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Implementation and Evaluation of an Ohmic Heating System to Produce Curd

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ABSTRACT

In the food industry, different heating processes are used to condense and then prevent the corruption of food. Ohmic heating is one of the new methods in which food materials act as electrical resistances. In the method, two electrodes are used to be in contact with food materials, and electricity is transmitted through them. Curd is one of those products that is obtained from heating doogh. The novelty of the present research is producing crud using ohmic heating. An experimental system system was implemented to do this. Then the effects of voltage and electrode on the final temperature and time duration of the crud production process were investigated. The applied voltages were 60, 70, 80, and 90 V, and two electrode types, stainless steel and brass, were tested. The results showed a significant relationship between time duration process and voltage at a 1% probability level, but not for electrode type. The minimum time duration and energy consumption were obtained by steel electrode with 80 V as 57.83 s and 18.97 kJ, respectively.

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INTRODUCTION

The growing population of the world shows the importance of food and also food treatment process. In addition, agricultural products are always subjected to corruption due to chemical reactions so that it is not possible to maintain them without considering the proper conditions and processing. To increase the food stability by reducing the water activity of foods, condensation, drying, and juicing of agricultural products are important processes in the food industry which increase the food (Hosainpour et al., 2022).

Milk is one on the main agricultural products that provide nutrition (Sharifi et al., 2023). Milk products, also is called as dairy products, and are the products fermented by lactic acid bacteria such as lactobacilli, lactococcus and leuconostoc. This fermentation process increases the shelf-life of the product as well as the taste and marketability of the products (Tamime et al., 2005). Doogh is one of the fermented milk products that produced by mixing of yogurt with water and salt, or the mixing of milk with water and salt before the heat treatments and fermentation process.

Doogh is one of the traditional Iranian beverages and some other nations in Eastern Europe, the Middle East and Asia. This product is made from dilution of yogurt by water and separating from butter. The nutritional properties of doogh can be attributed to more vitamins and nutrients, calcium absorption and digestibility than milk (Foroughinaia et al., 2007).

Today, different methods based on hybrid, non-reactive, and enzymatic are used to produce high quality foods with consideration of decreasing time duration, energy consumption and costs of the processes. In order to avoid the growth of microbes in transformation products, deactivation of enzymes by applying high temperatures over a very short periods of time are essential step (Darvishi et al., 2013). Dairy products are rich in vitamins, fats and carbohydrates, which are destroyed by various types of chemical and physical microbial decay if appropriate methods aren't used for keeping significant amounts of them. Therefore, manufacturers have invented and implemented various methods in order to preserve the foods and prevent the food corruption such as heating and condensation processes.

Ohmic heating is an advanced temperature process in which foods act as electrical resistances. The laboratory system usually consists of two electrodes that are in contact with food and electrical current is transmitted in the food materials. Compared to conventional heating that heat is transferred from the outside by a hot surface, in ohmic heating the heat is uniformly transferred across the food materials. The success of the ohmic heating system depends on the amount and rate of heat transfer in the system and the electrical conductivity of the food materials (Hosseini et al., 2022; Icier & Bozkurt, 2011).

Ohmic heating has various applications such as food drying, fermentation, extraction, sterilization and pretreatment heating before the main heating processes (Kumar et al., 2014). In a study, Rajabizadeh et al. compared the ohmic heating method and conventional treatment for producing pomegranate juice under vacuum and atmosphere condition. They reported that ohmic heating method hadn't effects on the rheological properties and color of pomegranate juice and they recommended ohmic heating as an alternative method (Rajabizadeh et al., 2014).

Compared to other common methods, the ohmic heating is faster and more uniform process that has higher efficiency and causes to preserve more nutritional values of the foods (Icier & Ilicali, 2005c; Nolsøe & Undeland, 2009; Vikram et al., 2005). Electrical characteristics such as electrical conductivity, field gradient and voltage play important roles in the ohmic heating process. For these, the foods with high amounts of water and ionic salts are most suitable to be heated by ohmic method (Palaniappan & Sastry, 1991). In the heating process, the electrical conductivity is the most important parameter that depends on temperature, voltage gradient, frequency and electrolyte concentration (Castro et al., 2003; Icier & Ilicali, 2005a, 2005b; Sastry & Palaniappan, 1992). Castro et al. reported that the

relationship between electrical conductivity and temperature based on the food materials maybe linear or quadratic (Castro et al., 2003).

In the literature, ohmic heating was not reported to be applied in curd production. So, the novelty of the present research is production of curd using ohmic heating. Therefore, the aim of the present research was to implement and evaluate an ohmic system to heat doogh and produce curd. Also the effects of voltage and electrode on the process have been investigated.

MATERIALS AND METHODS

The study was conducted in the Mechanical Engineering of Biosystems Department, Ilam University, Ilam, Iran.

Implementation of the system

The experimental ohmic system included heating cell, electrodes, a voltage regulator and electrical conjunctions (wires). The heating cell was a hollow cylinder with inner diameter of 100 mm and length of 400 mm made from Teflon. A hole with a diameter of 20 mm was created on the cell to pure the food material in the cell and also to place the thermometer probe inside the food. TM-903A Thermometer was used to measure the food temperature inside the heating cell. The voltage regulator (Emersan Co., Tehran, Iran) was used to change the applied voltage to study the effects of voltage on the process. Fig. 1 shows the ohmic heating system and heating cell, respectively.

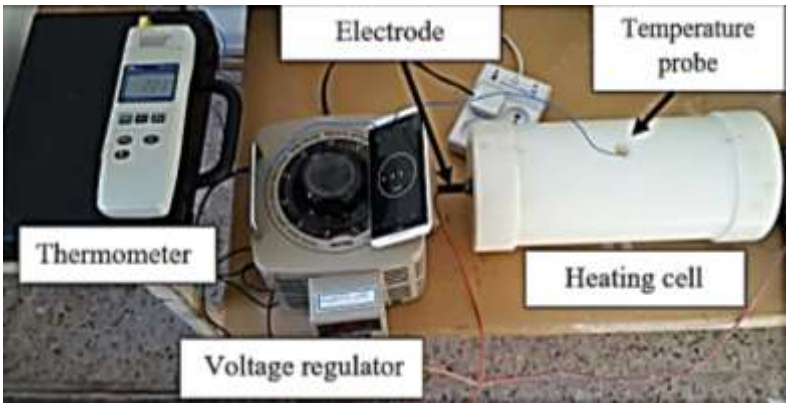

Figure 1. The experimental ohmic system.

Evaluation of the system

Doogh was the based material to produce curd. Local produced doogh from cow milk was purchased from the markets in Ilam City. The doogh was kept at 4 °C in a refrigerator to be used in the experiments.

A factorial experiment was done based on completely randomized design. The main factors were voltage and electrode. Four voltage levels including 60, 70, 80 and 90 V and two levels of electrode factor including stainless steel and brass electrodes were considered in the experiment. So, eight treatments were tested. Each treatment was tested in three replications. Totally, 24 tests were done. The observations were final temperature and time duration of the process.

Table 1. The experimental factors.

Factor	Level			
Voltage (V)	60	70	80	90
Electrode	Stainless steel	Brass		

For each test, the heating cell was filled by 100 cc doogh. After setting the voltage using the voltage regulator, the temperature of doogh inside the cell was increased began to boil until the curd was obtained (Figure 2). The final temperature of the process in each test was measured using the TM-903A Thermometer and the time duration each test was measured using a chronometer.

The obtained data in each test were analyzed considering a factorial experiment based on completely randomized design. To do this, the variance analysis was done using SAS

Software. Also, the compare mean analysis was done using Duncan's' multiple range test in the SAS Software.

Figure 2. The produced curd.

Calculating energy consumption

Energy is the ability of making changes. So, it is an important input in production systems (Kheiralipour & Sheikhi, 2021; Pourmehdi & Kheiralipour, 2024; Ramedani et al., 2019). It is one of the main issues in production processes that must be studied in sustainable production (Kheiralipour & Sheikhi, 2021). Also, energy consumption in production systems must be evaluated because its effects on production cost and environmental impacts (Dekamin et al., 2022; Kheiralipour, Brandão, et al., 2024; Kheiralipour, Khoobbakht, et al., 2024; Kheiralipour, Rafiee, et al., 2024; Kheiralipour & Sheikhi, 2021; Pourmehdi & Kheiralipour, 2023). The energy consumption of the ohmic system was calculated. For that, the consumed power in each test was calculated using Eq. 1.

$$P = RI^2 = \frac{V^2}{R} = VI \quad (1)$$

Where P is electrical power (J/s or W), V is voltage (V), and I is electrical current (A). Then the energy consumption in each test was calculated using Eq. 2. This energy is sum of the useful and lost energy (Icier & Ilicali, 2005b).

$$E=Pt=RI^2t = \frac{V^2}{R}t = VIt \quad (2)$$

RESULTS AND DISCUSSION

Production temperature

The final temperatures of the conducted tests were shown in Figure 3. As seen in Figure 3, in almost all studied voltages in curd production process, the brass electrode caused to reach higher temperatures except for 90 V. The maximum and minimum temperatures were obtained as 90.87 °C by brass electrode with 70 V and 68.80 °C by steel electrode with 80 V, respectively.

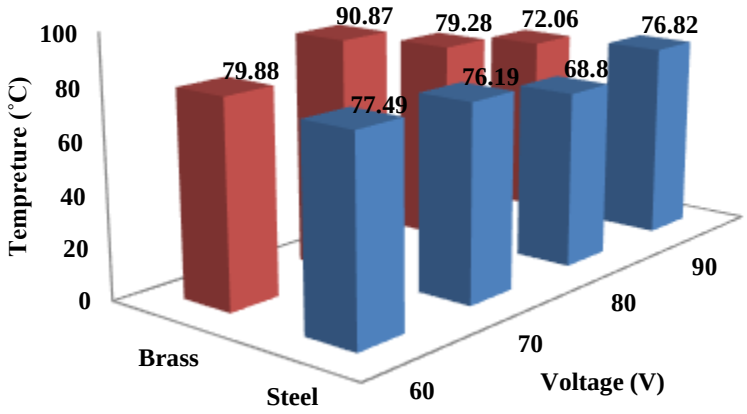

Figure 3. The final temperatures of curd production process.

In Table 2, the results of the variance analysis based on the completely randomized design in order to show the effect of voltage and electrode on the final temperature of the curd production process has been provided. As seen in the table, the effects of voltage and electrode

on the final temperature were statistically insignificant. These results show that the doogh temperature must be reached to a specific value to produce curd in each treatment.

Table 2. The effects of factors on the final temperature in curd production process.

Source of variation	Degree of freedom	Sum of squares	Mean square	Pr > F
Electrode	1	105.85	105.85	0.42
Voltage	3	221.62	73.87	0.67
Electrode×Voltage	3	136.92	45.64	0.80
Error	4	531.41	132.85	-

Production time

The time durations of the conducted tests to produce curd were shown in Fig. 4. In all studied voltages, steel electrode had the lowest time durations of the curd production process for all voltages except for 90 V. The minimum time duration belonged to voltage of 80 V for steel electrode as 57.83 and the maximum time duration was obtained for brass electrode for voltage of 60 V as 186.00 s. By increasing the voltage applied to doogh, the amount of energy converted to thermal energy increases and the doogh is heated faster, resulting in a decrease in the time duration of the process.

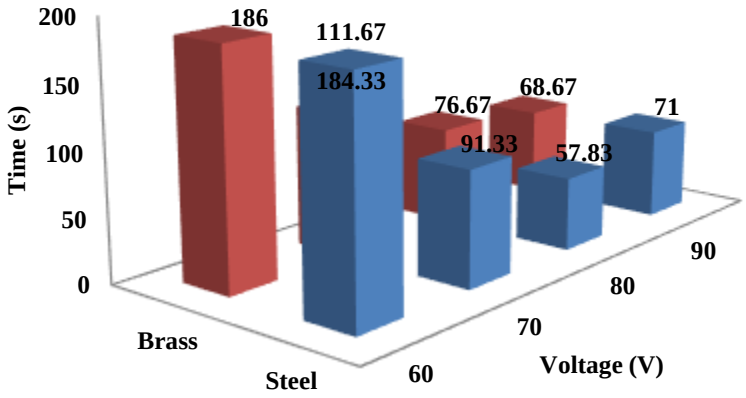

Figure 4. The time durations of the curd production process.

The results of the variance analysis to show the effects of the factors on the time duration of curd production process have been provided in Table 3. According to this table, the effect of voltage on the time duration of the curd production process was statistically significant at 1% probability level. There were no significant effects for electrode and electrode-voltage interaction on the time duration of the process. So, the results of the compare mean analysis for the voltage factor were reported in the next step.

Table 3. The effects of the factors on the time duration of curd production process.

Source of variation	Degree of freedom	Sum of squares	Mean square	Pr > F
Electrode	1	275.52	275.52	0.16595
Voltage	3	34440.04	11480.01	0.0002
Electrode×Voltage	3	347.04	115.68	0.4028
Error	4	370.13	92.53	

The results of compare mean analysis for the voltage factor have provided in a Table 4. The results showed that by increasing the voltage from 60 to 80 V, the time duration of the process is significantly decreased. The lowest time duration was obtained for 80 (66.88 s) and 90 V (69.50 s). So, this analysis show that 80 and 90 V provide time durations with no significant difference.

Table 4. The compare mean analysis to show the effect of voltage factor on time duration of curd production process.

Voltage (V)	Time duration (s)
60	187.00[a*]
70	102.00[b]
80	66.88[c]
90	69.50[c]

* Non similar letters show significant differences between the means.

The results of the present research are similar to those of the previous researches. Castro [18] also studied the effects of voltages (25, 40, 55, and 70 V) in carrot processing and reported similar results. Darvishi et al. applied different voltages as 30, 35, 45, and 55 on pomegranate juice and stated that the time duration of the process would be reduced with increasing the voltage (Darvishi et al., 2013). Gavahian and Chu developed an ohmic heating system to study the bioactive compounds of pineapple core. They observed that increasing voltage from 110 to 260 V cause decrease in process time from 35.75 to 5.16 min (Gavahian & Chu, 2022).

Energy consumption

The energy consumed in each conducted test to produce curd was shown in Fig. 5. As seen in Fig. 5, totally the energy consumption of steel electrode was lower than that of brass but the highest energy was consumed by steel electrode as 41.54 kJ for 90 V. The energy consumption decreased by increase of voltage except for 90 V. The lowest energy consumption was obtained for steel electrode with voltage of 80 V as 18.97 kJ.

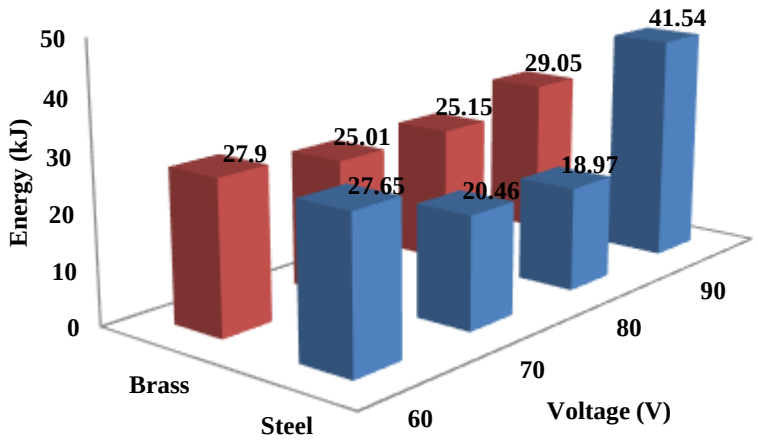

Figure 5. The energy consumption of curd production process.

CONCLUSIONS

In the presented research, an ohmic heating system was implemented, as a new technique in the processing of food materials, for producing curd from cow doogh. The system was evaluated under the effects of voltage and electrode on final temperature and time duration of the process. The results showed that the effect of voltage and electrode on the final temperature of the process and the effect of electrode on the time duration were insignificant, but the effect of voltage on the time duration of the process was significant at

1% probability level. By increasing the voltage from 60 to 90 V, the time duration of the process was significantly decreased. The minimum time duration was obtained by steel electrode with 80 V as 57.83 s and the maximum time duration (186.00 s) was observed when brass electrode was used and minimum voltage was applied. The lowest energy consumption was calculated for steel electrode with 80 V as 18.97 kJ. In future, quality characteristics of the curd can be assessed under the effects of the studied factors. Also, energy indicators and environmental impacts may be evaluated in curd production process.

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Conflict of interest

The authors have declared no conflict of interest.

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