependent on the electrical conductivity when the voltage is constant. Ohmic heating induced a significant ($p \leq 0.05$) increase in system performance coefficient (SPC) values with increasing voltage gradients, resulting in heating rates (°C/minute).

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INTRODUCTION

To assure microbiological safety in the food sector, pasteurization, sterilization, drying, and evaporation are some of the most often utilized industrial thermal methods (Kurian and Raghavan, 2020). Food elements, particularly vitamins and phenols, which are heat-sensitive and connected to food quality, suffer significant harm as a result of these treatments. (Zhang *et al.*, 2018). Ohmic heating was discovered to be one of the most cost-effective options for the food business, as it just uses electricity (Tian *et al.*, 2018). Conventional methods of heat treatment of food products were successful up to a point when consumers became aware of the food's nutritional content (Kaur *et al.*, 2016). The development of alternative technologies to pasteurize and sterilize food products, such as the direct Joule effect, is of major scientific and practical importance. In traditional heat treatment methods, non-uniform heating is a significant issue. The electrical conductivity of the

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food and the creation of the applied electrical field strength are directly proportional to the heat power produced by ohmic heating (Cappato *et al*., 2017). Ohmic heating is also preferred because it has a higher energy conversion efficiency (up to 90% of electrical energy can be converted to heat) and lower capital costs due to having fewer moving parts, however, the amount of heat produced depends on the electrical field, current, voltage, and conductivity of the food (Kumar *et al.*, 2018). Temperature and food concentration are inversely proportional. Ohmic heating involves sending an electrical current directly through the medium to be treated, between a pair of electrodes. Ohmic heating differs from other electrical heating techniques by having electrodes in direct contact with the food (as opposed to microwave and inductive heating), or by the frequencies and waveforms used (FDA, 2000). Solid food is more resistant to electrical conductivity since it rises directly as a function of temperature and water content (Kumar *et al*., 2014). The rate at which food is heated by ohmic heating is affected by a number of factors, including electrical conductivity, specific heat, particle size, shape, and concentration, as well as particle position in the electric field (Skudder and Biss, 1987). However, the electric field produced by ohmic heating can alter a variety of biological methods and aspects of food quality, including the inhibition of enzymes and microbes, the breakdown of chemicals that are sensitive to heat, the alteration of cell membranes, viscosity, pH, color, and rheological properties (Kaur *et al*., 2016). There are several factors to consider, including temperature, applied voltage gradient, frequency, and electrolyte concentration (Icier and Ilicali, 2005b). 50 Hz and 60 Hz are the two most frequently used frequencies for ohmic heating of food (Kolbe *et al*., 2001). According to Cappato *et al.* (2018), electrochemical reactions produced the most ascorbic acid degradation and a rise in color changes when a low-frequency electric field (10 Hz) was applied, whereas interactions at a high-frequency electric field (100 Hz) produced less. As a result, ascorbic acid dissociation was unaffected by high electric field frequencies, indicating that ascorbic acid oxidation was unaffected by sudden changes in electric field values. Relatively, treatments at low frequencies (>60 Hz), high electric field strength (>10 V/cm), and temperatures between 65 and 90 °C have been demonstrated to promote enzyme inactivation, but these extra effects are viewed as minor at the opposite conditions (high electric frequency and low electric field) (Samaranayake and Sastry, 2016a, 2016b). Due to its compositional compatibility, which is demonstrated by its high moisture content and the presence of ionic components, milk is a desirable choice for Ohmic heating (Nielen *et al*., 1992). Ohmic heating, as opposed to convection heating from a heat exchanger's heated surface, is defined as pure-volume, direct-resistance heating. The heat transfer coefficient between the hot wall and the fluid is therefore regarded to be unimportant as there isn't supposed to be a hot wall. The unit of measurement for electrical conductivity is Siemens per meter (S/m) (Sakr and Liu, 2014). The homogeneous heating of food is facilitated by its electrical, thermophysical, and rheological characteristics. The importance of potential electrochemical reactions at the food-electrode contact surface and non-thermal electric field effects affected by treatment settings must be emphasized (Jaeger *et al*., 2016). In contrast to the standard method, Jakób *et al*. (2010) investigated the effects of Ohmic heating at different temperatures on inhibition and assessment of the kinetics parameters of alkaline phosphatase in milk (indirect heating). They discovered that while the inhibiting mechanisms were unchanged, the kinetic parameters were altered, and the effect of ohmic heating resulted in significant changes and instability in the kinetics parameters of alkaline phosphatase. The objective of this research is to design and construct batch ohmic heating equipment that would assure adequate pasteurization of whole cow's milk while also investigating the electrical phenomena that occurred throughout the process.

MATERIALS AND METHODS

Cow's milk was purchased in Mosul, Iraq, at a local market. To remove any dirt that might have been present, the milk was filtered through two layers of muslin. In the batch ohmic heating experimental setup (Figure 1), 300 mL milk samples were treated with various voltage gradients (6.09, 9.56, and 19.13 V/cm) designed and built in the Food Sci. Dept., Coll. of Agric. and Forestry, Univ. of Mosul, Iraq. An ohmic heating tube constructed of PVC with two stainless steel electrodes at the tube ends, a temperature sensor to track temperature, an ampere recording screen, a voltage power converter, and a domestic power supply (220V, 60Hz) are all included. Figure (2) shows the actual designed and constructed batch type ohmic heat equipment.

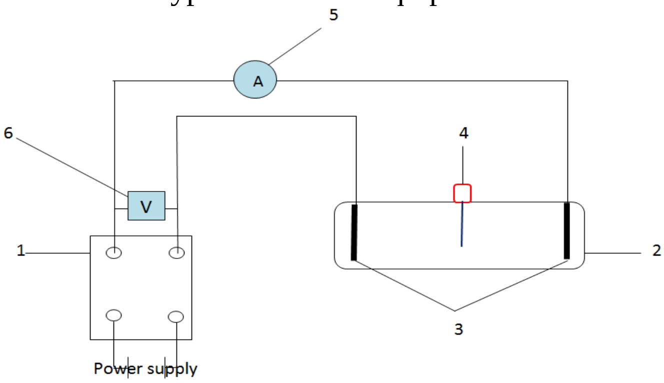

Figure (1): The ohmic heating experimental setup on a laboratory scale.1, power supply; 2, Ohmic heating tube; 3, electrodes; 4, thermometer; 5, Ampere digital monitor; 6, voltage converter.

Figure (2): Batch type ohmic heating device

In the conventional approach, milk is heated in a water bath for 15 seconds at 72°C, however in the ohmic heating method, milk is heated in an ohmic heating chamber with given voltage gradients (6.08 V/cm, 9.56 V/cm, and 19.13 V/cm) to attain 72°C temperature.. The electrical characteristics of milk samples subjected to various voltage gradients were determined.

Determination of Ohmic heating parameters:

Electrical conductivity,

The ability of a material to allow the passage of an electric charge or its capability to effectively flow electric current through it in ohmic heating is known as its electrical conductivity (σ) (Sakr and Liu, 2014). Voltage and current measurements were used to calculate the electrical conductivity (S/m) of the samples. To determine sample electrical conductivities from voltage and current measurements, apply the equation shown below (Wang and Sastry, 1993):

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

I is the electrical current (Amp), A is the cross sectional area of the ohmic tube (m^2), σ is the electrical conductivity (S/m), L is the length of the ohmic heating tube (m), V is the voltage value (V). The following equation can be used to estimate the contact area (Darvishi *et al.*, 2012):

$$A = \frac{m}{\rho L}$$

Where L is the distance between electrodes, A is the contact area (m^2), m is the sample mass (kg), and ρ is the density (kg/m3) (m).

Ohmic heating power,

The ohmic heating power (P) can be calculated using current (I) and voltage (V) measurements taken throughout the heating duration (t). The equation below can be used to determine the ohmic heating power (Icier and Ilicali, 2005a).

$$P = V\,I\,t$$

System performance coefficient (SPC),

When electricity is carried through a material to be heated, it produces sensible heat, allowing the substance's temperature to rise from its beginning temperature (T_i) to its final temperature (T_f). As a result, the equation below can be used to compute the quantity of heat provided (Q) to the system (Icier and Ilicali, 2005b).

$Q = m\, C_p\, (T_f - T_i)$

To determine the specific heat of milk, Dickerson (1969) utilized an empirical formula:

C_p (kJ/kg. °C) = 1.676 + 0.025 X

X = moisture content (%)

The SPC of ohmic heating was defined as the ratio of energy given to the system to energy absorbed by the orange juice (Icier and Ilicali, 2004).

$$SPC = \frac{\text{Energy consumed by heat the sample}}{\text{energy given to the system}}$$

$$SPC = \frac{m\, C_P\, (T_f - T_i)}{V\, I\, t}$$

Heating rate,

$$\text{Heating rate} = \frac{\text{Temperature (°C)}}{\text{Time (minute)}}$$

The final results were determined by averaging the three test results for each sample.

The data was evaluated using the Duncan Test among the treatments in a Complete Randomized Design (Anonymous, 2002).

RESULTS AND DISCUSION

The Department of Food Sciences, College of Agriculture and Forestry, University of Mosul, Iraq, designed and built an ohmic heating device for pasteurizing cow's milk for this research project, using voltage gradients of 6.08, 9.56, and 19.13 V/cm. The relationship between the ohmic heating time of milk samples and pasteurization at voltage gradients (6.08, 9.56, and 19.13 V/cm) in comparison with the usual heating time (72°C/15s) is shown in Figure (3). The batch ohmic heating system used in this experiment showed non-linear and non-exponential heating curves at a constant voltage gradient, and Kong *et al.* (2008) demonstrated that the non-uniform electric field and heat loss due to leakage from an ohmic heating device. Another reason that can lead to the non-linear curve of ohmic heating is due to deposits that may form on the heating surfaces (i.e. the electrodes), which affects the reduction of heat transfer rates, which negatively affects the heat transfer rate (Novy and Zitn 2004; Al-Hilphy *et al.*, 2012). Figure 3 demonstrates that the temperature rose when Ohmic heating was applied with various voltage gradients (6.08, 9.56, and 19.13 V/cm), which led to a considerable reduction ($p \leq 0.05$) in the heating time, which was 18:10, 19:58, and 3:59 minutes, respectively, in compared to conventional heating (16:58 minutes).

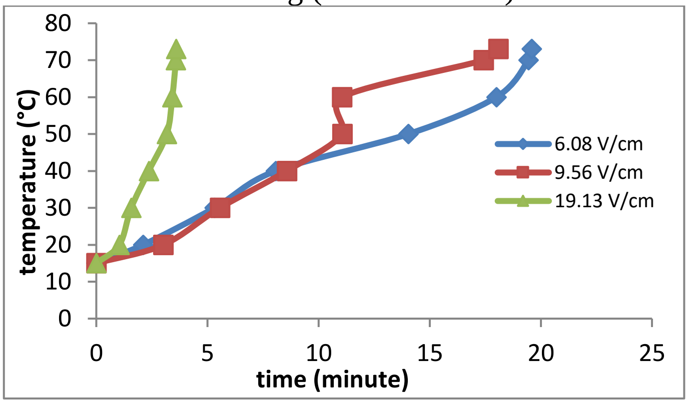

Figure (3): Relation between time and temperature of ohmically heated whole cow's milk

As a result, the application of the greatest voltage gradient (19.13 V/cm) produced the quickest time to pasteurization of milk when compared to alternative treatments for ohmic heating and conventional heating (3:59 minutes). The time required to ohmic heat the samples was influenced by the current that passed through the samples when they were exposed to different voltage gradients (Ahmad *et al*., 2022).

Higher voltage gradients caused the current flowing through the sample to be higher, which accelerated the production of heat. The findings revealed that as time passes, the temperature of the samples rises until the milk pasteurization temperature is attained (72°C/15s). When applying voltage gradients of 6.08 and 9.56 V/cm, the electric current increased significantly ($p \leq 0.05$) to 1.89 and 1.25 amp, respectively, to achieve pasteurization of milk (72°C/15s). When the voltage gradient is increased to 19.13 volts V/cm, the current value drops to 3.04 amp (Figure 4).

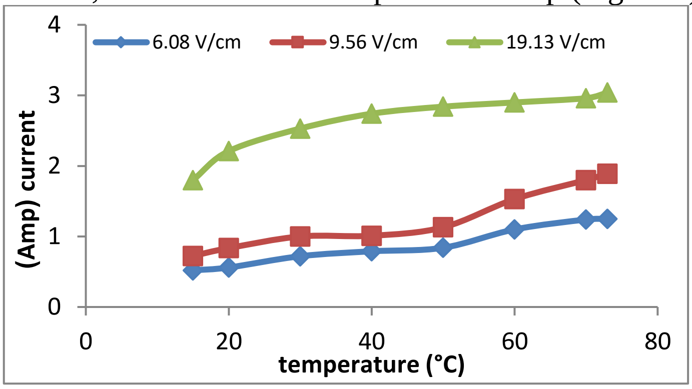

Figure (4): Temperature versus current as affected by different voltage gradients

Icier and Ilical (2005a) claim that the strength of the electric current resulting from a change in the voltage gradient that is transmitted by ohmic heating materials determines how much heat is produced. Because the changes in the electric current were demonstrated to be considerable when the electrical conductivity varied, the liquid and solid foodstuffs are heated simultaneously by turning the electric current in ohmic heating into direct electrical resistance heating (Figure 5).

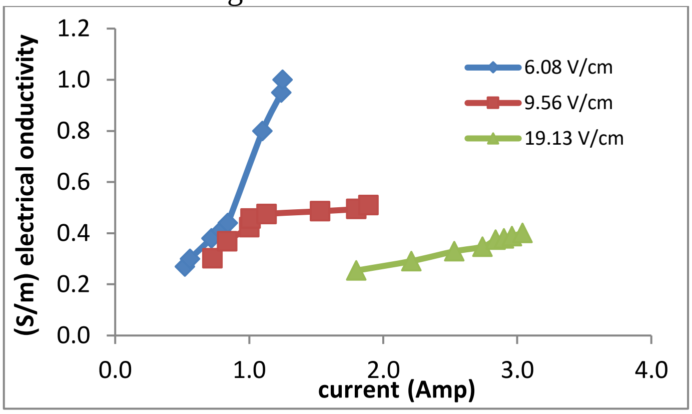

Figure (5): Current and electrical conductivity changes due to different voltage gradients application

The electric current passed through the sample increased (from 1.89 amperes to 3.04 amp) at the rate of high voltage gradients used (from 6.08 volts/cm to 19.13 V/cm) to reach the pasteurization temperature (72°C). The change in electric current during ohmic heating of liquid materials is only dependent on the electrical conductivity when the voltage is constant (Kong *et al.*, 2008). According to Darvishi *et al.* (2012), electrical conductivity significantly decreased ($p \leq 0.05$) as the electric field strength increased. This conclusion was verified by Al-Hilphy (2017), who found that when the electric field was increased, the electrical conductivity fell dramatically. When utilizing the voltage gradient (6.08 V/cm), the average maximum electrical conductivity was (0.996 S/m), and the average electric current required to achieve pasteurization of milk was (1.89 amp), while the electrical conductivity declined by an average of (0.401 S/m), then the value of the electric current needed to reach pasteurization of milk was (3.04 amp). It is shown known that when the voltage gradient increases, the electrical conductivity decreases (Meshaan and Khalil, 2022).

The electrical conductivity of the food, the type of food flow through the system, and the rate of heat generation in the ohmic heating system all affect how well the process works (Leizerson and Shimoni, 2005). According to Nistor *et al.* (2013), the maximum electrical conductivity values were between 1.07 and 1.09 S/m.

With increasing voltage gradients (6.08, 9.56, and 19.13 V/cm), ohmic heating caused a substantial rise ($p \leq 0.05$) in SPC values (figure 6), which were 31.5 %, 49.54 %, and 55.56 %, respectively. These results corroborated those of Cokgezme *et al.* (2017), who found that pomegranate juice's electrical energy use increased considerably ($p \leq 0.05$) as the electric field strength increased at different voltage gradients. The performance factor of the system was determined to be (43.09-90.69 %) in a research of pasteurization of cow's milk by ohmic heating, which fluctuates in the percentage of fat at a rate of (3-6 %) using an average voltage (30-50 volts) (Amitabh *et al*., 2019), i.e. raising the milk fat content and increasing the applied voltage via ohmic heating, the system performance coefficient rose. However, the rise in the system performance coefficient could be attributed to an increase in the specific heat of milk with a high fat content. Ohmic heating provided a significant increase in the system performance coefficient as voltage gradients increased.

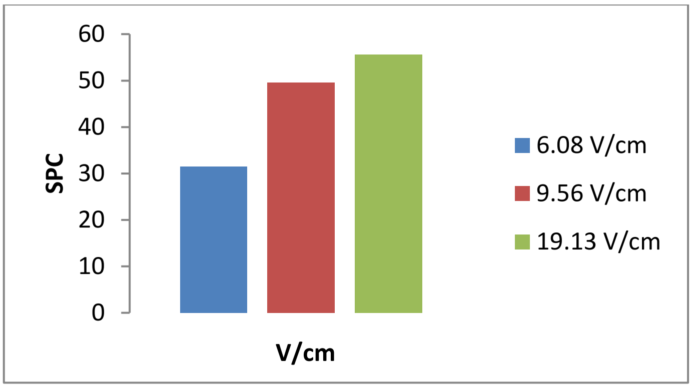

Figure (6): SPC at different voltage gradients

The findings demonstrated that the temperature of the milk samples always rose to the pasteurization temperature (72°C) over time and that the heating rate fell until the temperature essentially remained constant (Figure 7). With the increasing of voltage gradients (6.08, 9.56, and 19.13 V/cm), the heating rate rose significantly ($p \leq 0.05$).

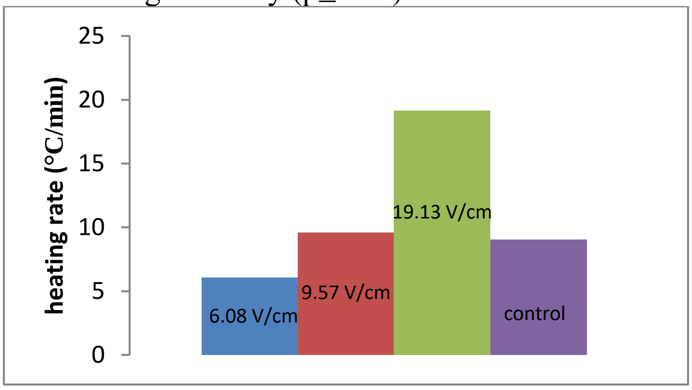

Figure (7): Heating rate at different voltage gradients

With a voltage gradient of 19.13 V/cm, the heating rate was significantly higher (20 °C/min), compared to smaller voltage gradients (6.08 and 9.56 V/cm), which produced heating rates of 3.97 and 3.67 °C/min, respectively. In comparison to the ohmic heating method, traditional pasteurization of milk resulted in a 4.32 °C/min drop in heating rate. This increase in voltage heating rate is consistent with Abdulstar *et al.* (2020), who showed that increasing the voltage increased the heating rate significantly ($p \leq 0.05$).

CONCLUSION

The proposed ohmic heating laboratory model performed successfully, making it straightforward, user-friendly, and secure to use when combined with digital measurement accessories such a thermocouple, ammeter, and voltmeter. The experimental ohmic heating units performed admirably. The strength of the electric current formed by a change in the voltage gradient conveyed by ohmic heating materials is related to the amount of heat generated in milk pasteurization by ohmic heating. The use of the highest voltage gradient (19.13 V/cm) produced the quickest pasteurization of milk when compared to the other used voltage gradients and conventional pasteurization. The temperature of the milk samples always increased to the pasteurization temperature (72°C) with time, and the heating rate dropped until the temperature became relatively stable, according to the findings.

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الصفات الكهربائية للحليب البقري المعرض للتسخين الاومي

ريان نضال مشعان **ثامر عبد القادر خليل**

قسم علوم الاغذية / كلية الزراعة والغابات / جامعة الموصل - العراق

الكلمات المفتاحية:
الحليب البقري, التدرج, الموصلية, التسخين الاومي, معدل التسخين.

الخلاصة

تعد تقنيات البسترة والتعقيم البديلة ، مثل الطاقة الكهربائية، ذات أهمية علمية وصناعية كبيرة في الوقت الحاضر. تم تصميم وتصنيع منظومة التسخين الاومي على دفعات لاستخدامها في هذه الدراسة لبسترة الحليب البقري. من خلال عملية بسترة الحليب بالتسخين الاومي تم دراسة الصفات الكهربائية للحليب التي تحدث خلال العملية ومقارنتها مع الطريقة التقليدية السريعة في بسترة الحليب (72 °م/15 ثانية). زادت درجة الحرارة عند تطبيق التسخين الأومي على عينات الحليب بتدرجات جهد مختلفة (6.08 و 9.56 و 19.13 فولت/سم)، حيث أدى إلى انخفاض معنوي ($p≤0.05$) في وقت التسخين للوصول الى درجة حرارة البسترة. في تدرجات الجهد العالي، ازدادت قيمة التيار الكهربائي خلال عينة الحليب, مما ساعد في سرعة ارتفاع درجة حرارتها. عند ثبات الجهدد الكهربائي, فإن التغيير في التيار الكهربائي أثناء التسخين الأومي للحليب يعتمد على الموصلية الكهربائية. تسبب التسخين الأومي في زيادة ملحوظة ($p≤0.05$) في قيم معامل أداء النظام (SPC) مع زيادة تدرجات الجهد ، مما أدى إلى زيادة في معدلات التسخين (درجة مئوية / دقيقة).