ISSN 2229-5518

Optimization of Specific Mechanical Energy Consumption of a Palm Nut-Pulp Separator Using Mathematical Programming Technique

Nwankwojike B. Nduka, Agunwamba C. Jonah, Ogbonnaya A. Ezenwa

Abstract

The influences of the driving power, P cake breaker speed, N_c auger speed, N_a and helix angle, α of a palm nut-pulp separating machine on its specific mechanical energy consumption, *SE* was evaluated and quantified in order to determine the optimal setting of these operational parameters at which the separator will operate with minimum energy consumption as well as maximum efficiency and throughput possible. This optimization was performed using mathematical programming modeling in which the developed *SE* model formed the objective function minimized, subject to the constraints of it efficiency, throughput and factor levels within which the operational parameters influence the responses significantly. *SE* model analysis showed that the main effects of all the operational parameters provided strong primary contribution to the specific energy mechanical consumption of the separator while the quadratic effects of the auger speed, N_a^2 and cake breaker speed N_c^2 and interactions of N_aN_c, N_aP, $N_a\alpha$, N_cP, $N_c\alpha$, $N_aN_c\alpha$, $P\alpha$ and $N_aP\alpha$ provided secondary effects to the response. The optimization results revealed that the palm nut-pulp separator is more efficient and energy saving when operate at an optimal driving power, cake breaker speed, auger speed and helix angle setting of 4.103kW (5.5Hp), 2821rpm, 2116rpm, and 45^0 for respectively. The machine performed with an average specific mechanical energy consumption of 16.41kJ/kg, efficiency of 95% and throughput of 900kg/h at this factor setting. This indicates 38.61% reduction in specific mechanical energy consumption of the separator, and increase in its efficiency and throughput by 1.06% and 3.72% respectively when compared with that of the factor settings previously obtained from the graphical optimization of the machine.

Key words: Mathematical programming model, Operational parameters, Optimization, Palm nut-pulp separator, Specific mechanical energy consumption

Nomenclature

m_o Total mass of the pulp and nuts separated, kg

m_i Mass of digested mash input into the machine, kg

t Processing time, s

SE Specific Mechanical Energy Consumption, kJ/kg

η Separating efficiency, %

TP Throughput, kg/h

N_a Auger speed, rpm

α Helix angle of the augers, ^{0}

N_c Cake breaker speed, rpm

P Mechanical power output of electric motor, W

1.0 Introduction

Palm nut-pulp separator is a machine developed for separating digested palm fruit cake into palm nut and pulp before pressing of the digested pulp for palm oil extraction in order to eliminate nut breakage and excessive loss of palm oil to pressed fibre in the mechanized palm fruit processing as proposed by [1]. Prior to the introduction of this new unit operation of nut-pulp separation in the mechanized palm fruit processing, the mash from oil palm fruits digestion process were usually pressed before the separation of the nuts and pressed fibre. Thus, the present day mechanized palm fruit processing is characterized by 9-22% nut breakage/crushing, 9-11% palm oil loss to pressed fibre, palm oil and palm kernel oil of undesired physiochemical properties and second pressing [2], [3], [4], [5]. The developed palm nut-pulp separator comprising a feed hopper, cake breaker, auger separator, electric motor, nut and pulp outlet chutes had its internal wall lined with score pad to ensure that the nuts neither break nor sustain internal injury as their hit the walls during cake breaking. The electric motor drives the auger shaft which in turn drives that of the cake breaker. The separation process starts with the slacking of the fairly compacted palm fruit mash from the digestion process as it falls from the hopper across the rotating cake breaker beaters (in the upper chamber of the machine) into the right end of the lower chamber of the machine by gravity, thereby detaching the entangled palm nuts from the digested pulp. The slacked mash is then separated into pulp and nuts as the auger conveys it from the right to the left end of lower chamber, the pulp escapes through the 2.5mm-wide slit into the pulp discharging chute, while the nuts (free of pulp) are conveyed and discharged to the nut chute through the 50mm-passage at the left end of the chamber [6].

Benefit cost analysis of incorporating this machine in a semi-mechanized palm fruits processing at Umuahia, Nigeria showed total elimination of nut breakage during pressing, significant reduction in the processing time and cost, and improvement in the quantity and quality of palm oil and palm nuts extracted as well as profit [7]. Performance analysis of the separator showed 90.05% efficiency and throughput of 419.92kg/h with its design driving power, cake breaker speed, auger speed and helix angle of 2.238kW, 730rpm, 730rpm and 45^0 respectively and also that these four operational parameters influence its efficiency and throughput [6], [8]. According to [8] the lower and upper levels of the limit within which these factors influence the performance of this separator significantly are 7.46-3.73kW, 2870-1900rpm, 2150-1425rpm and $25\text{-}45^0$ for driving power, cake breaker speed, auger speed and helix angle respectively. Ref. [8] further evaluated and quantified the effects of these parameters on efficiency and throughput of this machine within this limit using the following response surface models.

Efficiency, η (%):

$$\eta = 9.6554 - 1.0484\times10^{-2}N_a + 4.1728\times10^{-2}N_c + 4.3204\times10^{-3}P + 6.5171\times10^{-1}\alpha - 1.0701\times10^{-5}N_c^{\,2} - 4.7150\times10^{-7}P^2 - 0.0134\alpha^2 + 4.1738\times10^{-6}N_aN_c + 1.016\times10^{-6}N_aP + 7.3427\times10^{-5}N_a\alpha - 0.0134\alpha^2 + 6.3164\times10^{-7}N_cP + 1.1780\times10^{-4}N_c\alpha \qquad (1)$$

Throughput, TP (kg/h):

$$TP = 605.8977 - 2.02\times10^{-1}N_a - 3.787\times10^{-1}N_c + 1.05\times10^{-2}P - 2.15\alpha + 2\times10^{-4}N_aN_c + 3.521\times10^{-3}P\alpha \qquad (2)$$

Ref. [8] used Response Surface Methodology (RSM) in the performance analysis of this machine because the works of [9], [10] and [11] showed that the technique uses small number of experimental runs to quantify and optimize relationships among one or more measured responses under the influence of several variables. The driving power, cake breaker speed, auger speed and helix angle setting of 6.341kW, 2821.5rpm, 2113.75 rpm and 45^0 respectively were obtained using exploration data tips of surface and contour plots of these models as the optimal setting of these factors. The efficiency and throughput of the developed separator at this factor setting were predicted using the models at over 99.79% success and confirmed experimentally as 94% and 867.69kg/h respectively [8]. However, the influence of these factors on the effect specific mechanical energy consumption, *SE* of the palm nut-pulp separator was not assessed in the work despite the economic important of *SE* in the operation of engineering systems. Specific mechanical energy consumption is defined as the actual mechanical energy used in a system or process to produce a unit product [12]. Therefore, *SE* of the separator is the mechanical energy output of its motor used to separate a unit mass of digested palm fruit mash. Development of energy saving equipment is the one of the major international trend for production cost reduction in industries over the decades because a machine/system may be very efficient in operation, but the application may not be economical if its *SE* is not relatively small with respect to its throughput. Thus, minimization of specific mechanical energy consumption of processes and equipment remained one of the outstanding desires of present day researchers and designers [12], [13].

It was observed that the specific mechanical energy consumption of this separator at its design throughput of 419.92kg/h is 19.23kJ/kg while that at a throughput of 867.69kg/h is 26.73kJ/kg. This revealed that this machine runs at sub-optimal setting even though its throughput and efficiency of 867.69kg/h and 94% are higher because it consumes more energy per unit mass of digested palm fruit separated with this factors setting. This undesired observation is in agreement with the works of [9] and [14], which showed that some industrial systems are being run at sub-optimal settings even though each factor has been optimized individually over time, thus finding the compromise optimum that does not optimize only one response become the major problem in industries. Also, optimal level of the factors generated from the graphical plots of response surface models (graphical optimization) is usually based on individual factor pairs (two independent variables) versus one response [9]. It is desired that this machine operates with maximum efficiency and throughput, and minimum specific energy consumption possible, thus the need for a multi-response optimization technique that will enable simultaneous evaluation of these three responses. In order to apply the multi-response optimization approach to this problem, it is of economic sense to quantify the relationship between the specific mechanical energy consumption of the separator and its operational parameter using a response surface model like the throughput and efficiency.

Optimization of a single response system is usually simple, but in most practical industrial researches/applications, multiple outputs that are interrelated in a way that improving one will cause deterioration of another such as finding settings which will increase yield and decrease the amount of scrap/rework and energy consumption represent opportunities for substantial financial gain in industries; rate versus consistency; strength versus expense are always the case [9], [14]. In multi objective optimizations, models are developed with the objective of improving all the responses of interest simultaneously [9], [11], [15]. From a mathematical point of view, the objective is to find the operating conditions or factor levels, $x_1, x_2, \ldots, x_k$ that maximize or minimize the system response variables $Y_1, Y_2, \ldots Y_k$. This requires some trade- offs in order to find the process operating conditions that are satisfactory for most (and hopeful all) responses. The four major techniques often used for optimization of response surface models include graphical (inspection of interpretation

ISSN 2229-5518

plots), path of steepest ascent/decent, desirability function and mathematical programming approaches [9]. Path of steepest ascent approach is very useful for both single and multiple response cases when the responses exhibit adequate linear fit, while mathematical programming and desirability function approaches are adequately used for the optimization of higher order response surface models [9], [11], [16]. Mathematical programming technique is an outstanding tool for optimizing multiple outputs that are interrelated in a way that improving one will cause deterioration of another when one response can be chosen as the "primary" (or most important response) while bounds or targets can be defined on all other responses [9]. In the mathematical programming approach the primary response Y_P is either desired to be maximized or minimized as expressed in Equations 3 or 4 respectively, subject to appropriate constraints of all other responses $Y_1, Y_2, \ldots Y_k$ as;

Maximize: $Y_p(x_i)$

Subject to: $Y_i(x_i) \le T_i$ (3)

$L \le x_i \le U$

Minimize: $Y_p(x_i)$

Subject to: $Y_i(x_i) \ge T_i$ (4)

$L \le x_i \le U$

Where x_i constitutes the independent variables, L and U are the lower and upper limits of x_i, and T_i is target or bound on each response Y_i (i = 1, 2,…..n). Equations 3 and 4 are usually solved using software such as DRSALG (in the case of 2(dual) responses), Microsoft Excel, MATLAB and Design Expert. Base on these forgoing facts, this study aimed to develop a response model for the relationship between the specific mechanical energy consumption of the separator and its driving power, cake breaker speed, auger speed and helix angle and also determine the settings of these factors that will yield optimum efficiency, throughput and energy consumption of the separator using mathematical programming method.

2.0 Materials and Methods

The values of specific mechanical energy consumption used in this investigation were computed from the experimental data (Table 1) conducted and used by [8] in the optimization of the efficiency and throughput of the palm nut-pulp separator.

TABLE 1
EXPERIMENTAL EVALUATION OF THE PALM NUT-PULP SEPARATOR BY RESPONSE SURFACE METHOD

Run. Order	Na (rpm)	Nc (rpm)	P (Watts)	α (^{0})	Separated Products (kg)	Time taken (s)	η (%)	*TP* (kg/h)
1	1787.5	2385	5595	35	18.00	110.00	90.00	589.09
2	1425	1900	7460	25	16.39	108.00	81.95	546.33
3	1425	2870	7460	45	17.84	87.00	89.20	738.21
4	1425	1900	3730	45	15.95	132.00	79.75	435.00
5	1425	2870	7460	25	17.00	123.00	85.00	497.00
6	1425	2870	3730	25	16.16	253.00	80.80	229.94
7	2150	2870	3730	45	17.69	104.00	88.45	612.35
8	2150	1900	7460	25	16.51	90.00	82.55	660.40
9	2150	2870	3730	25	16.86	123.00	84.30	493.46
10	1787.5	2385	5595	35	18.00	110.00	90.00	589.09
11	2150	1900	3730	25	15.89	127.00	79.45	450.43
12	1425	1900	7460	45	16.50	74.00	82.50	807.50
13	2150	2870	7460	25	18.13	90.00	90.65	725.20
14	2150	2870	7460	45	18.50	85.68	92.50	777.31
15	1425	1900	3730	25	15.78	177.00	78.90	320.95
16	2150	1900	7460	45	17.09	84.00	85.48	732.43
17	1425	2870	3730	45	16.79	176.00	83.95	343.43
18	2150	1900	3730	45	16.27	104.00	81.35	563.19
19	1787.5	2385	5595	35	18.00	110.00	90.00	589.09

The specific mechanical energy consumption as per each factor setting of this experimental plan/data was computed using the following relation:

$$SE\left(kJ/kg\right)=\frac{Pt}{1000\,m_o} \qquad (5)$$

Thereafter, version 16 of Minitab software was used for the fitting and selection the response surface functions of the relationship between the specific mechanical energy consumption of palm nut-pulp separator and the four factors investigated. The model that best quantified the relationship between the factors and this response were selected by backward elimination method with the aid of model adequacy measures usually displayed by the software along with each fitted function. The adequacy of the selected model was also verified experimentally with six confirmation runs. The specific mechanical energy consumption of the separator at each combination of the variables was evaluated by feeding a 20kg of fresh digested palm fruit mash through the hopper into the machine for separation into palm nut and pulp. The processing time involved was taken using stop watch and the separated pulp and nuts weighed after each test and recorded. The *SE* of the machine was computed using equation (5) in each case, before comparing the actual experimental results with the predicted response (at α = 0.05) by computing the residuals and their percentage errors. The model adequacy measures used for the statistical verification of the fitted functions include regression analysis of model coefficients, analysis of variance (ANOVA) and lack-of-fit tests whilst residual diagnostic plots contains normal probability plots of residuals, histogram of residuals, dot plots of the residuals versus observation order and that of residuals versus fitted response. The calculated coefficients and equation of a good model must be significant (P-value < 0.05), lack-of-fit must be insignificant, various coefficients of determination, R^2 and adjusted R^2 values should be close to 1(100%) and SS of Error should be as small as possible (Steppan et al, 1998). Residual is the difference between the respective observed responses and their model predicted values. If a model is adequate, the points on the normal probability plots of the residuals should form a straight line. Small departure from the line in the normal probability plot is common, but a clearly "S" shaped curve indicates bimodal distribution of the residuals. Breaks near the middle of this graph are also indications of abnormalities in the residual distribution. The plots of the residuals versus run order and that of residuals versus fitted response should exhibit scatter feature without any obvious pattern (i.e. structureless) while histogram of the residuals is expected to portray dumb-bell shape [9]. After fitting and selection of the best response surface function of the *SE*, six pairs of interpretation plots (contour and three dimensional surface graphs) of the model were developed using version 7.5 of MATLAB software in order to explore and survey the feasible region of the minimum *SE* of the separator for guidance during the iterative solution of multi-response model and trade-offs.

The developed *SE* model and those of the efficiency and throughput (Equations 1 and 2) were simultaneously optimized using a non linear mathematical programming tool of the same software (MATLAB 7.5), the fmincon solver. A mathematical programming model was first formulated with the specific mechanical energy consumption function as the objective function to be minimized, subject to targets of more than 419.92kg/h and 90.05% placed on the throughput and efficiency of the machine. Since these two performance indicators are not desired to be less than these design values. In addition, bounds based on the high and low levels of the factors within which each influences the responses significantly as determined by [8] were placed on the factors. Thereafter, the formulated multi-response model was input into the fmincon solver for solution and further analysis/trade-offs before confirming the solution experimentally with four confirmation runs using the same procedure applied in the confirmation of the *SE* model.

3.0 Results and Discussion

The specific mechanical energy consumptions computed from the experimental trials/results of Table 1 are shown in Table 2. The run order and factor settings of Table 1 were retained in the Table 2 for clarity. Equation (6) is the final empirical model selected after inputing these computed *SE* response and their corresponding factor combinations into the Minitab software and examination of the adequacy measures and diagnostic plots of all the fitted functions for the response. The results from the confirmation tests of the developed *SE* model are shown in Table 3. This table revealed percentage error range between the actual and predicted value for specific mechanical energy consumption is between –1.30 and 2.48%. This indicates that the developed empirical *SE* model is reasonably accurate within 95% prediction and can be used for further analysis. Thus, the model revealed that the main effects of all the four operational parameters provided strong primary contribution to the specific energy mechanical consumption of the separator while the quadratic effects of the auger speed, $N_a^{\ 2}$ and cake breaker speed $N_c^{\ 2}$ and interactions of N_aN_c, N_aP, $N_a\alpha$, N_cP, $N_c\alpha$, $N_aN_c\alpha$, $P\alpha$ and $N_aP\alpha$ provided secondary effects to the response. The contour and 3D-surface plots of the *SE* model are as presented in Fig. 1 to 6. The curvilinear profiles of these figures (Fig. 1-6) portray the quadratic nature of the *SE* model and the minimization required for the response is very obvious from the orientation of plots as desired. These plots also indicate that the optimal value of the specific mechanical energy consumption of the separator falls between 11.89159 kJ/kg and 16.5708kJ/kg. The non-linear mathematical programming model formed as per the procedure described in section 2 above which was used for determining the optimum value of the specific mechanical energy consumption of the palm nut-pulp separator is also presented below.

TABLE 2
SPECIFIC MECHANICAL ENERGY CONSUMPTION OF THE PALM NUT-PULP SEPARATOR

Run Order	Na (rpm)	Nc (rpm)	P (Watts)	α (^{0})	Separated Products (kg)	Time (s)	SE (kJ/kg)
1	1787.5	2385	5595	35	18.00	110.00	34.19
2	1425	1900	7460	25	16.39	108.00	27.48
3	1425	2870	7460	45	17.84	87.00	21.93
4	1425	1900	3730	45	15.95	132.00	36.38
5	1425	2870	7460	25	17.00	123.00	30.87
6	1425	2870	3730	25	16.16	253.00	49.25
7	2150	2870	3730	45	17.69	104.00	29.81
8	2150	1900	7460	25	16.51	90.00	27.21
9	2150	2870	3730	25	16.86	123.00	58.40
10	1787.5	2385	5595	35	18.00	110.00	34.19
11	2150	1900	3730	25	15.89	127.00	33.46
12	1425	1900	7460	45	16.50	74.00	23.84
13	2150	2870	7460	25	18.13	90.00	27.94
14	2150	2870	7460	45	18.50	85.68	39.10
15	1425	1900	3730	25	15.78	177.00	40.64
16	2150	1900	7460	45	17.09	84.00	37.03
17	1425	2870	3730	45	16.79	176.00	53.98
18	2150	1900	3730	45	16.27	104.00	41.84
19	1787.5	2385	5595	35	18.00	110.00	34.19

$$\begin{aligned} SE = &-50.6 - 3.43N_a + 2.68N_c + 1.1\times10^{-2}P + 1.02\alpha + 9.74\times10^{-4}N_a{}^2 - 5.38\times10^{-4}N_c{}^2 \\ &- 5\times10^{-5}N_aN_c - 2\times10^{-6}N_aP - 2.51\times10^{-4}N_a\alpha - 8\times10^{-6}N_cP - 1.31\times10^{-3}N_c\alpha \\ &- 1\times10^{-5}P\alpha + 7.91\times10^{-7}N_aN_c\alpha - 4.65\times10^{-8}N_aP\alpha \end{aligned} \quad (6)$$

TABLE 3
CONFIRMATION TEST OF THE DEVELOPED SPECIFIC MECHANICAL ENERGY CONSUMPTION MODEL

S/No	Factors Settings				Separated products (kg)			Time (s)	SE(kJ/kg)			
	Na (rpm)	*Nc* (rpm)	*P* *(Watt)*	α (^{0})	Palm nut	Digested pulp	Total output		Actual	Predicted	Residual	Error(%)
1	1425	1900	3730	45	3.85	12.10	15.95	132.00	30.87	30.39	0.48	1.56
2	2150	1900	3730	45	3.15	13.12	16.27	104.00	23.84	23.93	-0.09	-0.38
3	2150	2870	7460	25	3.98	14.15	18.13	90.00	37.03	37.01	0.02	0.05
4	1435	1915	3730	45	3.20	12.80	16.00	132.00	30.77	31.17	-0.40	-1.30
5	1435	1915	7460	25	3.60	12.80	16.40	107.00	48.67	48.27	0.40	0.82
6	2150	2870	4103	25	3.08	14.02	17.10	118.00	29.45	28.72	0.73	2.48

THE MATHEMATICAL PROGRAMMING MODEL OF THE PALM NUT-PULP SEPARATOR

Minimize SE:

$$-50.6-3.43N_a+2.68N_c+1.1\times10^{-2}P+1.02\alpha+9.74\times10^{-4}N-5.38\times10^{-4}N_c{}^2-5\times10^{-5}N_aN_c-2\times10^{-6}N_aP^2$$
$$-2.51\times10^{-4}N_a\alpha-8\times10^{-6}N_cP-1.31\times10^{-3}N_c\alpha-1\times10^{-5}P\alpha+7.91\times10^{-7}N_aN_c\alpha-4.65\times10^{-8}N_aP\alpha$$

Subject to:

Non linear inequality constraints of $\eta\geq 90.05$ *and* $TP\geq 419.92$;

$$9.6554-1.0484\times10^{-2}N_a+4.1728\times10^{-2}N_c+4.3204\times10^{-3}P+6.5171\times10^{-1}\alpha-1.0701\times10^{-5}N_c{}^2$$
$$-4.7150\times10^{-7}P^2-0.0134\alpha^2+4.1738\times10^{-6}N_aN_c+1.016\times10^{-6}N_aP+7.3427\times10^{-5}N_a\alpha$$
$$+6.3164\times10^{-7}N_cP+1.1780\times10^{-4}N_c\alpha\geq 90.05$$

$$605.8977-2.02\times10^{-1}N_a-3.787\times10^{-1}N_c+1.05\times10^{-2}P-2.15\alpha+2\times10^{-4}N_aN_c+3.521\times10^{-3}P\alpha\geq 419.92$$

Linear inequality constraints of; $3.73\leq P\leq 7.46$

$$19002\leq N_c\leq 2870$$
$$1425\leq N_a\leq 2150$$
$$25\leq\alpha\leq 45$$

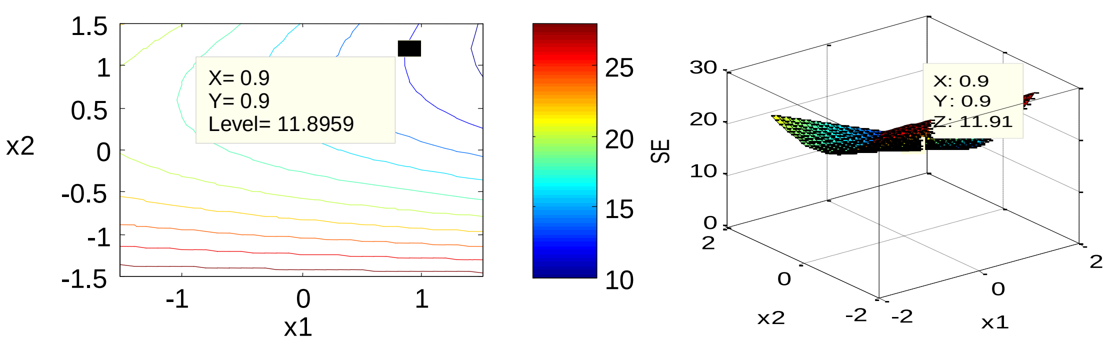

Fig. 1: Contour and 3D surface graph of SE versus auger and cake breaker speeds

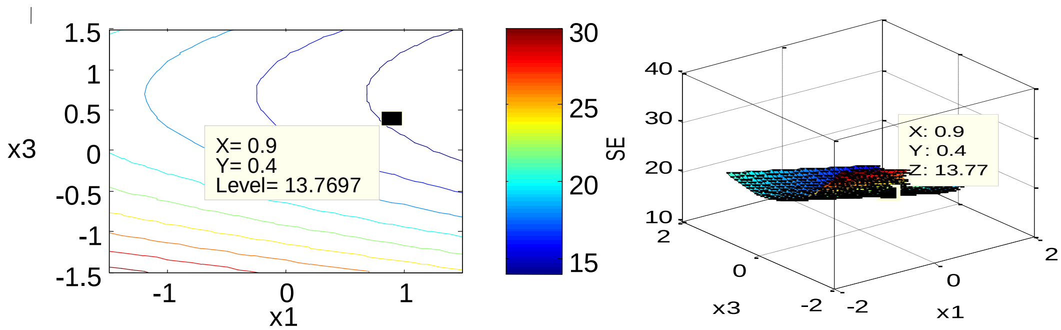

Fig. 2: Contour and 3D surface graph of SE versus auger speed and power

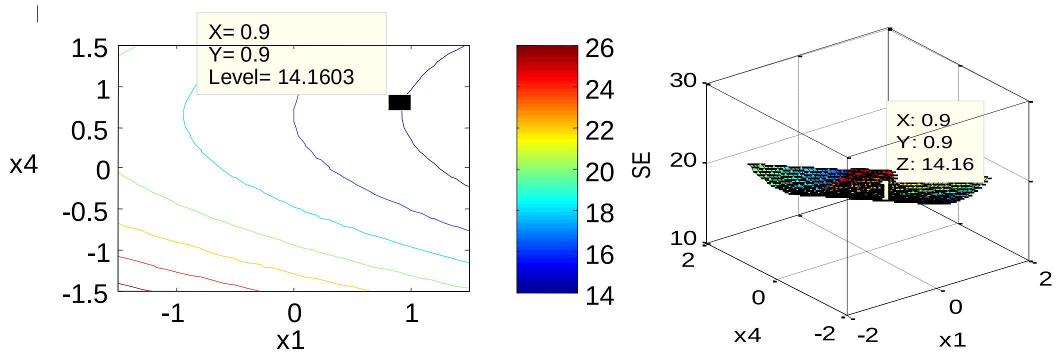

Fig. 3: Contour and 3D surface graph of SE versus auger speed and helix angle

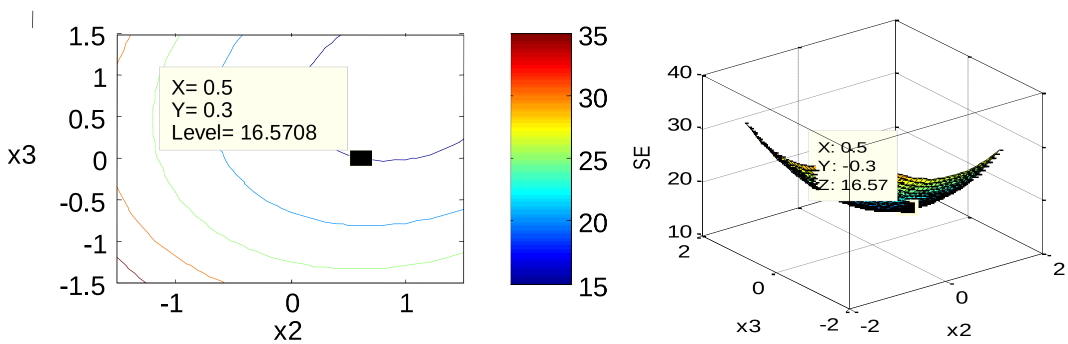

Fig. 4: Contour and 3D surface graph of SE versus cake breaker speed and power

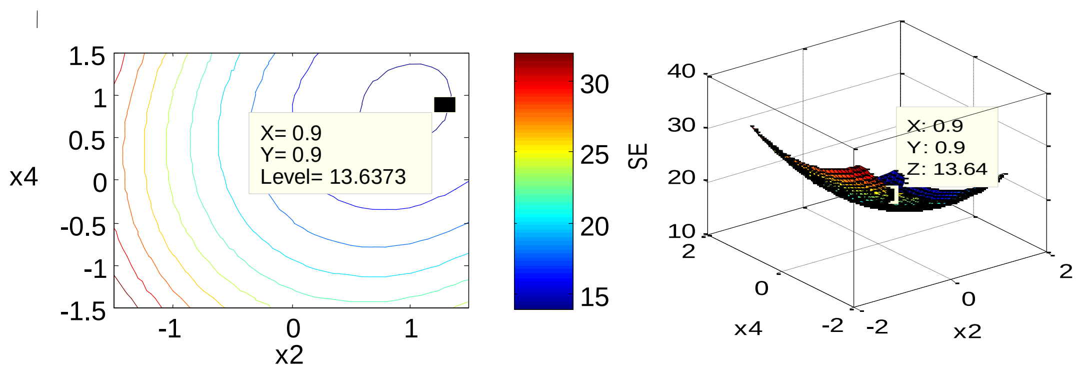

Fig. 5: Contour and 3D surface graph of SE versus cake breaker speed and helix angle

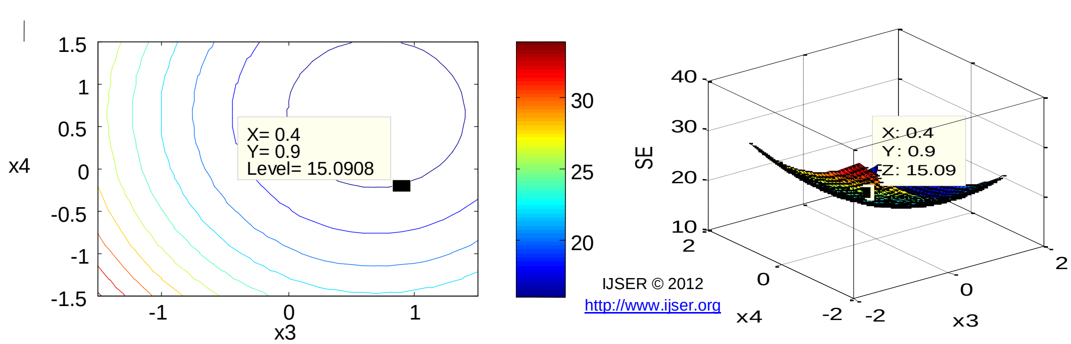

Fig. 6: Contour and 3D surface graph of SE versus power and helix angle

The set of optimal solution obtained after inputing this optimization model into the fmincon solver of MATLAB software is: N_a= 2116.0701, N_c = 2821.0200, P = 4.1027, α = 44.9980, *fval* = 16.2904. The *fval* = 16.2904 in this solution set represents the optimal value of the objective function (*SE*) thus, solution is in agreement with the feasible region (11.89159-16.5708kJ/kg) identified from the *SE* model plots (Fig. 1-6). After all the necessary approximation (trade-offs) were made on this solution set in line with possible practical operational values, the separator was test runned with driving power, P = 4.103kW (5.5HP), cake breaker speed, N_c = 2821rpm, auger speed, N_a = 2116rpm and helix angle of the auger worm, α = 45^0. The experimental results for the verification of the solution of the optimization model are shown in Table 4.

. The confirmation results of the optimization showed that the palm nut-pulp separator performs with an average specific mechanical energy consumption of 16.41kJ/kg, efficiency of 95% and throughput of 900kg/h at driving power, cake breaker speed, auger speed and helix angle setting of 4.103kW, 2821rpm, 2116rpm and 45^0 respectively. These experimental results indicate over 99% successful prediction when compared with the multi-response model solution of 16.29035kJ/kg, 95.00005% and 900.43154kg/h for specific mechanical energy consumption, efficiency and throughput respectively. Thus, performance of the palm nut-
pulp separator with the operational parameters (factor) setting determined in this multi-response optimization is better than its performance at both its design factor setting of 2.238kW, 730rpm, 730rpm and 45^0 for the driving power, cake breaker speed, auger speed and helix angle respectively and that of 6.341kW, 2821.5rpm, 2113.75 rpm and 45^0 determined from graphical optimization.

Recall that the separator performed with specific mechanical energy consumption, efficiency and throughput 19.23kJ/kg, 419.92kg/h and 90.05% respectively at its design factor setting while its specific mechanical energy consumption, efficiency and throughput at the factor setting from graphical optimization are 26.73kJ/kg, 867.69kg/h and 94% respectively.

TABLE 3
CONFIRMATION TEST OF THE OPTIMIZATION RESULT

Test	Separated Products (kg)			Time Taken (s)	Responses		
	Palm Nut	Digested Pulp	Total Output		***SE*(kJ/kg)**	η(%)	***TP*(kg/h)**
1	3.96	15.05	19.01	76.00	16.40	95.05	900.47
2	4.02	14.96	18.98	76.00	16.43	94.90	877.06
3	3.98	15.02	19.00	76.00	16.41	95.00	900.00
4	4.00	15.01	19.01	76.00	16.40	95.05	900.47
Average	**3.99**	**15.01**	**19.00**	**76.00**	**16.41**	**95.00**	**900.00**

4.0 Conclusion and Recommendation

The palm nut-pulp separating machine is more efficient and energy saving when operates at an optimal driving power, cake breaker speed, auger speed and helix angle of 4.103kW (5.5Hp), 2821rpm, 2116rpm, and 45^0 for respectively. Thus, this factor setting constitutes the optimal operational parameters of the separator. It is therefore recommended that the machine should be operated at these factor settings and also that its replication should be based on these optimal factor setting to ensure optimum performance.

Acknowledgement

Funding received from National Mathematical Centre/Raw Materials Research and Development Council (NMC/RMRDC), Abuja, Nigeria through Mathematical Modeling of Processing Equipment grant for the year 2009/2010 is gratefully acknowledged.

References

ISSN 2229-5518

[1] B. N. Nwankwojike, A. O. Odukwe, J. C. Agunwamba, Modification of Sequence of Unit Operations in Mechanized Palm Fruit Processing, *Nigerian Journal of Technology,Vol. 30*. No. 3, pp. 41-49, Oct. 2011.

[2] NIFOR Oil Mill Division, *Annual Production Report*, Nigerian Institute for Oil Palm Research (NIFOR), Benin City, 2000.

[3] R. N. Muthurajah, *Palm Oil Factory Hand Book* Palm Oil. Res. Institute NewDelhi, 2002

[4] FAO, Small-scale Palm Oil Processing in Africa, *FAO Agricultural Series 148*. pp. 1-55, 2002. http://www.fao.org/document/show

[5] A.B.N. Norilia, *Report of Industrial Training at Felda Palm Industries Mempaga palm Oil Mill*, PahangDarul Makmur, Malaysia, 2008

[6] B. N. Nwankwojike, A. O. Odukwe, J. C. Agunwamba, Design, Fabrication and Evaluation of Palm Nut-Pulp Separator, *Journal of EmergingTrend in Engineering and Applied Science (JETEAS) 3* (1),pp. Feb. 2012.

[7] B. N. Nwankwojike, A. O. Odukwe, J. C. Agunwamba, Benefit Cost Analysis of Introducing Palm Nut-Pulp Separating Machine in the Mechanized Small Scale Palm Fruit Processing, *Journal of Emerging Trend in Engineering and Applied Science(JETEAS) 3* (1),pp. 38-44, Feb. 2012.

[8] B. N. Nwankwojike, A. O. Odukwe, J. C. Agunwamba, Application of Response Surface Modeling in the Performance Optimization of a Palm Nut-Pulp Separator, *International Review of Mechanical Engineering, Vol. 6.* No. 2, Feb. 2012,

[9] NIST/SEMATECH, *Engineering Statistics, e-Handbook*, www.iel.nist.gov/dv898/handbook, 2006.

[10] J. A. Cornell, *How to Apply Response Surface Methodology* (Revised edition, Macmillan, 1990.

[11] R.H. Myer, D.C. Montgomery, *Response Surface Methodology: Process and Product Optimization Using Designed Experiments.* Wiley, 2002.

[12] M. Marcin, Changes of Specific Mechanical Energy during Extrusion Cooking of Thermoplastic Starch. *TEKA Kom, Mot. Energ. Roln, 5*, pp. 152-157, 2005.

[13] W. Li, S. Kara, An Empirical Model for Predicting Energy Consumption of Manufacturing Processes; A Case of Turning Process. *Journal of Engineering Manufacturing, Vol. 225,* No.9, pp. 1636-1646, 2011.

[14] V. Czitrom, P.D. Spagon, *Statistical Case Studies for Industrial Process Improvement*, (Philadelphia, P.A. ASA- SIAM series on Statistics and Applied Probability, 1997).

[15] M. Kahrom , S. M. Javadi , P. Haghparast , Application of Multi Objective GeneticAlgorithm to Optimize Heat Transfer Enhancement from a Flat Plate, *International Review of MechanicalEngineering,Vol.4.* No.2, pp. 167-175, 2010

[16] D. C. Montogomery, *Design and Analysis of Experiments: Response Surface Method and Design* Wiley, 2005.

Authors' Information

Nwankwojike, Bethrand Nduka *is a lecturer of Department of Mechanical Engineering, Michael Okpara University of Agriculture,Umudike, Nigeria. PH : +23480375178939*
E-mail: jikeobodo@yahoo.com

Agunwamba, Chukwuemeka Jonah *is the present Dean, Faculty of Engineering, University of Nigeria, Nsukka, Nigeria. PH : +2348035644561 E-mail: jcagunwamba@yahoo.com*

Ogbonnaya, Ezenwa Alfred *is the present Head of Department of Mechanical Engineering, Michael Okpara University of Agriculture,Umudike, Nigeria. PH : +2348037778406*
E-mail: ezenwaogbonnaya@yahoo.com