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ELECTRICAL CONDUCTIVITY APPLICATION IN OHMIC PASTEURIZATION OF ORANGE JUICE

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ABSTRACT

The conversion of electrical energy into heat energy, which results in internal energy generation, is the underlying premise of Ohmic heating. An experimental batch Ohmic heating unit was built and manufactured for this study. The effect of voltage gradient of alternating current during batch Ohmic heating on orange juice was investigated. Parameters such as temperature, electrical current, time consumption, system performance coefficient, and heating rate of orange juice under Ohmic heating process were studied. The time consumption such as (23.02, 11.25, and 2.19 minutes) to reach the Ohmic pasteurization temperature (95 °C) was decreased as the voltage gradients (9.20 V/cm, 12.64 V/cm, and 25.28 V/cm) increased respectively. The electrical current was rapidly increased (4.46 Amp.) in accordance with the higher voltage gradient (25.28 V/cm) to attain the pasteurization temperature. With rising voltage gradients, Ohmic heating resulted in greater system performance coefficient values. The heating rate appears to have grown dramatically as the voltage gradients increased.

INTRODUCTION

The most common heating techniques for liquids and slurries are based on heat transfer and conduction from a hot surface, such as a hot pasteurizer, through a heated medium, usually steam. The disadvantages of this heating method are the thermal deterioration of some products or their combustion on hot surfaces which negatively affects the quality of the product as well as a decrease heat transfer rates, poor heating efficiency and frequent cleaning requirements due to contamination of the surfaces of some products and the need for mechanical agitation to obtain the required level of heat transfer and uniformity to avoid severe damage to the physical structure of the product.(Maloney and Harrison, 2016).

Pasteurization, sterilization, drying, and evaporation are common industrial thermal processes for ensuring microbiological safety in the food sector. (Kurian and Raghavan, 2020). These procedures inflict serious damage to food constituents, particularly vitamins and phenols, which are heat-sensitive and linked to food quality. (Zhang *et al*., 2018). Consumers seek healthier foods with fresh attributes and longer shelf life, therefore researchers have devised a variety of approaches to improve food quality and safety (Pratap-Singh *et al*., 2017). Ohmic heating was shown to be one of the most cost-effective options for the food business, as it relies solely on electrical energy (Tian *et al*., 2018). Ohmic heating preserves the food's nutritional components while causing fewer alterations in its sensory properties (Zhang *et al*., 2018).

Ohmic heating, which employs joule heating, generates heat directly within the foodstuff by passing an electric current through it as an electrical conductor, raising the temperature of the food (Gavahian *et al*., 2020; Makroo *et al*., 2020). Many liquid food products and liquid-solid mixes can be cured quickly using Ohmic heating (Lee *et al*., 2013). The efficiency of Ohmic heating is influenced by both external (e.g., electric field and frequency) and internal elements (e.g., pH and glycemic content of food) (Kim *et al*., 2019). All areas of the food are subjected to the same temperature rise, which prevents the food's surface temperature from rising and keeps its organoleptic qualities (Leizerson and Shimoni, 2005). According to several research works, samples treated with Ohmic heating had a storage life that was comparable to or greater than samples treated with conventional heating (Cho *et al*., 2016).

In Ohmic heating, the electrical conductivity of a liquid food product is an important characteristic. Temperature, applied voltage gradient, frequency, and electrolyte content are all things to think about (Icier and Ilicali, 2005a). The temperature dependence of electrical conductivity liquid products follows linear or quadratic relationships, depending on the product type studied (Amiali *et al*., 2006). Ohmic heating's electric field can cause a number of changes in food quality and biological processes, such as enzyme and microbe inhibition, heat-sensitive chemical breakdown, changes in cell membranes, viscosity, pH, color, and rheological characteristics (Kaur *et al*., 2016).

Electrical, thermophysical, and rheological aspects of food all play a role in uniform heating. It's critical to underline the importance of potential electrochemical processes at the food-electrode contact surface, as well as non-thermal electric field effects that are affected by treatment settings (Jaeger *et al*., 2016). Despite the fact that food products were treated at high temperatures to ensure their microbiological safety, thermal damage occurred, resulting in changes in flavor, texture, taste, and nutrient content. As a result, a new study has found that improved thermal treatment processes are crucial in preventing food degradation and eliminating microbes including bacterial cells and spores (Mercali *et al*., 2015). Ohmic heating can inactivate bacteria not only by heating them but also by the non-thermal activities of the electrical current (Murashita, 2018). Bacterial count is one of the most basic and often used ways for determining a food's microbiological stability. The effect of Ohmic heating on the total number of bacteria in juices, fruits, milk, and seafood has been studied in several research works (Makroo *et al*, 2020). The rupture of the microbial cell membrane, which results in the electroporation of cell contents, is the mechanical effect of Ohmic heating (Lyng *et al*., 2018). Bacteria, yeasts, and molds were completely inactivated when they were heated using the Ohmic method with orange juice (Leizerson and Shimoni, 2005). Electrical conductivity has long been linked to processing variables such as temperature, soluble solid concentration, applied voltage, and so on, according to many researchers. Specific conductance, or electrical conductivity, is a property of food materials that influences how well they conduct electricity.

The unit of measurement for electrical conductivity is the Siemens per meter (S/m) (Sakr and Liu, 2014). The most often utilized frequencies for Ohmic heating of foods are 50 Hz and 60 Hz (Kolbe *et al*., 2001). One of the disadvantages of low alternating current frequency in Ohmic heating is that electrolytic reactions at the electrode surface might produce product burning and electrode corrosion (Goullieux and Pain, 2005). Cappato *et al*. (2018) found that utilizing a low-frequency electric field (10 Hz) generated the greatest ascorbic acid degradation and an increase in color changes due to electrochemical reactions, while interactions at (100 Hz) caused less. As a result, high electric field frequencies had no influence on ascorbic acid dissociation, indicating that rapid changes in electric field values had no effect on the ascorbic acid oxidation reaction.

Several investigations have looked at the impact of Ohmic heating on bioactive component content, phenolic content, and antioxidant activity in various food items. Abedelmaksoud *et al*. (2018) looked at how a 60 Hz electrical frequency affected phenolic and ascorbic components in apple juice at different electrical fields (30-40 V/cm) and temperatures (60-80 °C). As a result, when compared to fresh apple juice, the total extracted phenolic content was increased with Ohmic heating compared with the conventional technique, while the loss of ascorbic acid and carotenoids was lower in the Ohmic treated sample. Vitamin C was dramatically reduced during Ohmic heating compared to conventional heating, according to a study employing an Ohmic process for *Aloe vera* juice with varied electrical fields (30-55 V/cm) and temperatures (20-85 °C) at 60 Hz (Saberian *et al*., 2015).

The purpose of this research was to develop, produce, and test a static lab-scale Ohmic heating system. With various alternating current voltage settings, the ability of this self-designed setup to pasteurize orange juice was tested.

MATERIALS AND METHODS

Orange juice sampling preparation:

Fresh oranges were acquired in Mosul, Iraq, from a local store and maintained at 4°C until the trials were completed in one day. The oranges were hand-pressed using a plastic bowl juicer after being rinsed under running water. A muslin cloth was used to filter the juice, which allowed gravity to flow through it.

Ohmic heating apparatus:

The static Ohmic heating experimental setup (Fig. 1) was devised and built for this work in the Food Science Department, College of Agriculture and Forestry, University of Mosul, Iraq. It comprises an alternating current (AC) locally power supply with a frequency of 60 Hz, Ohmic heating tube of (6.4 cm diameter, 10 cm length, and 4 mm thickness) constructed of PVC with two stainless steel electrode rods of (5 mm diameter, and 5 cm length) at the tube's ends, a thermocouple to monitor temperature, ampere recording screen, and a voltage transformer. Figure 2 illustrates the real Ohmic heating device used in this research.

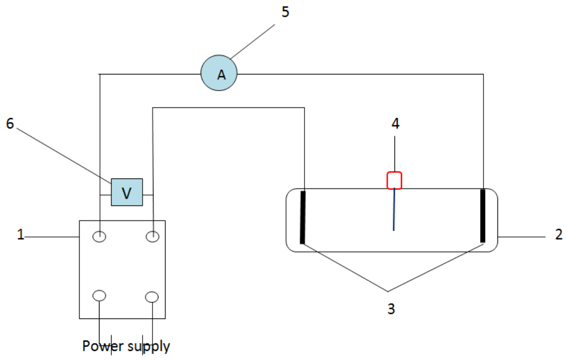

Figure 1: The scale in the laboratory Experimental system for ohmic heating. 1, Ohmic heating tube; 2, electrodes; 4, thermocouple; 5, Ampere digital screen; 6, Voltage transformer.

Figure 2: Manufactured batch Ohmic heating apparatus Ohmic heating of the orange juice.

The performance of the Ohmic heating unit was evaluated using batch studies. To continuously monitor sample temperature, the thermometer was inserted and fixed into the geometric center of the Ohmic heating tube. 300 mL of samples were placed into the Ohmic heating tube. All of the Ohmic heating studies began at room temperature (25°C±2). Using various output voltage gradients (9.20, 12.64, and 25.29 V/cm) , the orange juice samples were heated to pasteurization temperature (95 °C/15 s). At 10 °C intervals, the current (Ampere) and time (minute) were recorded. The outcomes of different voltage treatments of orange juice were compared to the results of conventional pasteurization of orange juice. The time consumed by various voltage gradients was compared to the time required for conventional pasteurization of orange juice (95/15 s) which was conducted in water bath.

Determination of Ohmic heating characteristics:

Electrical conductivity,

Electrical conductivity (σ) is a measurement of a material's ability to accommodate the passage of an electric charge or its capacity to efficiently flow electric current through it in Ohmic heating (Sakr and Liu, 2014). Voltage and current data were used to determine the electrical conductivity (S/m) of samples. It was calculated by using the following equation (Palaniappan and Sastry, 1991):

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

A is the cross-sectional area of the electrodes (m^2), I is the current (Amp), V is the voltage, L is the distance between electrodes (m).

Power of Ohmic heating,

The Ohmic heating power (P) can be calculated using current (I) and voltage (V) measurements taken throughout the heating duration (t). It can be calculated using the equation below (Icier and Ilicali, 2005b).

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

performance coefficient (SPC),

When an electricity is passed through a material to be heated, it creates sensible heat, which allows the temperature of the material to rise from the starting temperature (T_i) to the ending temperature (T_f). As a result, the amount of heat supplied (Q) to the system can be calculated using the equation below (Icier and Ilicali, 2005a).

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

The specific heat of the orange juice was determined through the empirical formula (Dickerson, 1969):

Cp (kJ/kg. °C) = 1.676 + 0.025 X

X = moisture content (%)

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

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

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

Heating rate,

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

All the samples were determined three times and the final results are the average of these.

Statistical analysis,

The data was analyzed according to Complete Randomized Design using Duncan Test among the treatments.

RESULTS AND DISCUSSION

The recommended laboratory model of Ohmic heating performed well when used with aqueous materials (eg. orange juice). With this setup, orange juice could be heated from 20 to 95 °C utilizing voltage gradients of 9.20 to 25.28 V/cm. Digital measuring attachments such as a thermometer, ammeter, and voltmeter make it simple, easy to handle, and safe to use. Ohmic heating is one of the fastest-growing technologies in the food sector. It permits the creation of new, high-value, shelf-stable, and higher-quality products.

The Ohmic heating time curves for pasteurization of orange juice samples (95 °C/15 s) under different voltage gradient processing and conventional procedure (control) are presented in figure (3).

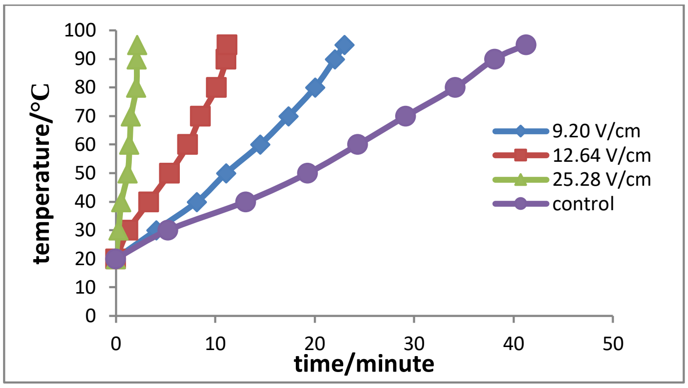

Figure 3: Curves of Ohmic heating time versus temperature of orange juice at different voltage gradients (9.20, 12.64, 25.28 V/cm).

Under a constant voltage gradient, non-linear and non-exponential heating curves were seen in the batch Ohmic heating system. Kong *et al*. (2008) reinforced this point, speculating that nonuniform electrical fields and heat dissipation may have caused nonlinear heating curves. Fouling of the heating surfaces (i.e. electrodes) can also cause this, lowering heat transfer rates and negatively influencing non-linear temperature-time curves (Novy and Zitny, 2004). The temperature was gradually increased ($p \leq 0.05$) over time in voltage gradients of 9.20 and 12.64 V/cm, taking 23.02 and 11.25 minutes, respectively, to reach the pasteurization temperature (95 °C). However, in order to attain pasteurization using 25.28 V/cm, the temperature was rapidly increased over a shorter period of time (2.19 minutes). It is also self-evident that when the voltage gradient is higher, the heating is more efficient and quick (Lima, 2007). Nevertheless, the time required for traditional pasteurization (43.33 minutes) was longer than the time used for Ohmic heated samples.

When various voltage gradients were applied to Ohmic heated samples of orange juice, the current, as well as the temperature, rose over time (Fig. 4).

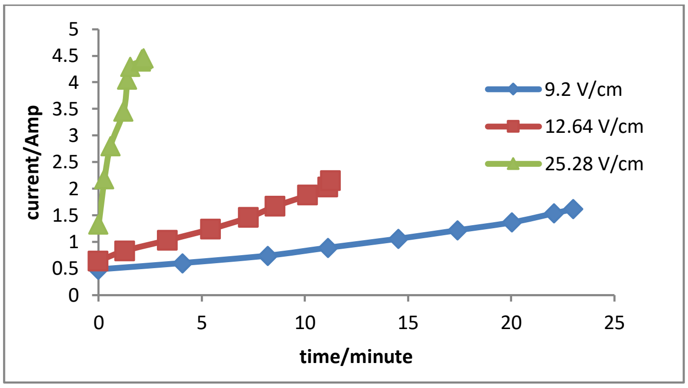

Figure 4: time and current profiles as affected by different voltage gradients (9.20, 12.64, 25.28 V/cm).

The produced currents of 1.62 and 2.15 Amp were induced when voltage gradients of 9.20 and 12.64 V/cm were used to reach the pasteurization temperature (95 °C) of orange juice samples respectively. To achieve the pasteurization temperature, the current was raised rapidly (4.46 Amp.) in accordance with the larger voltage gradient (25.28 V/cm). 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 samples. According to Icier and Ilicali (2005b), the amount of heat created is proportional to the current induced by the voltage gradient in the field and the electrical conductivity of the materials to be heated.

The sample's electrical conductivity increased over time. The electrical conductivity of the sample increased (0.15-0.55 S/m) when the voltage gradient increased from 9.20 to 25.28 V/cm ($p \leq 0.05$) (Fig. 5).

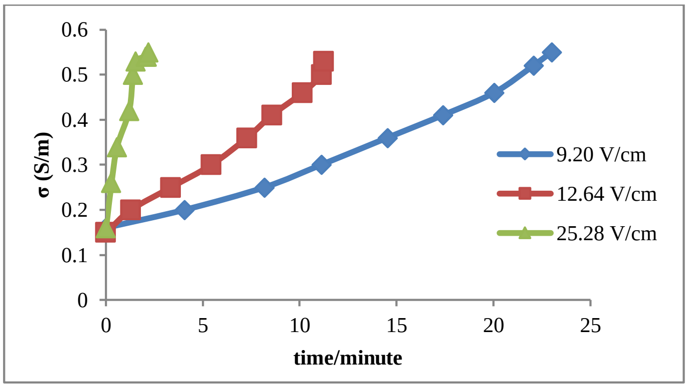

Figure 5: Electrical conductivity depending on-time processing according to voltage gradients (9.20, 12.64, 25.28 V/cm).

The voltage gradient has a significant effect on heating time ($p \leq 0.05$). Figure (5) shows that the slope obtained for the 25.28 V/cm data has a higher inclination angle than the other two slopes for 9.20 and 12.64 V/cm, which could indicate that the processing time is shorter in this case and that the temperature increase is exponential in comparison. As the electrical conductivity values increased (0.15-0.55 S/m), the heating time to reach the target temperature (95 °C) decreased significantly ($p \leq 0.05$). When employing different voltage gradient values (9.20, 12.64, and 25.28 V/cm), the time necessary to attain the pasteurization temperature varied greatly. As a result, setting the pasteurization temperature for orange juice took 23.02, 11.25, and 2.19 minutes, respectively, using voltage gradients of 9.20, 12.28, and 25.28 V/cm. Darvishi *et al*. (2012) discovered that electrical conductivity has a substantial impact on the duration of Ohmic heating of food using five different voltage gradients (6–14 V/cm) while heating tomato using Ohmic heating at five different voltage gradients (6–14 V/cm). Kong *et al*. (2008) found that the voltage gradient had a substantial impact on the Ohmic heating time for all four materials evaluated when they used different voltage gradients to explore the heating behavior of liquid food items (tap water, fruit-vegetable juice, and yogurt).

Food liquids and solids are heated simultaneously by sending an electric current through them in Ohmic heating (direct resistance heating). Changes in current profiles were shown to be considerable ($p \leq 0.05$) when electrical conductivity was changed, and current levels had a roughly linear connection with electrical conductivity values (Fig. 6). The current traveling through the sample was higher (1.62-4.46) at higher voltage gradients (9.20-25.28) to attain the pasteurization temperature (95 °C), which induced heat generation faster. As the voltage gradients were raised, the current grew ($p \leq 0.05$) and then remained increasingly steady. While the voltage is kept constant during Ohmic heating of liquid materials, Kong *et al*.

(2008) discovered that the current flow fluctuations are solely dependent on the electrical conductivity. As a result, the electrical conductivity and current relationships are shown in figure (6) depicted the electrical conductivity change of orange juice samples as a function of current during Ohmic heating. The maximum electrical conductivity values are between 0.53 and 0.55 S/m, however, the current required to reach them is between 2.15 and 4.46 Amp.

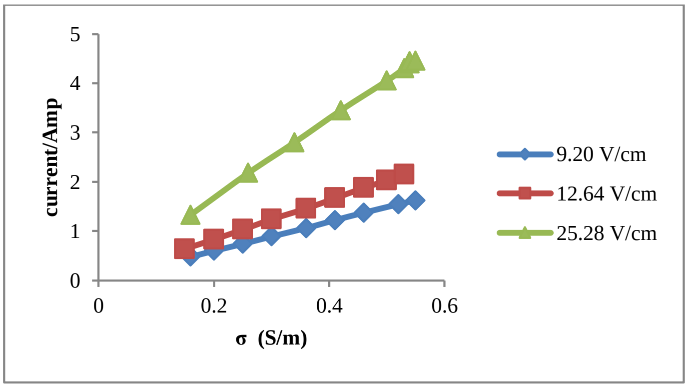

Figure 6: current profile changes with increasing electrical conductivity at different voltage gradients.

At varied voltage gradients (9.20, 12.64, and 25.28 V/cm), Figure (7) displays the SPC of the constructed Ohmic heating device. Ohmic heating induced higher SPC values with increasing the voltage gradients. At voltage gradients of 9.20, 12.64, and 25.28 V/cm, the SPC vales were 50 %, 57 %, and 76 % respectively. This finding was in line with that of Cokgezme *et al*. (2017), who discovered that the power consumption of pomegranate juice rose considerably (p 0.05) as the electric field intensity increased at voltage gradients of 7.5, 10, and 12.5 V/cm. Further study by Al-Hilphy *et al*. (2012) on Ohmic heating milk, showed that SPC was increased as voltage gradient increased.

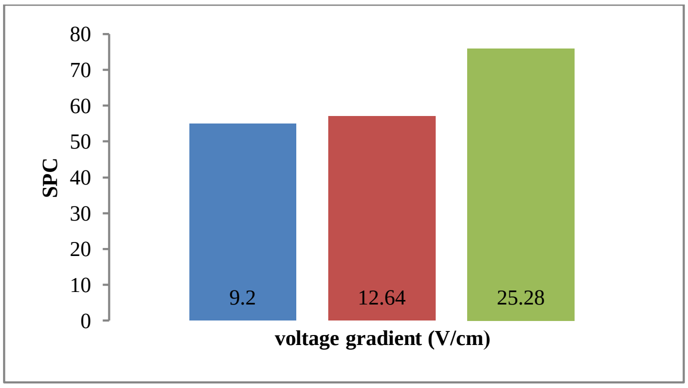

Figure 7: SPC of the manufactured Ohmic heating device at different voltage gradients.

Figure (8) shows the effect of several voltage gradients (9.20, 12.64, and 25.28 V/cm) on the heating rate (°C/minute) of pasteurized orange juice samples (8).

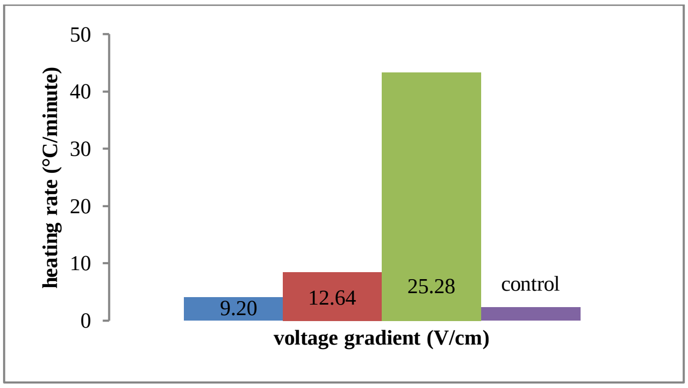

Figure 8: The heating rate at different voltage gradients.

The heating rate appears to have grown dramatically as the voltage gradients increased. The application of a voltage gradient of 25.28 V/cm, on the other hand, resulted in a substantial rise in the heating rate (43.38). Other voltage gradients (9.20 and 12.64 V/cm) were found to be less than the latter one, with values of 4.13 and 8.44, respectively. Nonetheless, when compared to Ohmic heated samples, conventional pasteurization of orange juice resulted in the lowest heat rate (2.30). This increase in heating rate with voltage matched the findings of Abdulstar *et al*. (2020), who showed that the heating rate increased significantly ($p \leq 0.05$) when the voltage was raised.

CONCLUSION

The designed Ohmic heating laboratory model performed well when combined with digital measuring accessories such as thermocouple, ammeter, and voltmeter, making it simple, easy to handle, and safe to use. The experimental Ohmic heating units showed a good performance. The orange juice samples could be successfully heated at 95 °C from room temperature. When the voltage gradient is high, Ohmic heating processing takes less time and the temperature rises faster in direct proportion to the electrical conductivity values. Using larger voltage gradients, the time it took to attain the pasteurization temperature of orange juice (95 °C) was lowered. With increasing voltage gradient, the SPC rose correspondingly. When the voltage gradient rose, however, the utilized power decreased significantly.

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CONFLICT TO INTEREST

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

تطبيقات للموصلية الكهربائية في البسترة الأومية لعصير البرتقال

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الخلاصة

المبدأ الأساسي للتسخين الأومي هو تحويل الطاقة الكهربائية إلى طاقة حرارية، مما يؤدي إلى توليد الطاقة الداخلية في المادة الغذائية. في هذه الدراسة، تم تصميم وتصنيع وحدة تسخين أومية تجريبية عل دفعات. تم دراسة تأثير تدرج الجهد Voltage gradients للتيار المتردد أثناء التسخين الأومي على عصير البرتقال. من خلال عملية التسخين الأومي تم قياس درجة الحرارة والتيار واستهلاك الوقت ومعامل أداء النظام ومعدل تسخين لعصير البرتقال تحت عملية التسخين الأومية. كان الوقت المستغرق هو (23.02 و11.25 و2.19 دقيقة) للوصول إلى درجة حرارة البسترة الأومية (95 درجة مئوية) عند زيادة التدرج في الجهد قدره (9.20 فولت/سم و12.64 فولت/سم و25.28 فولت/سم) على التوالي. لقد ازدادت قيمة التيار الى (4.46 أمبير) وفقًا لتدرج الجهد العالي المستعمل (25.28 فولت / سم) للوصول إلى درجة حرارة البسترة. مع ارتفاع انحدار الجهد، أدى التسخين الأومي إلى زيادة قيم معامل أداء النظام. لوحظ أن معدل التسخين قد ازداد بشكل كبير مع زيادة تدرج الجهد.

الكلمات الدالة: الموصلية الكهربائية، عصير البرتقال، تدرج الجهد الكهربائي، درجة الحرارة.

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