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Ohmic heating process characterizations during apple puree processing

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Abstract

The study intends to determine the temperature variation of the apple puree treated by ohmic heating, the necessary time to reach the final purpose of the heating and the apple puree viscosity before and after ohmic heating, which has the role to facilitate some rheological parameters calculation. For heating, it was used a batch ohmic installation. The heating process has been driven at different voltage gradients from 15 to 20 V/cm; it was also observed the bubbling moment, which concurred with the finish of the ohmic heating process. Therefore, bubbling was observed in all cases above 60°C and the processing time depends on the voltage gradient. There were calculated also the correlation coefficients with the Statistica 8.0.

Keywords: Ohmic heating, apple puree, voltage gradient

1. Introduction

Electrical and electro thermal methods for processing food and biomaterials have attracted much recent attention in industry. Methods include microwave and ohmic heating and pulsed electric field processing [1]. So ohmic heating (OH) (also called Joule heating, electrical resistance heating, direct electrical resistance heating, electro heating, or electro conductive heating) is defined as a process where electric currents are passed through foods to heat them. Heat is internally generated due to electrical resistance. OH is distinguished from other electrical heating methods by (1) the presence of electrodes contacting the foods (if microwave and inductive heating electrodes are absent), (2) the frequency applied (unrestricted, except for the specially assigned radio or microwave frequency range), and (3) waveform (also unrestricted, although typically sinusoidal). [2].

The substance is heated by the dissipation of electrical energy. When compared to conventional heating, where heat is conducted from the outside by using a hot surface, ohmic heating uniformly conducts heat throughout the entire mass of the food. The success of ohmic heating depends on the rate of heat generation in the system, the electrical conductivity of the food, and the type of food flow through the system Leizerson and Shimoni (2005a) [3].

Many studies showed that ohmic heating in food processing could save energy and it was cleaner than water bath heating [4] reported that even heating of both large solid particles and the liquid phase in a high temperature short time (HTST) process was obtained during ohmic heating. [5,6] indicated that the main reason for the additional effect of ohmic treatment may be related to the low frequency (50–60 Hz), which allows cell walls to build up charges.

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Ohmic heating of food products is regarded as a potential alternative to conventional heating.

Fruits are attractive and nutritional foods, due to their color, shape, unique taste and smell, and to being rich in minerals, vitamins and other beneficial components Cassano et al. (2003) [7]. The apple is a pomaceous fruit, belonging to the species Malus domestica Borkh in the rose family Rosaceae, one of the most widely cultivated tree fruits. Among fruits, apple is the most important, economically and industrially. It is consumed in different forms, such as fresh fruit, concentrated juice or thin dried slices. Apples contain a high percentage of their fresh weight as water (86%) [8].

As the fruit consumption and fruit products are continuously increasing in the European Union, in the same way the consumers' demand for "fresh looking", more convenient and healthier fruit and fruit products has led to increasing the research on minimal preservation techniques like high pressure processing Bull et al. (2004), Houška et al. (2006) [9,10], modified atmosphere packaging Soliva-Fortuny & Martín-Belloso (2003); Soliva-Fortuny, Elez-Martíınez, & Martín-Belloso (2004), or biopreservation Janisiewicz, Conway, & Leverentz, (1999); Leverentz et al. (2006); Trias, Badosa, Montesinos, & Bañeras, (2008) [11, 12, 13,14,15,16]. Therefore, in conventional industrial processes for apple purée production, raw apples are first diced and cooked at a temperature between 93 and 98 °C for 4 to 5 min, then pulped and pasteurized at 90 °C during 20 min to give, at 30 °C, a shelf life of 6 months Oszmianski, Wolniak, Wojdyło, & Wawer, (2008) [17].

A few determinations have been made over the ohmic heating process depending on time, temperature and electrical conductivity parameters being measured at different voltage. The viscosity of the raw apple puree and the treated variants were also determined. The obtained data were interpreted statistically with the Statistica 8.0 program.

Nomenclature

A_e - area of cross-section of the electrodes (m^2)
L - distance between the electrodes (m)
m - mass of sample (kg)
Q - the amount of heat (J)
Q_t - the energy required to heat the sample (J)
R - resistance of the sample (m)
τ - time (s)
t - temperature (°C)
V - voltage applied (V)
σ - electrical conductivity (S/m)
△V- voltage gradient (V/cm)
E_g – the amount of energy given (J)
E_{loss} – the lost energy (J)
SPC - system performance coefficient
c_p - specific heat capacity (J/kg K)
I - current intensity (A)
Q - the amount of heat (J)
R – electrical resistance (Ω)
ρ – product density (kg/m^3)
m – sample mass (kg)
V – sample volume (m^3)
X_w – the humidity content (kg/kg)

2. Materials and methods

The ohmic heating batch installation used in this study (Figure 1) was configured and implemented in the Unit Operations Laboratory from Food Science and Engineering Faculty, Galati, Romania.

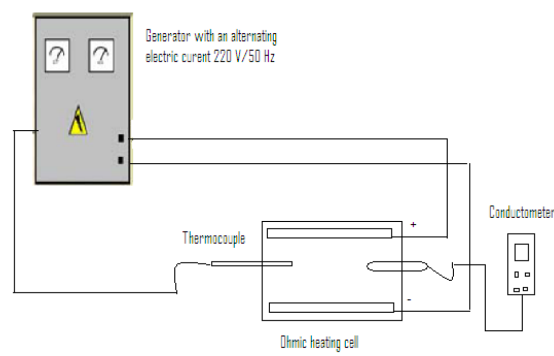

Figure 1. Batch ohmic heating installation

The installation contains: a generator for alternating electric current, a voltmeter for voltage measurement, an intensity meter for current intensity measurement, a conductivity meter to measure electrical conductivity, an ohmic heating cell with a thermocouple to register temperature variation and two electrodes made of stainless steel.

The ohmic cell is by parallelepiped shape (28 x 18 x 5 cm) which contains two cylindrical electrodes (0.5 x 26 cm).

The Idared apple varieties were supplied by a local producer to be used in the experiment. The parameters were measured after each sample heating at different temperatures and processing times.

The samples were poured through the electrodes and the thermocouple port and then the electronic temperature sensors were inserted.

The sample was ohmically heated up to a boiling temperature at 50 Hz frequency using different voltages. Voltage, current, temperature data were logged at every 5 minutes during heating. The voltage gradients applied over the samples of apple puree were 15/17/17.5/20 V/cm. The experiments were replicated three times.

Some important details about the ohmic heating cell characteristics are shown under Table 1.

It should be mentioned that all the measures are explained below.

Electrical conductivity of samples was measured with a conductivity meter and also calculated from voltage and current data using the following equation. [18,19]:

$$\sigma = \frac{L}{Ae \cdot R} \qquad (1)$$

There were also calculated or measured some parameters dealing with the ohmic heating installation such as: the energy given to the system and the ohmic heating system performance coefficients and other closely related with the apple puree properties such as: density, specific heat of apple puree, the heat required to heat the sample to a prescribed temperature.

The density was determined using the classical method of measuring the apple puree volume and mass.

$$\rho = \frac{m}{V} \qquad (2)$$

The specific heat of apple puree was also determined through the empirical formula:

$$Cp = 1.675 + 2.5 \cdot X_w \qquad (3)$$

The values obtained have been compared with the specialty literature values, hereby:

$\rho = 990$ kg/m^3 and $Cp = 3420$ J/(kg·K).

The purpose of calculating the measures was to determine the ohmic system performance SPC that indicates if the quality of the ohmic heating process is feasible.

It is also mentioned by Icier & Ilicali (2004) [20] that for a system with zero E_{loss}, SPC will be equal to 1.

Voltage intensity of the current and temperature values determined during the experiments were used to calculate the following: the energy given to the system (E_g) and the heat necessary for sample heating (Q_t).

$$E_g = \sum \Delta V \cdot I \cdot t \quad (4)$$

$$Q_t = m \cdot c_p \cdot (T_f - T_i) \quad (5)$$

The energy given to the system can also be expressed as the energy required heating the sample plus the energy loss. This method is given by Icier & Ilicali (2005a) [21].

$$E_g = Q_t + E_{loss} \quad (6)$$

Ohmic heating system performance coefficient (SPC) was defined as a ratio between the energy taken by the apple puree and the energy given to the system. The formula was presented by Icier & Ilicali (2004) [20].

$$SPC = \frac{Q_t}{E_g} \quad (7)$$

The samples (untreated and treated by ohmic heating apple puree) viscosities were measured by using a Brookfield viscometer.

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

3.Results and discussion

The experiments were developed with a batch ohmic heating installation which was run at different temperatures, voltage gradients and time intervals, the purpose of the experiments being the determination of the boiling temperature, the comparison between experimental values of electrical conductivity and calculated ones (obtained by using the distance between electrodes, the cross section area of ohmic heater and the resistance values) and the measure of samples viscosity evolution.

For purposes of this study, we used apple puree produced at laboratory scale by mincing the apples with a blender, after having submitted it to some preliminary operations such as washing, peeling, cutting, eliminating the seeds. Following pictures (Figure 2) show the measured electrical conductivity evolution (σ) and the calculated electrical conductivity (σ_c) according to temperature variation.

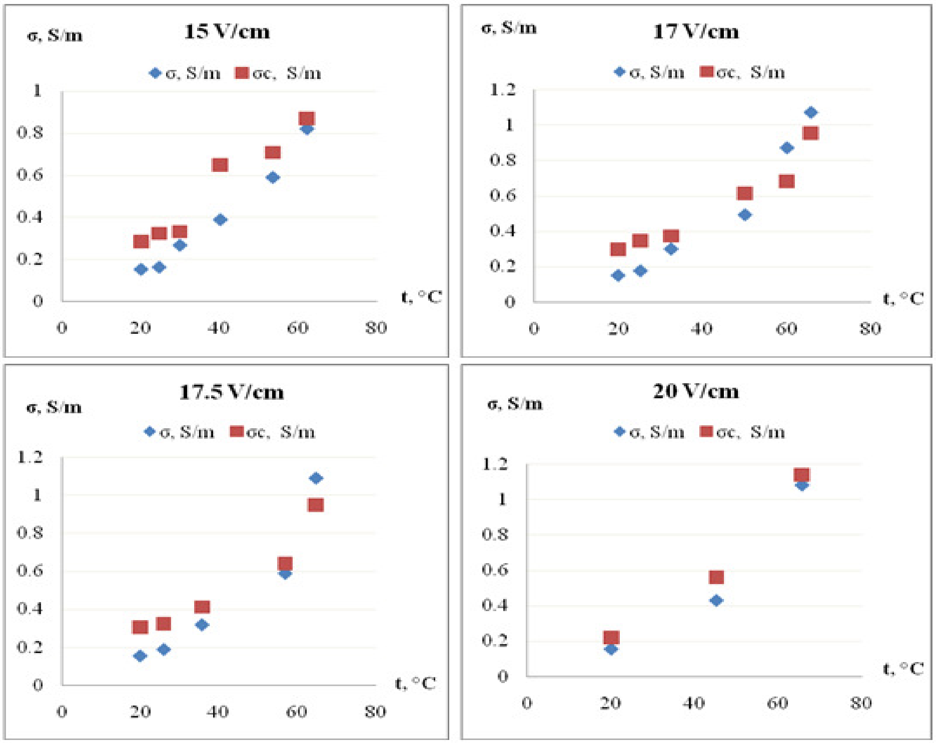

Figure 2. Calculated and measured electrical conductivity changes of apple puree during ohmic heating at different voltage gradients: 15/17/17.5/20 V/cm

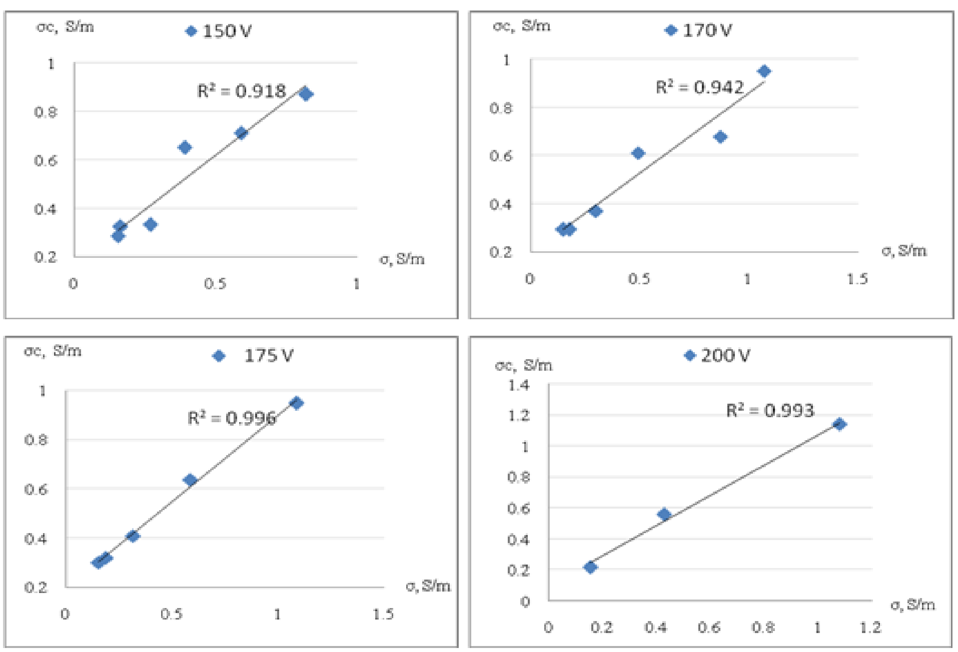

Figure 3 The mathematic correlation between the theoretical and empirical values for the electrical conductivity

Table 1. Multiple Regression Results of the ohmic heating process data

Voltage gradient = 15 V/cm		
Temperature, ^{0}C Electrical conductivity, S/m	R = 0. 97689495 R²= 0. 95432375 adjusted R²= 0. 94290468 Std.Error: 2.405885	F = 83.57285 df = 1.4 p = 0. 000795
Voltage gradient = 17 V/cm		
Temperature, ^{0}C Electrical conductivity, S/m	R = 0.96498202 R²= 0.93119029 adjusted R²= 0.91398787 Std.Error: 3.358924	F = 54.13133 df = 1.4 p = 0.001818
Voltage gradient = 17.5 V/cm		
Temperature, ^{0}C Electrical conductivity, S/m	R = 0. 98441496 R²= 0. 96907281 adjusted R²= 0. 95876374 Std.Error: 2.804113	F = 94.00201 df = 1.4 p = 0. 002330
Voltage gradient = 20 V/cm		
Temperature, ^{0}C Electrical conductivity, S/m	R = 0. 99845176 R²= 0. 99690592 adjusted R²= 0. 99381184 Std.Error: 1.703252	F = 322.1979 df = 1.1 p = 0. 035430

R- Regression factor
*) 0.7 – 0.99 strong correlations, 0.5 – 0.69 intense correlations; 0.25 – 0.49 medium intensity.

As shown in all four pictures, the electrical conductivity growth also measured and calculated is proportional with the temperature increasing. Both curve allures are similar. The temperature evolutions as well as the bubbling temperature depend on the voltage gradient. However, as a general rule, the bubbling temperature appeared over 50°C. It is also obvious that the heating is more efficient and fast when the voltage gradient is higher, so if at 15 V/cm were done six determinations then at 20 V/cm there were done only three. The boiling point is reached faster for a higher voltage gradient (20 V/cm) than for a lower one (15 V). The highest value of the electrical conductivity corresponding to a lower value of time processing has been obtained at a 20 V/cm voltage gradient (1.08 S/m at 65.7°C for 300 s) while a similar value can be reached at a lower voltage gradient (15/17/17.5 V/cm) only in a much longer time, that is 1200 s.

Figure 3 is confirming the mathematic correlation between the electrical conductivity theoretical and empirical values.

In order to confirm the relationship between the theoretical and empirical values for the electrical conductivity the values for the both electrical conductivity variants are continuous and normally distributed [24].

Usually correlation coefficients are calculated such that the numerical values lie between −1 and +1. A magnitude of 1 indicates maximum correlation, and 0 indicates minimum correlation. So if the variables increase in a positive direction together, there is a positive correlation. These values are describing a linear relationship.

An associated measure is the coefficient of determination (R^2) which is obtained by squaring the correlation coefficient and in all cases its values are near to 1 so the correlation is almost perfect.

Figure 4 demonstrates the electrical conductivity depending on time processing according to the voltage gradients.

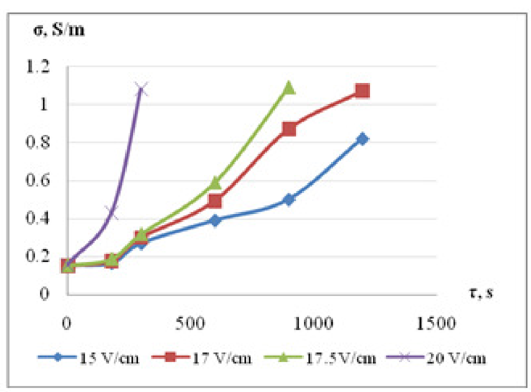

Figure 4. Electrical conductivity depending on time processing according to voltage gradients (15/17/17.5/20 V/cm)

The electrical conductivity depending on time shows that at a higher voltage gradient (20 V/cm), the processing time is lower (300 s) compared to the lower values of the voltage gradient (15/17 V/cm) for which the processing time is 1200 s and 900 s respectively for 17.5 V/cm. The highest values for the electrical conductivity are between 1.07 – 1.09 S/m, but the 1.08 value is registered at only 300 s for 20 V/cm.

Figure 5 shows the temperature variation during ohmic heating processing measured for different voltage gradients.

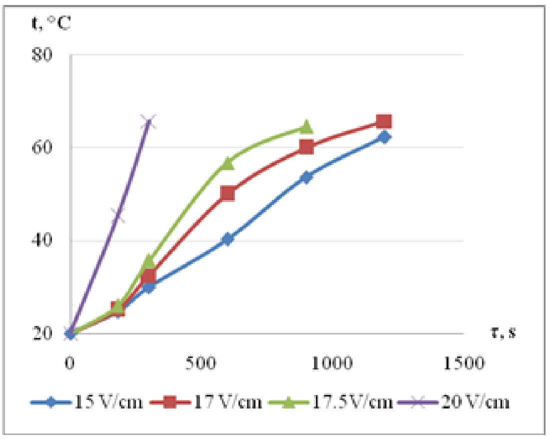

Figure 5. Temperature variation during ohmic heating processing

The temperature variation is similar to the electrical conductivity variation in time, which indicates that the electrical conductivity is directly dependent on the temperature increase. It can be also observed that the maximum registered temperature is between 62.3 – 65.7 °C, but for the lower voltage gradients (15/17 V/cm) the achieving time is longer (1200 s) than for a higher one (17.5 V/cm) at 600 s and at last for the maximum voltage gradient (20 V/cm) at 300 s.

Figure 6 shows the shear stress (τ, Pa) values for the untreated puree, which are in decreasing scale compared to those of treated apple puree for which the shear stress is increasing.

The highest value for the shear stress (1.36 Pa) is registered by the apple puree treated at 17.5 V/cm. It can be also seen that at the first 3 voltage gradients τ is unitary, while only for the 20 V/cm ohmic processing the values are sub unitary. The allures of τ for the first two treated apple puree samples at 15 and 17 V/cm are similar and the same situation is for the other two higher voltage gradients, 17.5 and 20 V/cm, respectively.

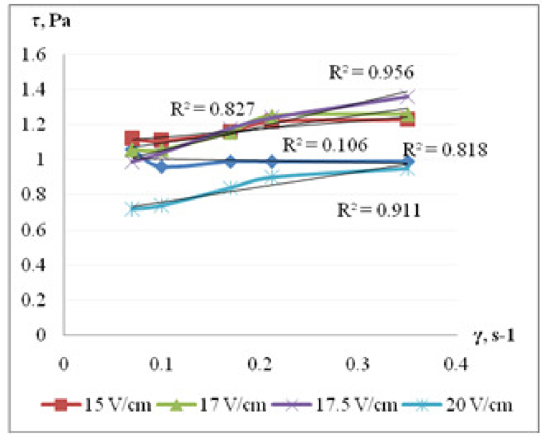

Figure 6. The shear stress values for the raw and treated apple puree at different voltage gradients (15/17/17.5/20 V/cm) depending on shear rate

It was noted for all samples that at low shear rates, the variation of tangential shear stress depending on the shear rate is linear (regression coefficient values R^2 varies between 0.818 and 0.956 except the value for the 17 V/cm which is 0.106).

The dynamic viscosity variation depending on shear rate is shown under Figure 7.

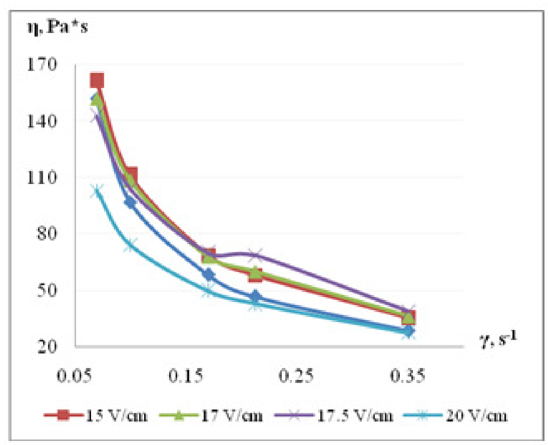

Figure 7. The dynamic viscosity variation of apple puree depending on shear rate

The allure of the curve is similar for all voltage gradients. The dynamic viscosity maximum values for the apple puree performed between 103 -161.3 Pa·s. All the values described the curves from the highest values to the lowest ones.

Both graphs determine a pseudoplastic rheological behavior of the apple puree treated by ohmic heating, as the definition affirms the pseudoplastic behavior represents the type of fluid of which dynamic viscosity decreases with the shear rate increasing.

Due to the apple puree composition which is represented by a dispersion of nutritive substances, this is the most common type of fluids – the non-Newtonian. This type of flow behavior is also known as "shear-thinning". Therefore, his is the type of food that changes its molecular structure when the spindle is stirring in its mass and if the speed of the spindle increases, the structural changes could be irreversible.

Statistical parameters have been equally determined by means of the statistic analysis using the Statistica 8.0 program.

There were used all the data plotted (electrical conductivity, temperature and time processing) by ohmic heating process for the four voltage gradients (15/17/17.5/20 V/cm).

Figure 8 shows the electric conductivity and temperature depending on time.

These types of graphs have resulted into some statistical data which are conceiving a mathematic model.

All the graphs explained the rigorous dependence between the electrical conductivity and temperature, as the temperature increases, the electrical conductivity is directly proportional with it. Both physical sizes depend on processing time.

One can also notice that the slope generated for the 20 V/cm data has a higher inclination angle than the other three slopes for 15/17/17.5 V/cm; this can mean that the processing time is lower than in the other three cases and also that the temperature increase is exponential comparing to the other one.

These data depend on the voltage gradients ohmic heating processing presented under Table 1.

The meanings of the coefficients calculated after the interpretation of the statistical data's are:

df – degrees of freedom, F – statistic test, P-value – probability.

The values of the regresion factor (R) demonstrate that if it is close to 1 then the mathematical model chosen for the obtained data is appropriate.

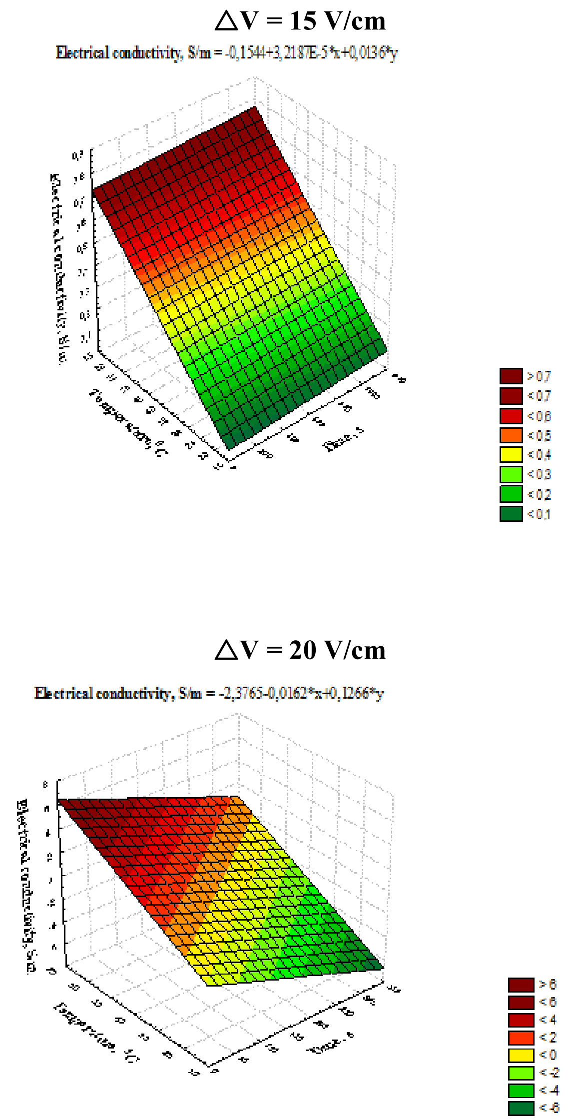

Figure 8. The electric conductivity and temperature depending on time represented in response surfaces graphs

4. Conclusion

Ohmic heating process is defined by some installation (distance between electrodes, diameter of electrodes), process (voltage, current intensity, temperature, processing time) and product parameters (current avidity which induce the electrical conductivity value).

The electrical conductivity is influenced by the product nature, meaning if the product is a good electricity conductor, also by temperature and by the value of the voltage gradient. If the voltage gradient is high, the time of ohmic heating processing is shorter and the temperature is rising faster in close relation to the electric conductivity values.

As Icier & Ilicali (2005b) [22] observed in their research, the characteristics of the ohmic heating system are involved in the system performance.

The results obtained for temperature variation and electrical conductivity are similar to those obtained by Icier & Ilicali (2005) [23] for peach and apricot puree treated by ohmic heating. Also the dependence temperature – time and electrical conductivity – temperature is marked by Castro et al (2004) [4]. Also Icier & Ilicali (2005) [23] established that the proper boiling temperature is above 60°C value.

The ohmic heating does not change the pseudoplastic rheological character of the apple puree.

The statistic analyses determine the best possible correlation between the obtained data (electrical conductivity – temperature – time dependence) and the nominated mathematic model.

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Compliance with Ethics Requirements

Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human and/or animal subjects (if exists) respect the specific regulations and standards.

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