Application of the response surface method in the analysis of ohmic heating process performance in sour orange juice processing

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Abstract: Three voltage gradients (8.38, 10.83, and 13.33 V cm^{-1}) and three weight loss percentages (10%, 20%, and 30%) were examined; also the system performance coefficient, input current, heating process duration, power consumption and electrical conductivity investigated. The response surface method was also used for modeling and optimization. For the response surface method, weight loss percentage and voltage gradient were selected as independent variables; and factors system performance coefficient, heating process duration, input current, power consumption and electrical conductivity were selected as responses. According to results, all obtained models were significant for responses factors, but the voltage gradient and weight loss percentage were insignificant for all factors except for the electrical conductivity and power consumption. The best model was a quadratic model against interaction for the system performance coefficient, input current and power consumption; and the linear model against mean was the best model for electrical conductivity and heating time.

Keywords: sour orange juice, ohmic method, response surface method, modeling

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1 Introduction

Sour orange (*Citrus aurantium* L.) belongs to the citrus family and is applied as a sedative, antioxidant, jam and appetizer in Iran (Hosseini et al., 2019). It is also called ‘C. bigaradia Duh, C. vulgalis’ in the southwestern Asia, and has a rounded and acidic fruit that is called sour orange, sour orange or Seville (Amiri and Niakousari, 2008). Its another products are orange blossom jam, sour orange juice concentrate, and pickled orange peel. Due to the unique properties of sour orange, its cultivation is common in most temperate regions including the northern and central parts of Iran. The sour orange juice is a widely-used sour orange product with a very hearty appearance and unique flavor. The sour orange juice has citric acid, sugar, gum minerals and vitamins, especially vitamin C. The determinants of quality of this product such as color are strongly influenced by environmental conditions due to the high levels of vitamin C during the maintenance period and they have significant effects on the customer satisfaction (Da-Silva et al., 1991). Therefore, food and agriculture product processing is essential; and heating process is a method for using agricultural crop processing. In conventional heating processes, the heat transfer mechanism is done using the conduction, convection and radiation. The product resistance to thermal conduction leads to a loss of quality to a significant extent. Therefore, alternative technologies

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should be used to solve these problems. In this regard, the Ohmic heating is an alternative method for food processing, in which the heat inside food is generated by the current of electricity (Akanbi et al., 2006; Contreras et al., 2008; Duan et al., 2011; Ozkan et al., 2007). Based on physical methods for preserving food, thermal and non-thermal technologies have potentials to meet consumer demands and provide high-quality products with long lifespans that are additive-free and not subject to extreme heat treatment (Varghese et al., 2012) .The generated heat in the ohmic process directly occurs in the food; and amount of generated heat in food directly correlates with the amount of current through voltage gradient and electrical conductivity of samples (Icier and Ilicali, 2005a). Ohmic heating is an alternative method in heating systems and is used for liquid food (pumping capability) and can be used in continuous and non-continuous sterilization and cooking systems, and thus it is important to have electrical information in this system (Palaniappan and Sastry, 1991). In order to have a successful ohmic process, we need to know content such as amount of heat generation and the electrical conductivity coefficient in an ohmic system. Factors such as conductivity and electrical current should be investigated for the evaluation of this system (Bozkurt and Icier, 2010). In this regard, various studies have been conducted on the ohmic process. Some of them are as follows:

Sarang et al. (2008) examined the electrical conductivity of fruits and meat in the ohmic heating method. They argued that the effective design of an ohmic heating system depended on electrical conductivity of foodstuff. They obtained electrical conductivity coefficients for six fresh fruits including pear, golden apple, peach, red apple, strawberry and pineapple, as well as three pieces of meat including chicken, boar and beef at room temperature. They stated that the electrical conductivity increased at higher temperature in all samples, and the electrical conductivity of fruits was higher than meat samples. They also reported the highest electrical conductivity in peaches and strawberries than apple and pear (Sarang et al., 2008).

Icier and Ilicali (2005b) investigated the dependence between the electrical conductivity and temperature by an ohmic heating method in 2005. In this research, the apricot and peach puree drying was carried out using an ohmic heating method in voltage gradients of 20 to 70 V cm^{-1} and it was found that there was a linear relationship between the electrical conductivity of puree and temperature. It was also reported that the puree boiling occurred at the highest gradient at a temperature of 60˚C; and the electrical conductivity increased at higher temperature; however, the rate of temperature changes was greater in apricot puree than peach puree. In addition, fluid boiling bubbles occurred at 60°C and high gradients; and the electrical conductivity in the ohmic heating was an important parameter in designing the heating cell (Icier and Ilicali, 2005a).

Bozkurt and Icier (2010) examined the impact of amount of electrical conductivity changes on cooking beef-fat blends using an experimental ohmic process. Their results indicated that current rates were different and significant in a variety of voltages; and the electrical conductivity of samples also increased at higher heating temperature of the electrical conductivity coefficient (Bozkurt and Icier, 2010).

Zareifard et al. (2003) conducted an experiment on the use of an ohmic heating method in dual phase materials and reported that the electrical conductivity was proportional to material size, concentration and temperatures of samples; and increasing process time enhanced concentrations and dimensions of materials.

Due to the fact that thermal processes are essential for health of foods, we need to carefully consider side factors of devices and food in a thermal process. In the present research, the surface response method was used for data and experiments to examine changes in electrical conductivity, system efficiency, power consumption, input current, and heating process duration at created intervals in order to gain a comprehensive and complete view of a process.

2 Materials and methods

2.1 Preparation of the sample

The sour oranges were purchased from a gardenlocated in the city of Gorgan, Golestan Province. The prepared oranges were washed and divided into two halves in the middle and immediately after purchase, all the samples juice was taken manually in the same conditions, and the samples were prepared to conduct the test during the ohmic process with voltage gradients and the percentages of different weight loss to investigate the amount of energy efficiency, exergy efficiency, exergy loss, and improvement potential during the process.

2.2 The experiment method

A reservoir made of plastics thermoset was considered for this process, and the samples were poured into the reservoir between two electrodes and the initial temperature was recorded after stabilization and after recording the temperature, the voltage was applied to the set, and the samples were heated. Three heating gradients of 8.33, 10.83 and 13.33 V cm^{-1} were selected for the heating process. Approximately 10% (from 90 g to 81 g), 20% (from 90 g to 72 g) and 30% (from 90 g to 63 g) of the total weight of the sour orange juice samples is poured into the steam cell, and evaporated in the heating process. All the samples were 90 g. Figure 1 presents a schematic diagram of the heating process and the system components.

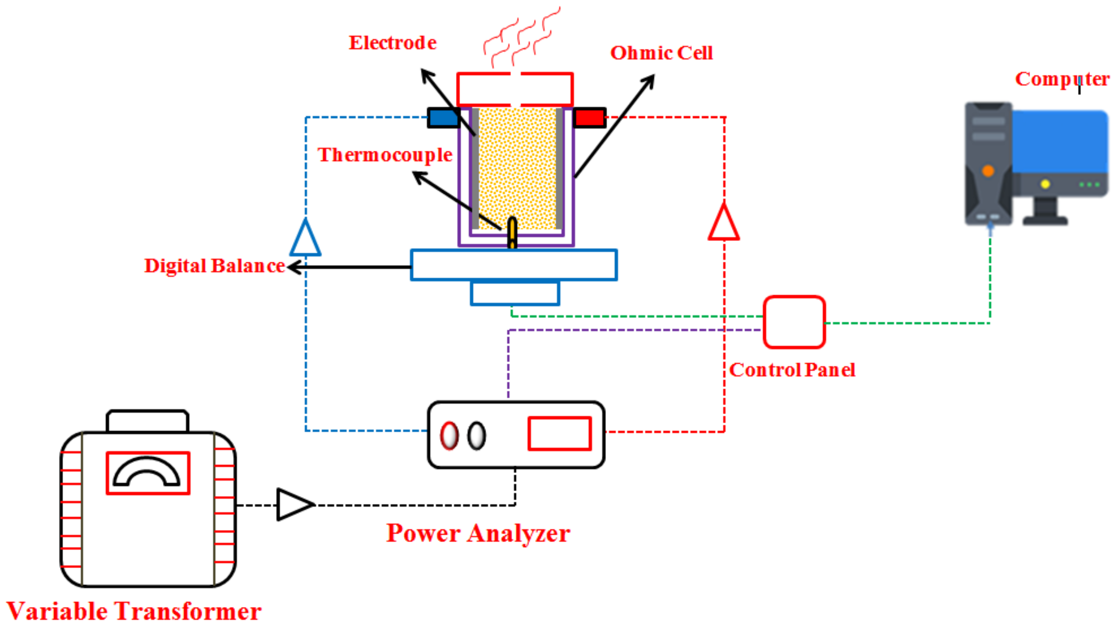


Figure 1 Schematic of the equipment used for the heating process of ohmic

The experiments were conducted in a static ohmic heating system. The system used consisted of a compact and transparent plastic cell (length 6 cm, width 6 cm, height 10 cm wall thickness of 0.3 cm), an electrode made of stainless steel (thickness of 0.1 cm) that the distance between the two electrodes is 6 cm, a variable transformer that is responsible for generating different voltages (3 kW, 0–300 V, 50 Hz, MST – 3, Toyo, Japan), a power analyzer (Lutron DW-6090) responsible for monitoring the pattern of energy behavior of the system, a thermocouple, and a computer to store data with their profile. A scale (±0.01grams) was used to measure the cell weight and its contents during the process that was placed under the cell. All the experiments were conducted in the Bio-system Mechanics Department of Agricultural Sciences and Natural Resources of Gorgan University.

2.3 The equations of the ohmic heating process

Electrical conductivity was calculated using the resistivity of the samples and used with Equation 1 (Castro et al., 2004; Cappato et al., 2017):

$$\sigma = \frac{LI}{AV} \quad (1)$$

In this formula, σ = electrical conductivity of the sample (S/m), L: the distance between the two electrodes (m), A: the cross-sectional area of the plates (m^2), V: the input voltage (V), I: the input current (A).

During the heating, the contact surface between the samples and the electrode decreases due to the evaporation of the vapor, the contact surface can be calculated using Equation 2 (Darvishi et al., 2015):

$$A = \frac{M_t}{\rho_t L} \quad (2)$$

$$\rho_t = 1340 - 3.26M_t^2 \quad (3)$$

Where, Mt is moisture content at any time. Also power consumption was calculated using Equation 4 (Kanjanapongkul, 2017).

$$P=VI=I^2R \quad (4)$$

I= Current intensity (A)

R=Resistor (Ω)

V=Voltage(volt)

The formula P is the power consumption (W).

The energy given to the system according to Equation 5 is presented.

$$E_{given} = E_{taken} + E_{loss} \quad (5)$$

$$\sum(VIt) = mc_p\left(T_f - T_i\right) + E_{loss} \quad (6)$$

The energy loss of system is the sum of necessary energy to increase cell temperature, and the energy system of environment through displacement and electrical energy that becomes heat. Voltage values were specified in equations; and input current and time values were calculated. The initial and final temperatures of orange juice were measured using a thermometer; and its mass of water was calculated by the scale. Where, C_p is specific heat capacity (J/kg.K); m is mass of the sample (kg); T_f is final temperature of the sample (ºC); T_i is initial temperature of the sample (ºC); t is time (s) E_{given} is the electrical energy given to the system (J); and Eloss is the energy loss (J).

The system efficiency coefficient was equal to the ratio of taken to given energy by a system and was calculated by the following equations (Darvishi et al., 2013).

$$\mathrm{SPC} = \frac{E_{taken}}{E_{given}} \quad (7)$$

$$\mathrm{SPC} = \frac{mc_p(T_f - T_i)}{\sum(VIt)} \quad (8)$$

In the formula, E_{given} is the energy given to the system (J); T_f is the final temperature (°C); E_{taken} is the energy taken from the system (J). T_i is the input temperature (°C); E_{loss} is the energy loss in the system (J); t: Time (s); SPC: System performance coefficient; m: Sample mass (kg).

2.4 Analyze the response surface method

The response surface method (RSM) is a statistical and mathematical approach used to analyze experimental results (Han et al., 2015). This method is also very useful in designing, improving and formulating new products. The grade 2 model is suitable for industrial processes and has many strengths. Also, using the analysis of variance (ANOVA), the models presented for the responses were evaluated and regression coefficients were estimated for linear, interactions and grade 2 sentences and the fitting quality of the models equation was expressed using the convergence coefficient (R^2) (Myers et al., 2009). In order to investigate the properties and optimization of system performance factor, heating process duration, input current, power consumption and the electrical conductivity of sour orange juice during the heating process, the surface response method, a central composite design (CCD) with 5 central points and with Design Expert 11 software was used. In this study, the independent variables were voltage gradients and percentage of weight loss (Table 1), dependent variables were method as responses to investigate the process of the desired changes to the levels of independent variables. Finally, the best condition of heating process will be obtained using this method.

Table 1 Independent test variables

Variable	Level	
	-1	+1
Voltage gradient (V cm^{-1})	8.33(50 v)	13.33(80 v)
Percentage weight loss (%)	10	30

3 Results and discussion

Table 2 showed results of the analysis of variance and response surface method analyses for system performance, input current, heating process duration, power consumption and electrical conductivity. According to the table for the system performance coefficient, the applied model and voltage gradient were all significant at the level of P<0.0001 and the weight loss percentage was also significant at 0.0006. The interaction of these two factors was significant at the level of P<0.0130, and the quadratic mode of voltage gradient was significant at 0.0069. The weight loss percentage was insignificant for the gradient mode. Given that its lack of fit was not significant, the model was suitable after reducing number of insignificant terms. According to the table and R^2 and adjusted R^2 values, it can be argued that since values were very close, the prediction model was a very strong and appropriate process; and amount of predicted R^2 was also very suitable and desirable. The predicted model and voltage gradient were significant at the level of P<0.0001 for the process time, and also significant at the level of P<0.0007 for the weight loss percentage. In all models, the amount of lack of fit was significant; and the model was selected according to R^2 and adjusted R^2 values; and it had better values of adjusted and predicted R^2 values than the rest of models. For the input current of applied model, the voltage gradient and weight loss percentage were all significant at 0.0035, 0.0036 and 0.036, respectively. The interaction and second order mode of voltage gradient were insignificant; and quadratic mode of weight loss was significant at 0.0016. The applied model and gradient were significant at 0.0066 and 0.016 respectively for power consumption, but weight loss percentage was not significant. The interaction between two factors of quadratic values was not significant for voltage gradient, but the weight loss percentage of 0.0073 was significant for quadratic values. Value of lack of fit was not significant; and the predicted model could be considered acceptable. The electrical conductivity of model and weight loss percentage were significant at levels of 0.020 and 0.011, but the voltage gradient was not significant. Furthermore, amount of Lack of Fit was insignificant.

Table 2 Analysis of variance and predictive coefficients of system performance factor, heating process time, input current, power consumption and the electrical conductivity

Source	Sum of Squares	Coefficient Estimate	df	Mean Square	F-value	p-value	
	System performance coefficient						
Model	0.0732	0.7313	5	0.0146	49.57	< 0.0001	significant
A-Voltage gradient	0.0545	-0.0953	1	0.0545	184.46	< 0.0001	
B-Percentage of eight loss	0.0103	-0.0359	1	0.0103	34.82	0.0006	
AB	0.0032	0.0284	1	0.0032	10.93	0.0130	
A^2	0.0042	0.0364	1	0.0042	14.31	0.0069	
B^2	0.0006	0.0142	1	0.0006	2.09	0.1917	
Residual	0.0021		7	0.0003			
Lack of Fit	0.0015		3	0.0005	3.41	0.1333	not significant
Pure Error	0.0006		4	0.0001			
Cor Total	0.0753		12				
R^2	0.9725						
Adjusted R^2	0.9529						
Predicted R^2	0.8352						
Adeq Precision	23.0449						
	Heating process time						
Model	6.088E+05	689.31	2	3.044E+05	41.37	< 0.0001	significant
A-Voltage gradient	4.406E+05	-271.00	1	4.406E+05	59.88	< 0.0001	
B-Percentage of eight loss	1.682E+05	145.00	1	1.682E+05	22.86	0.0007	
Residual	73592.77		10	7359.28			
Lack of Fit	72748.77		6	12124.79	57.46	0.0008	not significant
Pure Error	844.00		4	211.00			
Cor Total	6.824E+05		12				
R^2	0.8922						
Adjusted R^2	0.8706						
Predicted R^2	0.8161						
Adeq Precision	20.1891						
	Flow rate						
Model	2.71	2.71	5	0.5427	10.79	0.0035	significant
A-Voltage gradient	0.9303	0.3938	1	0.9303	18.49	0.0036	
B-Percentage of eight loss	0.3194	0.1998	1	0.3194	6.35	0.0398	
AB	0.0472	-0.1086	1	0.0472	0.9375	0.3652	
A^2	0.0892	-0.1669	1	0.0892	1.77	0.2248	
B^2	1.25	-0.6401	1	1.25	24.82	0.0016	
Residual	0.3522		7	0.0503			
Lack of Fit	0.3265		3	0.1088	16.98	0.097	not significant
Pure Error	0.0256		4	0.0064			
Cor Total	3.07		12				

R^2	0.8851						
Adjusted R^2	0.8031						
Predicted R^2	0.2174						
Adeq Precision	11.3933						
	Power consumption						
Model	33868.19	202.66	5	6773.64	8.66	0.0066	significant
A-Voltage gradient	19555.31	57.09	1	19555.31	25.00	0.0016	
B-Percentage of eight loss	1157.77	12.03	1	1157.77	1.48	0.2632	
AB	78.52	-4.43	1	78.52	0.1004	0.7606	
A^2	1285.34	-20.04	1	1285.34	1.64	0.2407	
B^2	10934.98	-59.90	1	10934.98	13.98	0.0073	
Residual	5475.73		7	782.25			
Lack of Fit	3835.99		3	1278.66	3.12	0.1503	not significant
Pure Error	1639.74		4	409.94			
Cor Total	39343.92		12				
R^2	0.8608						
Adjusted R^2	0.7614						
Predicted R^2	0.3772						
Adeq Precision	10.0279						
	Electrical conductivity						
Model	0.2598	1.11	2	0.1299	5.93	0.0200	significant
A-Voltage gradient	0.0505	0.0917	1	0.0505	2.30	0.1600	
B-Percentage of eight loss	0.2093	0.1618	1	0.2093	9.56	0.0114	
Residual	0.2190		10	0.0219			
Lack of Fit	0.1692		6	0.0282	2.27	0.2241	not significant
Pure Error	0.0498		4	0.0124			
Cor Total	0.4788		12				
R^2	0.5426						
Adjusted R^2	0.4511						
Predicted R^2	0.3220						
Adeq Precision	7.1307						

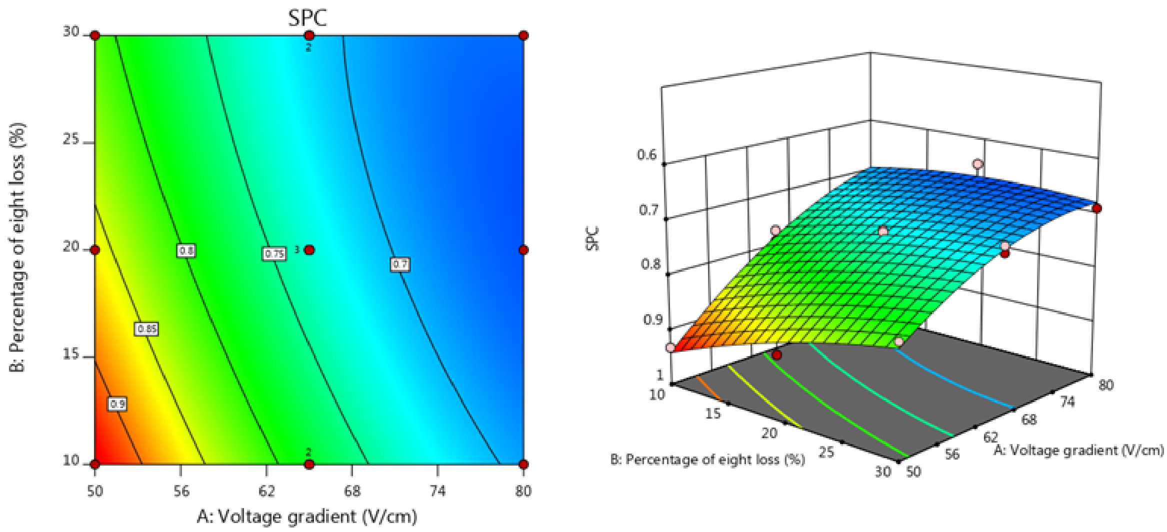
The results of the Sequential Model Sum of Squares show that how complexes phrase participates in the final model. Table 3 shows the results of the models for system performance, heating time process, input current, electrical conductivity and power consumption. The linear and factors interaction model was selected as the best model for the energy efficiency, and the second-order model versus the two factors was chosen as the best model for the system performance, input current, electrical conductivity and power consumption. The best model for the heating time process was proposed the linear model versus average.

Table 3 Best Models for data

Source	System performance coefficient					
	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	7.45	1	7.45			
Linear vs Mean	0.0648	2	0.0324	30.83	< 0.0001	
2FI vs Linear	0.0032	1	0.0032	3.99	0.0768	
Quadratic vs 2FI	0.0052	2	0.0026	8.82	0.0122	Suggested
Cubic vs Quadratic	0.0015	2	0.0007	6.28	0.0432	Aliased
Residual	0.0006	5	0.0001			
Total	7.52	13	0.5786			
	Heating process time					
Mean vs Total	6.177E+06	1	6.177E+06			
Linear vs Mean	6.088E+05	2	3.044E+05	41.37	< 0.0001	Suggested
2FI vs Linear	21904.00	1	21904.00	3.81	0.0826	
Quadratic vs 2FI	17238.08	2	8619.04	1.75	0.2417	
Cubic vs Quadratic	3155.00	2	1577.50	0.2520	0.7865	Aliased
Residual	31295.69	5	6259.14			
Total	6.859E+06	13	5.276E+05			
	Flow rate					
Mean vs Total	64.91	1	64.91			
Linear vs Mean	1.25	2	0.6249	3.44	0.0729	
2FI vs Linear	0.0472	1	0.0472	0.2400	0.6359	
Quadratic vs 2FI	1.42	2	0.7083	14.08	0.0035	Suggested

Cubic vs Quadratic	0.2687	2	0.1343	8.05	0.0274	Aliased
Residual	0.0835	5	0.0167			
Total	67.98	13	5.23			
	Power consumption					
Mean vs Total	3.186E+05	1	3.186E+05			
Linear vs Mean	20713.07	2	10356.54	5.56	0.0238	
2FI vs Linear	78.52	1	78.52	0.0381	0.8496	
Quadratic vs 2FI	13076.60	2	6538.30	8.36	0.0140	Suggested
Cubic vs Quadratic	738.00	2	369.00	0.3894	0.6963	Aliased
Residual	4737.74	5	947.55			
Total	3.579E+05	13	27533.93			
	Electrical conductivity					
Mean vs Total	16.04	1	16.04			
Linear vs Mean	0.2598	2	0.1299	5.93	0.0200	Suggested
2FI vs Linear	0.0014	1	0.0014	0.0593	0.8131	
Quadratic vs 2FI	0.0607	2	0.0304	1.36	0.3181	
Cubic vs Quadratic	0.0576	2	0.0288	1.45	0.3183	Aliased
Residual	0.0992	5	0.0198			
Total	16.52	13	1.27			

Table 2 shows the coefficients values of the effect model of the voltage gradient and the weight loss percentage in which the impact of the voltage gradient (0.0953) has a much greater effect than the weight loss percentage (0.0359), since its coefficients are higher. It is also shown in Figure 2 that the System performance coefficient increases with the decrease of the voltage, and the highest red color is at the 8.33 V cm^{-1} (50 V) voltage gradient and the 10%-15% weight loss percentage and the lower the voltage and the lower the weight loss percentage, it has led to a red color that indicates a highest System performance coefficient. The increased voltage gradient and weight loss percentage decreased the System performance coefficient. As shown in Figure 2, the maximum values of System performance coefficient are observed in gradient of voltages 8.33 to 9.33 (50 to 56 V) and a weight loss percentage of 10% to 15%.



A: Contour

B:3D surface

Figure 2 Response surface curve of SPC showing interaction between voltage gradient and percentage of weight loss

As can be seen from Table 2, the voltage gradient (-271) has a much lower effect than the weight loss percentage (145). It is also shown in Figure 3 that with increasing the voltage gradient, the process time was reduced, and the highest red color was in the voltage gradient of 8.33 V cm^{-1} (50 V) and the percentage weight loss was 25%-30% .It can be explained by the fact that an increase in voltage gradient leads to the rapid increase in temperatures of sample sour orange juice; hence, the evaporation rate of sample also increases, but rate of temperature rise of process is slow in the low-voltage gradient; hence, a greater time is required to reach high temperatures and a boiling point. On the other hand, an increase in weight loss will enhance the amount of time for the weight loss process.

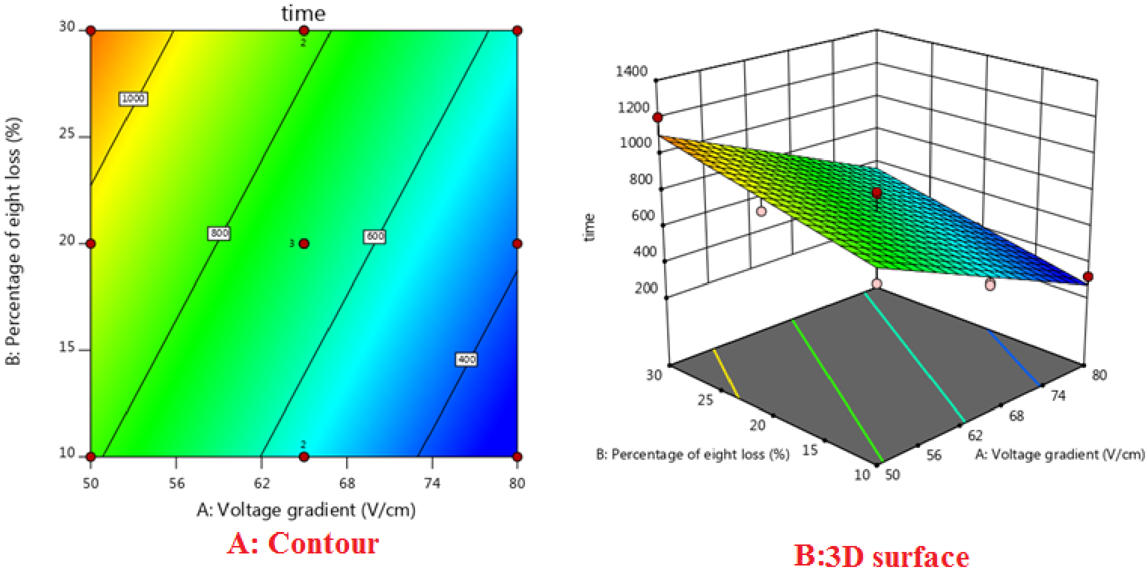


Figure 3 Response surface curve of ohmic heating time showing interaction between voltage gradient and percentage of weight loss

Table 2 shows the coefficients values of the effect model of the voltage gradient and the weight loss percentage for input current which the impact of the voltage gradient (0.93) has a much greater effect than the weight loss percentage (0.31). It is also shown in Figure 4 that the input current increases with the increasing of the voltage gradient, and the highest red color is at the 8.33 V cm-1 (50 V) voltage gradient and the 29% weight loss percentage and the lower the voltage gradient and the lower the weight loss percentage. It has led to a blue color that indicates the lowest input current. Reducing voltage gradient and increasing percentage decrease the amount of process input current. As shown in Figure 4, the maximum input current was observed on gradient of 10.33 to 13.33 voltages (62 to 80 V), and the weight loss percentage of 13% to 29%. According to obtained results, in the low voltage gradient, an increase in weight loss resulted in a much higher amount of process time, and the increase in time led to the increased corrosion at the electrode surface leading to a reduction in their electrical conductivity.

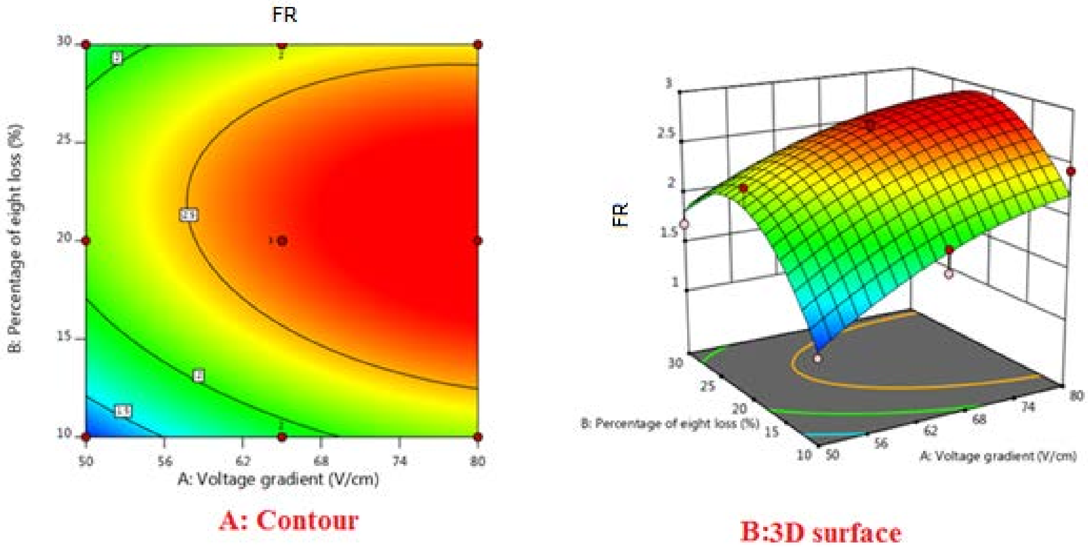
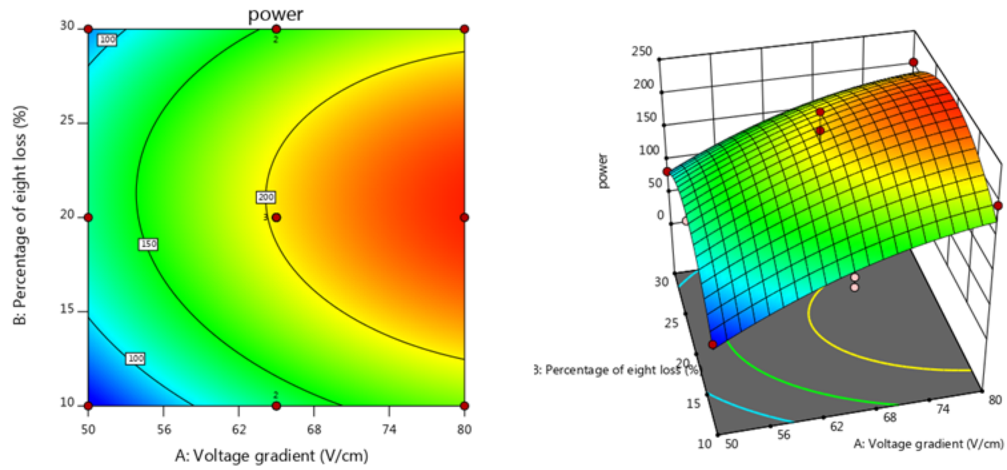


Figure 4 Response surface curve of current flow showing interaction between voltage gradient and percentage of weight loss

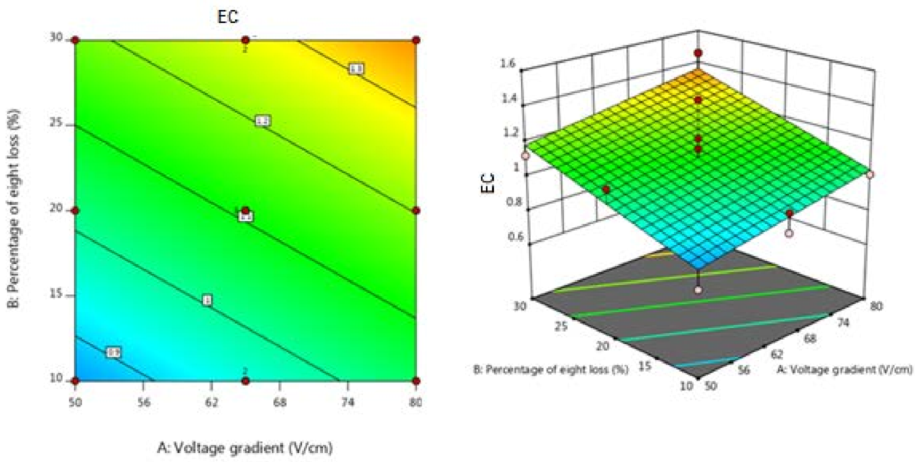
Table 2 shows the coefficients values of the effect model of the voltage gradient and the weight loss percentage for power consumption which the impact of the voltage gradient (57.09 V) has a much greater effect than the weight loss percentage (12.03%), because it has the highest coefficient. It is also shown in Figure 5 that the power consumption increases with the increasing of the voltage gradient, and the highest red color is at the 13.33 V cm^{-1} (80 V) voltage gradient and the 15% to 28% weight loss percentage and whatever the voltage gradient and the weight loss percentage amount decreased, it has led to a blue color that indicates a lowest power consumption.



A: Contour B:3D surface

Figure 5 Response surface curve of power consumption showing interaction between voltage gradient and percentage of weight loss

Table 2 shows the coefficient values of the effect model of the voltage gradient and the weight loss percentage for electrical conductivity which the impact of the voltage gradient (0.0917) has a much lower effect than the weight loss percentage (0.1618), because it has the lowest coefficient. It is also shown in Figure 6 that the electrical conductivity increases with the increasing of the voltage gradient, and the highest red color is at the 13.33 V cm^{-1} (80 V) voltage gradient and the 28% to 30.6% weight loss percentage and whatever the voltage gradient and the weight loss percentage amount decreased, it has led to a blue color that indicates a lowest electrical conductivity. Since the input current and electrical conductivity were directly correlated, the amount of input current was lower at the beginning of the process; hence, the amount of electrical conductivity decreased. According to obtained results, the increased weight loss percentage resulted in a much higher amount of process time in the low voltage gradient; and the increase in time led to increased corrosion at the electrode surface and then a reduction in their electrical conductivity.



A: Contour B:3D surface

Figure 6 Response surface curve of electrical conductivity showing interaction between voltage gradient and percentage of weight loss

The present study is aimed to find conditions in which we could have the highest system performance coefficient, the minimum input current, power consumption, and heating process duration in weight loss percentage and gradient of different voltages using mathematical models. The process optimization was done using the numerical optimization option in the software. Therefore, the subject goal was selected for each variable and response from the menu. For independent factors, namely voltage gradient and weight loss, it was minimum and within the range; maximum for the system performance coefficient; minimum for heating process duration; minimum for input current; minimum for power consumption; and within the range for the electrical conductivity. The amount of obtained utility from the optimization process represented the experimental model and desired conditions and its range was from zero to one. The more it was close to one, the more it indicated the closeness of responses to an ideal value and the suitability of optimization process. The purpose of optimization was to find the best power consumption, input current, heating process duration and the system performance coefficient in the voltage gradient and different weight loss percentages. Figure 7 shows the optimal predicted conditions for each parameter. The maximum voltage gradient was 9.29 V cm^{-1} (55.779 V), weight loss: 16,554, performance coefficient: 0.823, heating time(s): 8.05 (s); power consumption: 147.72 (W); electrical conductivity: 0.998 (S/m); and the input current was 2.23 (A) with the desirability value of 0.814.

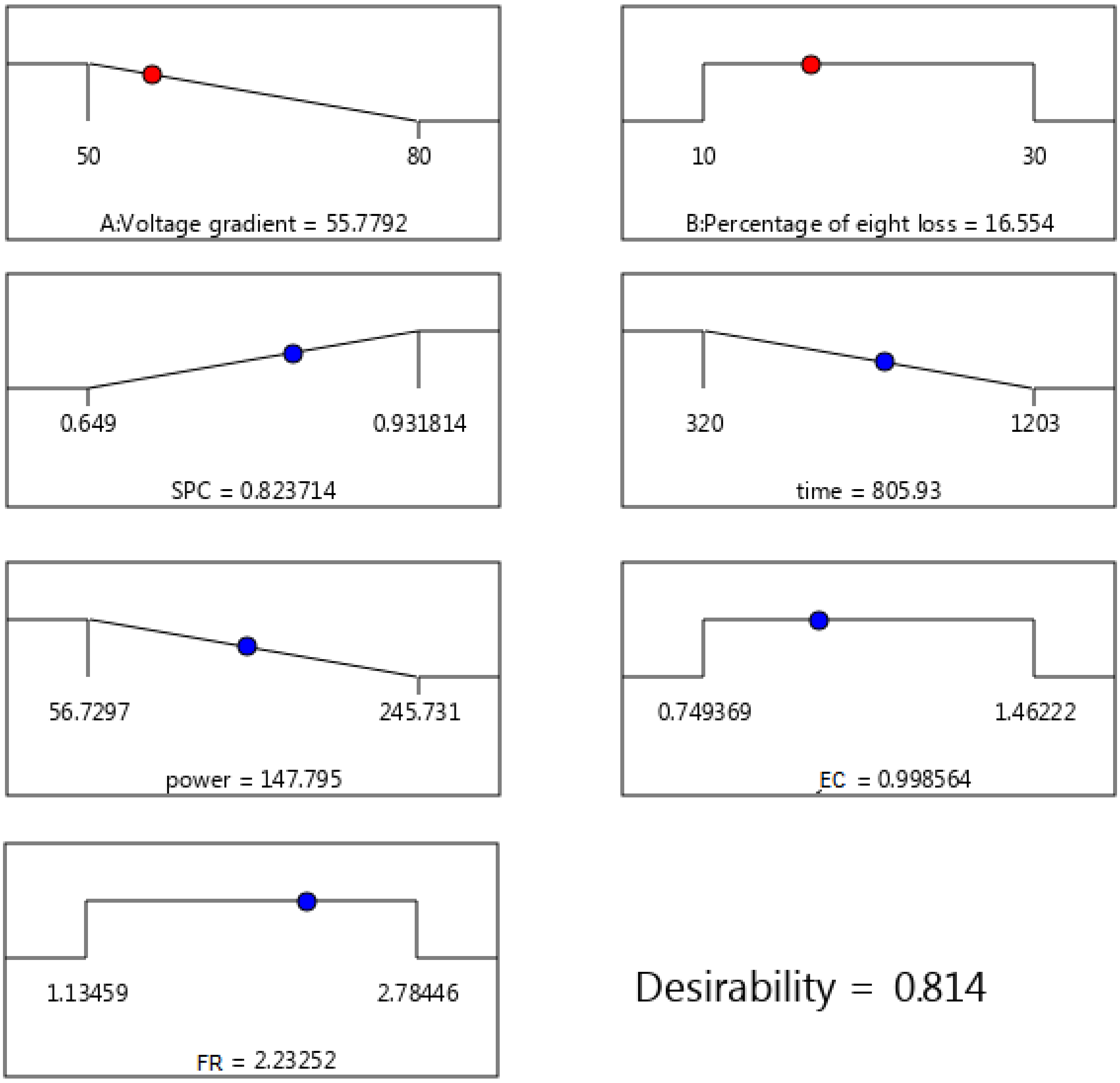


Figure 7 Utility curve used for the numerical optimization

4 Conclusion

According to obtained results from the surface response method, values of Lack of fit were not significant for any factor of system performance coefficient, heating process duration, current rate, power consumption and electrical conductivity. Value of R^2 was greater than 0.80 and was suitable for all studied factors except for the electrical conductivity. On the other hand, the maximum electrical conductivity values were in the range from 70 to 80 V (12.33 and 13.33 V cm^{-1}) and a weight loss percentage of 26%-30%; the maximum heating process duration was at 50 to 54 V (voltage gradient of 8.6 to 9 V cm^{-1}) and a weight loss percentage of 23% to 30%; the maximum power consumption was in a range from 69 to 80 volts (voltage gradient of 11.5 to 13.33 V cm^{-1}) and a weight loss factor of 13-28; and the maximum system performance coefficient was at 50 to 53 V (voltage range from 8.33 to 8.83 V cm^{-1}) and a percentage weight loss of 15%; and the maximum input current was at the voltage of 58 to 80 V (voltage gradient of 9.66 to 13.33 V cm^{-1}) and a weight loss percentage of 13% and above. Furthermore, the best values for weight loss and voltage gradient indicated the best response values in the maximum voltage of 55.779 V and weight loss percentage of 16.554%.

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