



OPTIMIZATION ANALYSIS OF HEAT ENERGY REQUIRED IN GARRIFICATION PROCESS USING A GARRI FRYER POWERED BY ELECTRICAL FILAMENTS AS HEAT SOURCE

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ABSTRACT

Frying is the most tedious unit of garri processing. The amount of heat applied during the processing operation determines the end quality and market value of the product. Thus, this study is aimed at investigating the effect of pre-processing conditions on the heat energy of an auto garri frying machine. A 4-factor, 5-level D-optimal design of response surface methodology (RSM) was used for modeling and optimization of the process. The mash quantity, frying time, initial moisture content and temperature were varied over 10, 20, 30, 40, and 50 kg; 15, 30, 45, 60, and 75 mins; 30, 35, 40, 45, and 50% wet basis (wb); and 140, 160, 180, 200, and 220 °C, respectively. The results showed that a linear model F -value of 61.08 implies that the model was significant with value of R^2 (0.8526) and $Adj-R^2$ (0.9092) indicating that there was a high correlation between the dependent and independent variables. In optimizing the process, the heat energy was maximized while the independent variables were set at ranges. Optimum heat energy of 14,000 J was obtained at 45.33 kg mash quantity, 67.37 mins frying time, 40% wb initial moisture content and 180 °C frying temperature at the desirability of 1. At $\alpha = 0.05$, the analysis of variance (ANOVA) showed that the mash quantity, frying time and temperature had direct significant impacts on heat energy of the garri frying machine while the initial moisture content had no significant effect on the heat energy.

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1.0 Introduction

Cassava plant (*Manihot esculenta* Crantz) is shrub farmed for its underground starchy tubers throughout the tropics and subtropics (Friday et al., 2021). The periderm, or outside layers of the tuber, the cortex, or thick layer immediately beneath the periderm, and the starchy fleshy, center region of the tuber, which comprises of parenchyma cells packed with starch granules are the three main areas of a cassava tuber or roots (Zierer et al., 2021). The tuber's edible starchy flesh accounts for 80 – 90% tuber's weight (Peprah et al., 2020; Salvador et al., 2014), making it a major source of carbohydrates and a staple diet eaten by not less than 800 million people worldwide (Jose-Luis et al., 2020; Lebot, 2009). The edible part of cassava contains about 1 – 3% protein, 30 – 35% of amyloses and amylopectins (carbohydrates) on a dry weight basis, 62% water, 1 – 2%, fibre, 1% minerals, and 3% fat (Salvador et al., 2014) and the peels are used for processing of animal feeds and generation of biogas. Despite this huge benefit of cassava roots, about 820 million suffered from malnutrition and hunger in the world (Ashebir, 2021).

Cassava production has experienced consistent annual growth of about 3% globally ([FAO, 2018](#)). According to FAOSTAT (2019), the world cassava production stood at about 278 million tones. Africa led with about 56% (170 million tonnes) of the world production with Nigeria being the largest producer with an average production of 60 million tonnes. Despite the fact that Nigeria is the largest producer of cassava in the world, it is also largest consumer in the world as more than 90% of cassava produced is utilized or consumed locally (Tridge, 2021; Ikuemonisan *et al.*, 2020) - thus, this could be the reason for the massive production of it in Nigerian States. Therefore, this demonstrates that there is a feasibility and enormous potential in cassava business which could contribute greatly to the agricultural sector and Nigerian's economy at large. The majority (over 84 %) of cassava roots cultivated in Nigeria is used for human consumption which goes into processed products like garri, fufu, pellets, tapioca, tidbits, lafun, chin-chin, flour, abacha, bread, chips and so many other confectioneries (Ikuemonisan *et al.*, 2020; Kormawa and Akoroda, 2003). The remaining 16% of the roots is traceable to industrial usage such as starch, biogas, livestock feed, glue, ethanol and there is hope more portions of it could still go into industry in future (Ikuemonisan *et al.*, 2020).

In Nigeria, there is no doubt that cassava roots are most important food components capable of eradicating food insecurity. However, the major challenge with it is the short postharvest shelf life, 2 –3 days immediately after harvest. Therefore, the roots must be consumed or converted into long-lasting as fast as possible after harvest. Cassava root is an extremely high-energy containing food (Jose-Luis *et al.*, 2020), with a high yield of carbohydrates per acre which generates roughly 250,000 calories per hectare per day, placing it ahead of sorghum, wheat, rice, and maize. But it is subjected to postharvest losses (PHL) also known as physiological deterioration (PPD) shortly after the roots are harvested from the field faster than these food crops (Awoyale *et al.*, 2020). Garri, flour and Chips are the common products from cassava roots that can stay long period if well processed. Garri is the most widely traded cassava products, accounting for more than 75 per cent of produce extracted from cassava (Akinfenwa, 2020). It is the daily major source of food in Brazil, Nigeria and most West African nations. Garri manufacturing technology is the popular advanced cassava root processing technology now in Nigeria because of vitality of the food component. It is a pre-gelatinized grit with particle sizes ranging from less than 10 micrometers (fines) to more than 2000 micrometers (coarse) (Nwankpa, 2010). Garri frying is a cooking and dehydration process in which the food is cooked while still moist and then dehydrated. The amount of heat applied during frying determines the product's quality. In the village approach, the initial frying temperature is kept low to prevent many lumps or cakes formation. The temperature is further raised to cook and dehydrate the product as the moisture content decreases. At this time, most of the little lumps would have been broken down by constant agitation and pressing (Olagoke *et al.*, 2014). The heat is a form of energy that transfers from the higher temperature product to the lower temperature product, and is transferred through the conduction, convection and radiation mechanisms depending on the product's form. Therefore, the study is aimed to investigate the effect of heat energy applied to a given garri processing operation using an automated frying machine.

2. Materials and Methods

2.1 The Study Area and Sources of Materials

This research was carried out at a cassava processing centre (CPC) in the International Institute of Tropical Agriculture (IITA), Ibadan Headquarters. IITA is a non-governmental research for development (R4D) organization that offers research partnership to improve livelihoods, enhance food and nutrient security throughout sub-Saharan Africa. IITA is situated at Idi-Ose Moniya, Oyo Road, Ibadan, Oyo State, Nigeria. A research variety of cassava roots, TME 419 with low water and high dry matter (starch) content was obtained for the experimental study from one of the Institute's departments called cassava breeding. The variety was selected based on its high starch content for good garri production.

2.2 Sample Preparation

250 kg of wet mash sample was obtained and used for processing 1000 kg fresh cassava roots of TME 419 (Tropical Manihot Esculanta). The sample was divided into 5 different places each containing 50 kg. The initial moisture content was kept at 30% wb, frying time interval was 60 minutes and the normal speed of the machine was 84 rpm. Moisture content was determined in equation 1 and 2 using the American Society of Agricultural Engineers Standard S410.1 Dec. 1997 (ASABE Standards, 2003). The electrical filaments capacity of 2.5, 5.0, 7.5, 10.0 and 12.5 kW were used as the heat sources and the resultant heat effect generated at various temperature levels, 140, 160, 180, 200, and 220 °C, respectively. The choice of this temperature range was based on the report of Nwankpa (2010) which stated that the temperature range for garri varies from 120 – 200 °C. Also, the selection was based on the study carried out by Okorun et al. (2017) with a varying garri frying temperature range of 180 – 200 °C. The heat and time required for a given garri frying operation were estimated in equation 3 and 4.

$$MC_{db} = [MC_{wb}/(100 - MC_{wb})] 100\% \quad (1)$$

$$m_w = MC_{db} \times m_d \quad (2)$$

$$Q = M_a C \Delta T \quad (3)$$

$$\Delta t_m = \frac{\Delta m L_h}{\frac{\Delta Q}{\Delta t}} \quad (4)$$

Where: MC_{db} = moisture content (dry basis), MC_{wb} = moisture content (wet basis), m_w = mass of water to be added, m_d = mass of dry matter, Q = heat quantity, M_a = the mass of cassava mash in the cylinder C = the specific heat capacity of the mash, ΔT = temperature range, $\Delta t = \frac{\Delta Q}{\Delta t}$ = heat rate, L_h = Latent heat of transformation, Δt_m = time interval in minutes, Δm = mass of the cassava mash.

2.3 Description of the Machine

The automated industrial garri frying machine has two major component parts; the mechanical and the electrical/electronic part. The former gives the machine its shape and size in terms of capacity, while the later is the centre for control and operation of the entire system which consists of the automated parts. The mechanical components used include the following: 4 mm stainless sheet, 2 mm mild steel sheet, metal-steel rod of 32 mm, mild-steel rod of 2 mm, 205 pillow bearings, 2.0 hp electric motor, reduction gears in form of chain and sprockets, fan belts, cast pulleys, bolts and nuts, electrical filaments, u-channel mild steel, and heat resisting fibres. The electrical/electronic components include: Microcontroller, transformer, capacitor, temperature control modules, 3-phase control switch, electrical sockets and switches, 4MHz –crystals, 12V contactors, relays, capacitors, vero-board, resistors, transistors, regulators, integrated circuit; light emitting diodes (LED), leads, connecting wires, plugs insulating sleeves, board casing, LCD display sensors, solenoids push switches, 7 segment displays, rectifying diodes, and 4 x 4 Keypad Module.

The machine is user-friendly and can be operated by a single user. It has a switch button for starting and ending the operation. Immediately the switch-on button is engaged, the mechanical paddles start to rotate (fry the garri) and the automated system comes on but allows the user to adjust the frying temperature, time and final moisture content (humidity of friable substance) to his/her desirable measurable level with the set of the buttons on it. After the adjustment and the okay button is clicked, the paddles continue to fry the garri as the electrical filaments temperature start rising not until it reaches the set level with time or final moisture content intervals inputted. Also, as soon as the desired product quality or set parameter level is reached, the automated system trips off while the mechanical paddles continue in rotation to prevent the burning of the product and aid the cooling process of the product. During evacuation time, as the paddles are still in continuous rotation and the discharge chute gate is opened, the products are pushed out of the frying chambered.

2.4 Statistical Optimization Analysis

Optimization analysis was carried out using Response Surface Methodology (RSM). In the optimization process. RSM at 4-factors and 5-levels (Initial Moisture Content 30, 35, 40, 45, and 50%; Frying Temperature 140, 160, 180, 200, and 220°C; Frying Time 15, 30, 45, 60, 75 minutes; and Mash Quantity 10, 20, 30, 40, 50 kg) was used to carry out the simultaneous testing of the effects between and within parameters in the optimum experiment. The raw data of the independent variables (Initial MC, temperature, time, and mash quantity) were inputted into the research software as shown in Table I. D-optimized design module in Design Expert software (Version 11.0) was used to develop mathematical equations where the predicted results were assessed as a function of mash quantity (x_1), frying time (x_2), Initial moisture content (x_3) and frying temperature (x_4) and calculated as the sum of a constant, four first-order as shown in equation 5:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + \quad (5)$$

The coefficients of the polynomial were represented by b_0 (constant); b_1, b_2, b_3, b_4, b_5 (linear effects); $b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, b_{34}$ (interaction effects); $b_{11}, b_{22}, b_{33}, b_{44}, b_{55}$ (quadratic effects); and (random errors). The quality of the polynomial model is expressed using the determination coefficient, namely R^2 and Adj- R^2 . ANOVA equations were modified by eliminating the statistically insignificant terms. At 0.05 level of significant, the calculated F value was compared with the tabulated F when the df was 14 and $n = 25$.

3. Results and Discussion

3.1 Effect of Independent Variables on the Heat Energy of the Machine

The heat energy of the automated garri frying machine analysis was based on the mash quantity, frying time, initial moisture content, and temperature. As shown in Table 1, the heat energy of the machine was in the range of 1794.51 to 18793.2 J having the maximum fraction to minimum of 10.47. A fraction greater than 10 usually means that a change is needed and a fraction smaller than 3 indicates a small effect. The main impact of the interaction determined for each factor on the heat energy is given in Table 2. The Table depicts the analysis of variance in the result generated with average heat energy at different processing conditions (mash quantity, frying time, initial moisture content, and frying temperature). The results also showed the design of experiment matrix generated through the use of RSM; having actual and coded values of the input variables along with one output response effects (terms in x_1, x_2 , and x_4) and one interaction effect (x_1x_2) as shown in equation 6. A reduced linear model in terms of coded factors was observed and the model was significant ($p < 0.05$). The following coded response equation was obtained for variation of Heat Energy, Y_{HE}

$$Y_{HE} = 7551.88 + 4482.01x_1 + 2288.41x_2 + 1030.86x_4 + 2280.69x_1x_2 \quad (6)$$

It was observed from the model equation (6) that the coefficients of x_1, x_2 and x_4 are all positive. This implies that a unit increase in the mass quantity (x_1), frying time (x_2) and frying temperature (x_4) will lead to a significant increase in the heat energy of the automated garri fryer by 4482.01 J, 2288.41 J, and 1030.86 J, respectively. The interaction between the mass of the cassava mash and the frying time gives a progressive increase value of 2280.69 J when there is a unit change in the production process. This result is in close agreement with that of Sanni et al (2015a; 2015b) which stated that time and temperature have greatest effect on the drying process. Although, there was increase in heat energy as the moisture content of the samples was increased, however, statistical analysis showed that the initial moisture content (x_3) has no significant impact on the samples used as shown in Figure 1. This conformed with the result Sanni et al (2016) that initial moisture content has no significant impact on heat energy.

Table I: D-optimal design experiments and experimental Results

Run	Factor 1 A: Mash Quantity (kg)	Factor 2 B:Frying Time (mins)	Factor 3 C:Initial MC (%)	Factor 4 D:Temperature (Deg.Celcius)	Response 1 Heat Energy (J)
1	10	15	50	220	3477.62
2	40	15	30	140	5255.85
3	30	30	40	160	5896.11
4	50	75	30	220	16751
5	10	75	40	220	3400.37
6	50	15	40	220	5630.19
7	50	45	40	160	10672.5
8	50	75	50	220	18793.2
9	20	30	50	140	3900.72
10	30	30	40	160	7039.32
11	10	15	40	140	1794.51
12	30	15	50	180	5595.99
13	50	30	50	140	9748.61
14	10	60	35	180	2698.82
15	20	30	30	180	4851.13
16	10	15	30	220	3252.6
17	10	75	30	140	1968.9
18	10	60	35	180	2703.62
19	50	75	40	140	11402.6
20	10	75	50	140	2220.42
21	30	45	40	220	10367.6
22	50	75	40	140	17706.6
23	50	45	30	180	13617.1
24	30	15	50	180	5578.12
25	30	45	40	220	10674.7

Table 2: Model Analysis Data for the Heat Energy Response Variable for the Automated Garri Fryer

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	5.822E+008	4	1.455E+008	61.08	< 0.0001	Significant
x_1	3.161E+008	1	3.161E+008	132.67	< 0.0001	
x_2	8.066E+007	1	8.066E+007	33.85	< 0.0001	
x_4	1.733E+007	1	1.733E+007	7.27	0.0139	
x_1x_2	5.816E+007	1	5.816E+007	24.41	< 0.0001	
Residual	4.766E+007	20	2.383E+006			
Lack of Fit	2.709E+007	15	1.806E+006	0.44	0.9006	not significant
Pure Error	2.057E+007	5	4.114E+006			
Cor Total	6.298E+008	24				

Design-Expert® Software

Factor Coding: Actual

Heat Energy (J)

● Design points above predicted value

18793.2

1794.51

X1 = B: Frying Time

X2 = C: Initial MC

Actual Factors

A: Mash Quantity = 30

D: Temperature = 180

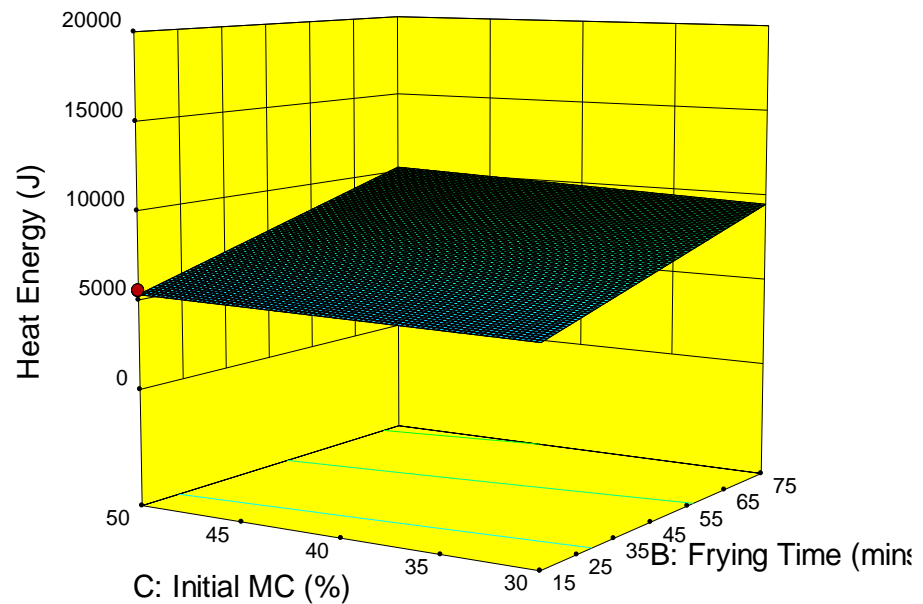


Figure 1: The 3-Dimensional Surface Curve for Variation in the Heat Energy at the Mash Quantity of 30 kg and Frying Temperature of 180°C

The model F-value of 61.08 implies that the model is significant. The value of R^2 (0.8526) and Adj- R^2 (0.9092) are in a close agreement since the difference between them is less than 0.2. Thus, indicating that there was a high correlation between the observed values and predicted values. According to the Demirel and Kayan (2012), the regression model provides an excellent explanation of the relationship the independent variables and the response. P-value for the interaction between mash quantity (x_1) and frying time (x_2) was significant. The 3-dimensional surface curve for variation in the heat energy of the automated garri fryer was shown in Figure 2. This Figure shows that the heat energy in respect to frying time and mash quantity gives greatest impact or effect on the garri drying process. It was observed from the figure that as mash quantity and frying time increase in the production process, the heat energy of the fryer increases progressively. It was observed from the figure that as mash quantity and frying time increase in the production process from 10 – 50 kg and 15 – 75 minutes, respectively, the heat energy of the fryer also increases from about 3,000 J to 16,500 J. The result of Sanni (2014) corresponded with this finding which stated that heat energy increases with increase in mash sample and processing time. Figure 3 confirms that the interaction between the frying time and temperature is statistically significant and that as heat energy increases, the frying time and temperature directly increases.

In Figure 4, the minimum heat energy (4,000 J) was observed at the processing conditions of mash quantity (18 kg), frying time (14.16 mins), initial moisture content (40% wb) and frying temperature (180 °C) while the maximum heat energy range seen at 14,000 J at mash quantity (36 kg), frying time (67.37 mins). The Figure is called Contour graph and was used to shows minimum and maximum values of the heat energy at chosen factors of initial moisture content and frying temperature. It was used to represent the points where all processing parameters used in the experiment meet the desirable heat energy. This also confirms that the heat energy increases with the increase in mash sample and frying time. Additionally, Figure 5 shows the graph of the predicted values versus actual values which proved that approximately linear data points obtained were devoid of any statistical problem i.e there was no sign of any problem in the data. The closeness of the data along the curve line is the indication that the result better fit the model. Similarly, Figure 6 shows the perturbation plot of the heat energy and the independent variables used indicating the silhouette view of the response surface. That is, how heat energy changes as each factor (mash quantity, time, temperature and initial MC) moves from a chosen reference point, 30 kg, 45 mins, 180°C, and 40% wb, respectively with all other factors held constant at reference value of 7,500 J.

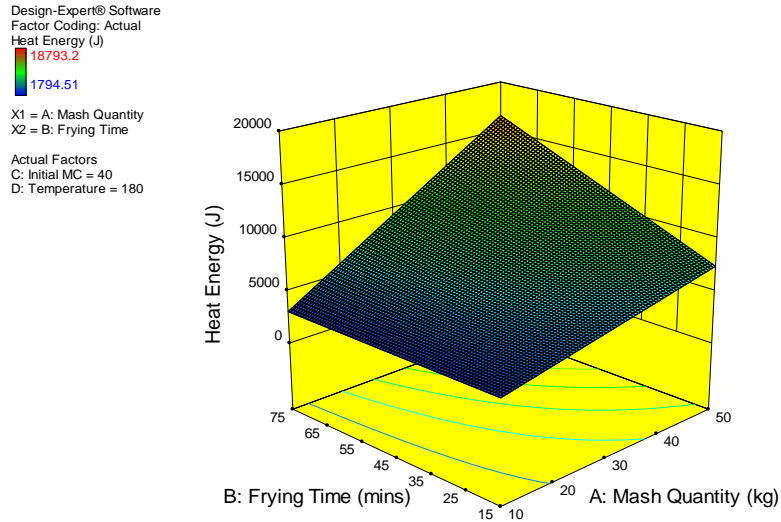


Figure 2: The 3-Dimensional Surface Curve for Variation in the Heat Energy at the Initial Moisture Content of 40% and Frying Temperature of 180°C

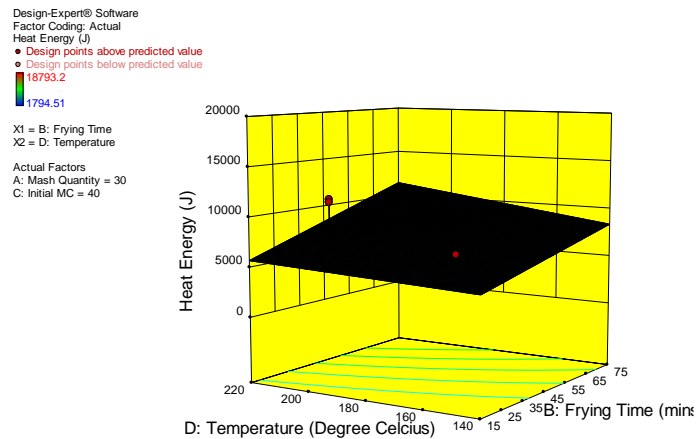


Figure 2: The 3-Dimensional Surface Curve for Variation in the Heat Energy at the Mash Quantity of 30 kg and Initial Moisture Content of 40%

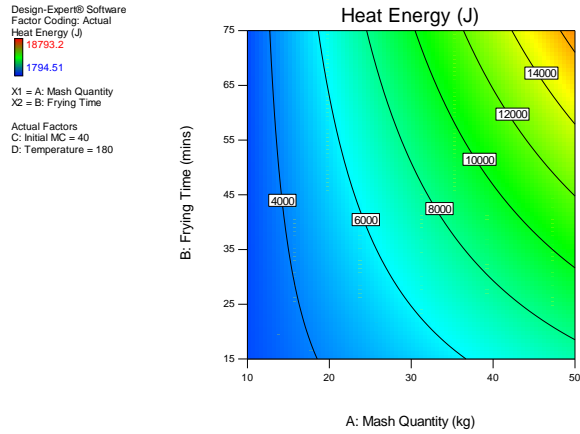


Figure 4: The Contour Graph for the Variation in the Heat Energy at the Initial Moisture Content of 40 % and Frying Temperature of 180 °C

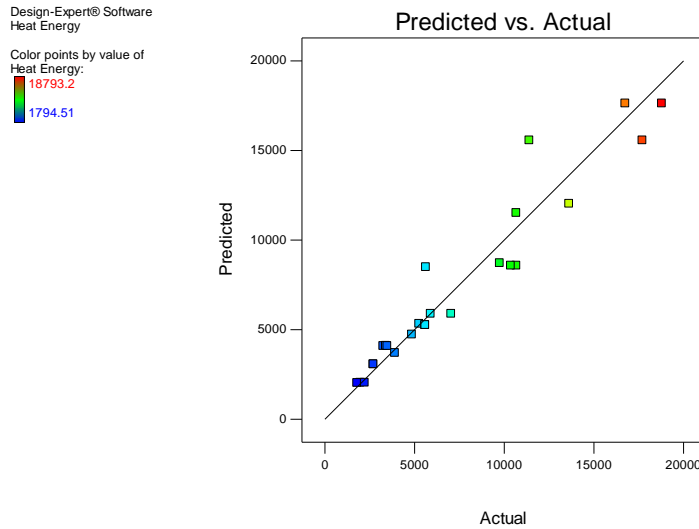


Figure 5: The Graph of the Predicted Values versus Actual Values for Heat Energy

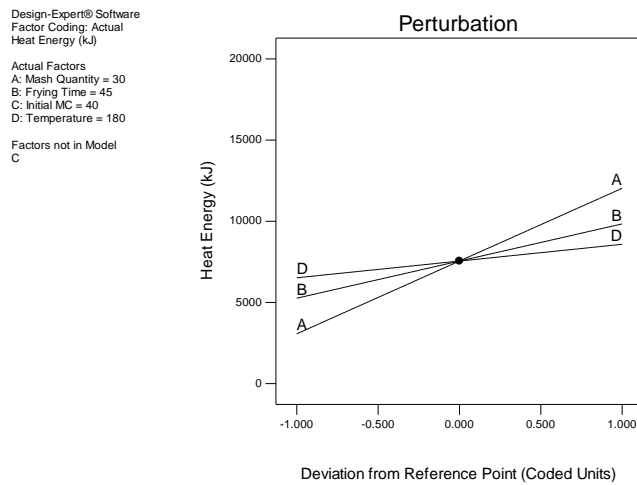


Figure 6: The Perturbation Plot for Heat Energy

4. Conclusion

The effect of the processing parameters such as mash quantity, frying time, initial moisture content and frying temperature on the heat energy in an automated garri frying machine made with electrical heating filaments as the heat sources was investigated. Models predicting the relationships between the variables were developed. Optimum heat energy of the system obtained was 14,000 J at the mash quantity (45.33 kg), frying time (67.37 mins), initial moisture content (40% wb) and frying temperature (180 °C). The model validation showed an excellent agreement between the preprocessing conditions and the response. The result of the analysis indicated that mash quantity, frying time and temperature had a significant effect on the heat energy of the automated garri fryer.

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