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Performance evaluation of a continuous type ohmic heating unit on watermelon juice

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Abstract

Performance evaluation of developed continuous type ohmic heating unit with done by response surface methodology according to Box-Behnken Design for watermelon juice. The low and high levels of the variables were 40 and 50 Hertz for frequency of power supply; 25 and 35 V for applied voltage and 12 and 24lphfor capacity. Response studied was system performance coefficient (SPC). It was found that effects of frequency, voltage and capacity were significant on SPC. Optimum conditions (desirability = 0.825) obtained by numerical optimization were processing time- 5.75 min, Voltage- 75V and product thickness – 14.4 mm to achieve maximum SPC. Corresponding to the optimum conditions, the predicted value for frequency were 42 Hertz, applied voltage 30 V and flow rate 24 lphin order to obtain specific performance coefficient (SPC) of 76.8%.

Keywords: box-behnken design, ohmic heat, system performance coefficient

Introduction

Ohmic heating is a thermal process in which heat is internally generated by the passage of alternating electrical current (AC) through a body such as a food system that serves as an electrical resistance. During OH treatment electric currents are passed through foods, which behave as a resistor in an electrical circuit, and heat is internally dissipated according to Joule's law (Castro *et al*. 2003; De Alwis and Fryer 1989). Because the energy is almost entirely dissipated within the heated material, there is no need for heat intervening heat exchange walls – thus the process has close to 100% energy transfer efficiency (Salengke 2010).The major benefits claimed for ohmic heating technology are the processing without heat transfer surfaces, uniform heating of liquids and, under certain circumstances, heating of solids and carrier fluids at very comparable rates, thus making it possible to use High Temperature Short Time (HTST) technique (Kulshrestha and Sastry, 2003; Parrot 1992; Imai *et al.* 1995). The potential applications of this technique in food industry are very wide and include, e.g. blanching, evaporation, dehydration, fermentation and pasteurization.

OH seems to produce value added products of a superior quality without compromising food safety (Parrot 1992; Castro *et al*. 2003; Tucker 2004; Mudahar, 1989; Florosand Chinnan, 1987). Application of ohmic heating to liquid material foods has proven a greater challenge, and the concept has not yet led to commercial applications in the processing sector. Researches on application of ohmic heating for processing of liquid food have been limited to batch type operations. This limits its applicability for various foods with reduced processing capacity. Ohmic heating can have wider application in food processing when used in continuous mode. The continuous type system will not only increase the processing capacity but also increase its applicability.

Anohmic heating unit was developed at department of Processing and Food Engineering, DRPCAU, Pusa which had a volumetric/processing capacity of 18± 6lph and which can be able to elevate the temperature up to 30 ± 2 ^{0}C (Amitabh and Kashyap, 2014; Kumar, 2016). The present study was undertaken to evaluate the performance of a continuous type ohmic heating unit for watermelon juice.

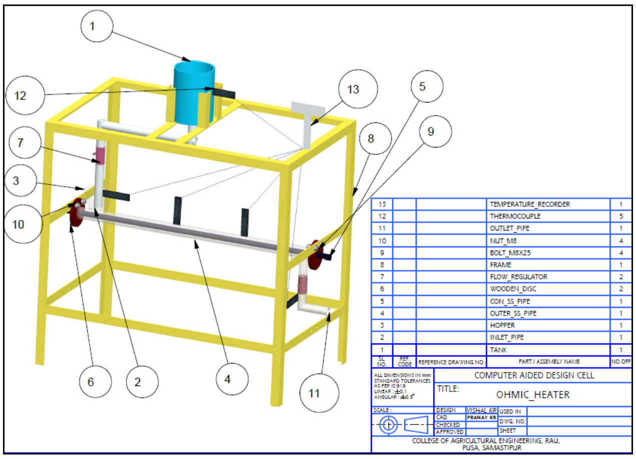
Material and Method

Experimental setup of Ohmic heating unit

The ohmic heating section consisted of two concentric hollow pipes of inner diameter and outer diameter of 50 mm and 75 mm respectively.. The continuous ohmic heating chamber, a concentric plugged with a Bakelite plate which was made leak proof. The electrode gap i.e distance between the two cylinders 1.25 cm, and the cross-sectional area was curved surface area of the cylinder. The product flows along the axis between the electrodes. Temperatures were monitored using a K-type thermocouple, placed at the exit and the geometric centre of the chamber. The supplied power in the chamber was alternating current at 40, 45 and 50 Hz, and voltage was controlled by a variac at 25, 30 and 35 Volts. The test sample was fed to the ohmic heating chamber by a gravity flow, and the flow rate was controlled using control valves at the inlet and outlet of the ohmic heating unit for experimentation at 12, 18 and 24lph. Samples were collected at regular intervals and average temperature of the liquid collected was recorded for the liquid. This sampling procedure was repeated at every 180 seconds up to 900 s.

Experimental Design

The developed ohmic heating unit was also tested for its performance at continuous mode using Box-Behnken Design and Response Surface methodology. This methodology is widely used for bioprocess optimization. RSM is known to be useful in parameter interaction studies which allowed building models and selecting optimum working ranges Around 17 analyses were carried out.The frequency of power supply (A), applied voltage to the ohmic heating unit (B) and flow rate of juice (C) during ohmic heating were taken as the independent variables while temperature attained and specific performance coefficient were dependent parameters. The corresponding parameter levels and codes are listed in Table 2.



SL. NO.	REF. CODE	REFERENCE DRAWING NO.	PART / ASSEMBLY NAME	NO.OFF
13			TEMPERATURE_RECORDER	1
12			THERMOCOUPLE	5
11			OUTLET_PIPE	1
10			NUT_M8	4
9			BOLT_M8X25	4
8			FRAME	1
7			FLOW_REGULATOR	2
6			WOODEN_DISC	2
5			CON_SS_PIPE	1
4			OUTER_SS_PIPE	1
3			HOPPER	1
2			INLET_PIPE	1
1			TANK	1

Fig 1: Schematic diagram showing ohmic heating experimental set up

Table 1: Independent variables used in the optimization.

Independent variable	**Coded value**		
	-1	**0**	**1**
A= Frequency (Hz)	40	45	50
B= Voltage (V)	25	30	35
C = Capacity (lph)	12	18	24

Analysis of data

The data were analyzed using Design Expert 8 (Stat-Ease, Minneapolis, MN, USA) to obtain a quadratic mathematical model. RSM has been used with composite Box-Behnken Designto optimize ohmic heating process variables. Regression analysis and analysis of variance (ANOVA) were conducted for fitting the model represented by Eq. (1) to the experimental data and to examine the statistical significance of the model terms.

$$Y = a_o + \sum_{i=1}^{n=3} a_i x_j + \sum_{i=1}^{n=3} \sum_{j=1}^{n=3} a_{ij} x_i x_j \qquad \ldots(1)$$

where: Y, a_0, X_i and X_j, a_i, and a_{ij} are the predicted responses of the dependent variable, second-order reaction constant, independent variables, linear regression coefficient, and regression coefficient of interactions between two independent variables, respectively.

The adequacies of the models were determined using model analysis, lack-of-fit test, and R^2 (coefficient of determination) analysis as outlined by Lee *et al.*, 2000; Weng *et al.*, 2001 and Sastry and Barach, 2000. The lack-of-fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression and variations in the models cannot be accounted by random error (Montgomery, 1984). If there is a significant lack of fit as indicated by a low probability value, the response predictor is discarded. The R^2 (coefficient of determination) is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit (Haber andRunyon, 1977). Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the model prediction. Response surfaces were generated and numerical optimization was also performed by Design Expert software.

Optimization Technique

Numerical optimization technique of Design Expert was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The possible goals were maximize, minimize, target, within range, none (for responses only). All the independents factors were kept within the experimental range while the responses were either maximized or minimized. In order to search a solution for multiple responses, the goals were combined into an overall composite function, D(x), called the desirability function (Myers and Montgomery, 2002) which is defined as ð2Þ

$$D(x) = [d_1 X d_2 X d_3 X \ldots\ldots d_n]^{1/n} \qquad (2)$$

where d_1, d_2,..., d_n are responses and n is the total number of responses in the measure. The function D(x) reflects the desirable ranges for each response (di). Desirability is an objective function that ranges from zero (least desirable) outside of the limits to one (most desirable) at the goal. The numerical optimization finds a point that maximizes the desirability function. The goal-seeking begins at a random starting point and proceeds up the steepest slope to a maximum. There may be two or more maximums because of curvature in the response surfaces and their combination into the desirability function. By starting from several points in the design space, chances improve for finding the best local maximum.

Parameter for performance evaluation: System performance coefficient (SPC)

Temperatures were monitored using a K-type thermocouple, placed at the exit and the geometry centre of the chamber. Temperatures were recorded at 180 sec. interval by temperature recorder attached with the thermocouple. The performance of the ohmic heating unit was evaluated by system performance coefficient (SPC) which is ratio of energy converted to useful work to energy provided to the system (Nargesi *et al.*, 2011).

$$SPC = \frac{Heatcapacity}{Joule'sheat} X\ 100 = \frac{mC_{p(T_{f}-T_{i})}}{VIt} x100 \ldots (3)$$

Where

m = mass (Kg)
C_p= specific heat capacity (J/Kg^{0}C)
T_f = final temperature (^{0}C)
T_i = initial Temperature (^{0}C)
V = electric potential (V)
I = Electric current (A)
t = Time (second)
SPC = system Performance Coefficient

Results and Discussion

Performance evaluation of Ohmic heating unit in continuous mode

The experimental data of various responses during OH of watermelon juice are presented in Table 2. The estimated regression coefficients of the quadratic polynomial models (Eq. (1)) for various responses and the corresponding R^2 and CV values are given in Table 3. Analysis of variance indicated that the models are highly significant at $p\leq 0.05$ for all the responses. The lack of fit did not result in a significant F-value in case of System performance coefficient (SPC) indicating that the models are sufficiently accurate for predicting these responses supported by low value of PRESS and CV and high values of both R^2 and adj-R^2 ($\geq$ 0.80). Despite the lack of fit is significant in the case of overall acceptability (O_A), acceptable PRESS, CV (less than 10%), R^2 and adeq. precision values indicates that the model is sufficient to predict the response (Madamba, 2002; Rustom *et al.*, 1991).

As a general rule, the coefficient of variation should not be greater than 10%. In this case, the coefficients of variation for all the responses were less than 7% (Table 4). A Model F-value of 7.399, 7.706, 6.706, 4.640 and 25.931 for colour index (L_a), temperature (T), water activity (a_w), penetrating force (H) and overall acceptability (O_A) respectively implies that the model is significant. The Fisher F-test with a very low probability value (P model ≥ F at 0.05) demonstrates

Table 2: Box Behnken Design Matrix with Calculated Values of Response (dependent) Variables

Exp. No.	Independent Variables						Dependent Variables SPC (%)
	Coded Level			Real Values			
	X_1	X_2	X_3	X_1	X_2	X_3	
1.	0	1	-1	45	35	12	63.80
2.	0	1	1	45	35	24	62.45
3.	0	-1	-1	45	25	12	56.71
4.	0	-1	1	45	25	24	50.07
5.	1	0	-1	45	30	12	59.58
6.	1	0	1	50	30	24	59.89
7.	-1	0	-1	50	30	12	60.59
8.	-1	0	1	50	30	24	54.09
9.	1	1	0	50	35	18	71.32
10.	1	-1	0	50	25	18	52.16
11.	-1	1	0	40	35	18	61.74
12.	-1	-1	0	40	25	18	51.12
13.	0	0	0	45	30	18	54.34
14.	0	0	0	45	30	18	54.34
15	0	0	0	45	30	18	52.89
16	0	0	0	45	30	18	55.78
17	0	0	0	45	30	18	52.88

Regression Analysis of Ohmic Heating Process

ANOVA was constructed to assess the significant effects of the variables on the responses. The full second order multiple regression models were regressed for all the responses at different processing conditions and the regression coefficients along with coefficient of determination (R^2) were calculated. The sign and magnitude of coefficients indicate the effect of variable on the response. Negative sign of the coefficients means decrease in response when the level of the variable is increased while positive sign indicates increase in the response. Significant interaction suggests that the level of one of the interactive variable can be increased while the other decreased for constant value of response.

The Model F-value of 5.668 implies the model is significant and there is only 2.511% chance that a "Model F-Value" this large could occur due to noise. The Fisher F-test with a very low probability value (P model ≥ F at 0.05) demonstrates a very high significance for the regression model. Values of "Prob> F" less than 0.0500 indicate model terms are significant.

The overall variation in system performance coefficient (SPC) was between 42.08 and 78.39. The minimum system performance coefficient (SPC) was 42.08 observed at combination of frequency (A) – 45 hertz, applied voltage (B) - 30 V and flow rate (C) - 18 lph. However, the maximum system performance coefficient (SPC) 78.39 was observed at combination of ohmic process frequency (A) – 50 hertz, applied voltage (B) - 35 V and flow rate (C) - 18 lph. The second order polynomial multiple regression equation for explaining the effect of variation in ohmic process parameters A, B and C on T is as follows:

$$\mathbf{SPC = 49.208 - 4.130\,A + 2.030\,B + 5.024\,C - 1.190\,AB - 4.588\,AC + 4.435\,BC - 1.012\,A^2 + 5.172\,B^2 + 7.070\,C^2}\ (R^2 = 0.883) \quad \dots (4)$$

[A= frequency, B = applied voltage and C = flow rate]

The relative magnitude of coefficients indicates the negative contribution of linear term of A; interactive effects of AB and AC and squared effect of A. The estimated regression coefficients of the quadratic polynomial models (Equation 4) for various responses and the corresponding R^2 and CV values are given in Table 2. Analysis of variance indicated that the models are highly significant at $p\leq 0.05$ for all the responses. The lack of fit did not result in a significant F-value in case of A, B and C indicating that the models are sufficiently accurate for predicting these responses supported by low value of

PRESS and CV and high values of R^2 ($\geq$ 0.80). Acceptable PRESS, CV (less than 10%), R^2 indicates that the model is sufficient to predict the response (Rustom *et al.*, 1991).

To visualize the combined effect of the two factors on the response, the response surface and contour plots were generated for each of the models in the function of two independent variables, while keeping the remaining independent variable at the central value (Fig 2). The flow rate (C) having lowest F-value, had least effect on SPC and therefore was kept fixed along to generate response surface diagram between B and C (fig 2). The figure clearly indicates increased system performance coefficient (SPC) changes with the rise A and B. An increase in B will increase SPC but increase in A will increase SPC but at higher values of A, there was decrease in SPC values

Table 3: ANOVA for effect of independent parameters for response surface quadratic model on temperature

Source	Sum of Squares	NF	Mean Square	F Value	Prob> F
Model	880.592	9	97.844	5.688	0.02511**
A-Frequency	136.458	1	136.458	12.355	0.0668*
B-voltage	32.980	1	32.980	8.569	0.0775*
C-Flow rate	201.925	1	201.925	3.485	0.0804*
AB	5.663	1	5.663	0.098	0.7637ns
AC	84.190	1	84.190	1.453	0.2672ns
BC	78.687	1	78.687	1.358	0.2821ns
A^2	4.315	1	4.315	0.074	0.7928ns
B^2	112.633	1	112.633	1.944	0.02059**
C^2	210.440	1	210.440	3.632	0.0984*
Residual	405.632	7	57.947		
Lack of fit	146.567	3	48.856	0.754	0.5747ns
Pure Error	259.065	4	64.766		
Cor Total	1286.224	16			
Std. dev.	7.162				
R^2	0.883				
C.V. %	5.969				
PRESS	9.669				

** Highly significant at 1 % level, * significant at 5 % level, ^{ns} non-significant

In order to optimize the process conditions during ohmic heating, the following considerations were taken: (1) Maximization of T and (2) Maximization of SPC. Optimization was carried out with the help of commercial statistical package (Design Expert, Trial Version 7.0, State Ease Inc., Minneapolis, IN statistical software). The optimum solution from this package was emerged out as frequency (A) – 42 Hertz, applied voltage (B) – 30 V and flow rate (C) – 24 lph in order to obtain system performance coefficient (SPC)-76.84% with desirability of 0.825

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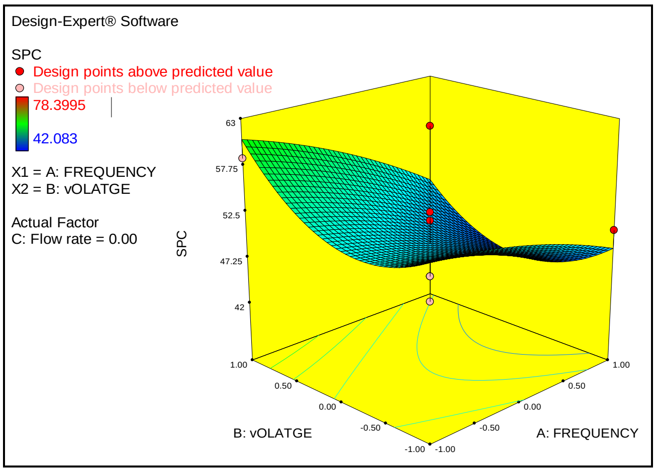

Fig. 2: Response surface showing effect of voltage (B) and frequency (C) on system performance coefficient (SPC)

Conclusions

Ohmic heating can have wider application in food processing when used in continuous mode. The developed ohmic heating was evaluated for its performance in continuous mode on watermelon juice at frequency (A) of alternating current at 40, 45 and 60 Hz; applied voltage (B) at 25, 30 and 35 Volts and volumetric flows rate (C) at 12, 18 and 24 lph.For ohmic heating of watermelon juice in continuous mode, the optimize the process conditions emerged out as frequency (A) – 42 Hertz, applied voltage (B) – 30 V and flow rate (C) – 24 lphin order to obtain optimized yield asspecific performance coefficient (SPC)- 76.84 with desirability of 0.825.

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