Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 6, Issue 1, 2021, Page 154-162
ISSN: 2616-1192

(www.ujesr.org)

Parametric Analysis and Improvement of a Pelleting-Drying Machine for Small Scale Fish Feed Production

Bashiru, G[1], Chinachi, E.A[2], Egwuagu, M.O[3] and Nwankwojike, N.B[4]
[1]Hartmann offshore Nigeria Limited, Port Harcourt
[2]Caritas University Amorji Nike, Enugu
[3]Enugu State University of Science and Technology
[4]Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike, Nigeria.
*Corresponding author's email: chinachiemeka1@gmail.com

Abstract
This study involved the parametric analysis and improvement of a pelleting-drying machine for small scale fish feed production usually fabricated by local artisans in Enugu, to achieve an optimal operation of the machine model. The machine's operational and performance parameters' correlations were empirically evaluated and quantified using response surface design and models while a desirability optimization of the models yielded its optimal parameters' settings. Performance analysis results revealed 400-900rpm, 0.3-0.7mm, 10-50%, 300-500kg/h, 6-10mm and 3-7mm as significantly limits within which the screw speed, particle size, feed moisture content, feed rate, die thickness and diameter influence the machine's performance, respectively. The developed response functions of this machine with over 95% prediction accuracy also showed significant effects of both main and quadratic levels of these parameters as well as their interactions on its performance indicators. The respective optimal settings of these operational parameters were also revealed as 1241rpm, 77%, 636Kg/h, 12mm, 9.327 and 0.9732cm. The fish feed pelletizing machine operates with throughput, pelletizing efficiency, specific energy consumption and mechanical damage of 16.23Kg/h, 80.62%, 17.12kJ/Kg and 6.32% respectively, at these optimal factors settings. This amount to over 26%, 10%, 12% and 27% improvement in these responses respectively. Thus, production and operation of the fish feed pelletizer with these optimal parameters setting is recommended.

Keywords: *Optimization, Modeling, Pelletizer, Fish, Feed, Machine*

Received: 17th November, 2021 *Accepted: 31st December, 2021*

1. Introduction

Fish and poultry are the most common animal protein sources for human consumption, with greater feed conversion efficiency than other creatures (Karthik et al., 2016). The success of fish rearing, on the other hand, is determined by the feed used. The feed should be created based on a detailed understanding of their nutritional requirements in order to accomplish the best possible development in a given amount of time (United Nations Development Programme, 1978). To fulfil basal energy requirements and to promote healthy growth, those organisms should be fed a balanced diet that includes protein, carbohydrate, fat, vitamins, and minerals (FAO, 2002). Protein, more than any other component of the prepared feed, plays a critical function in the diet. It's also an expensive component. The protein content in the diet should not be more or lower than what the organisms require. Various researchers have conducted a lot of tests in order to maximize the percent of protein necessary for fish (Mohanty et al., 1990; Ogino and Saito, 1970).

Generally, efficient mechanized pelleting is a challenge while manual pelleting process, presumed to be the most efficient, is grossly inadequate due to its drudgery, time consuming and low output capacity extremely too low to meet the huge contemporary need of processed fish feed. The methods used for locally made fish feed have become inappropriate occasioned by pre-operational activities and associated high useful feed loss. Most of the research efforts at developing suitable pelleting machines have concentrated on the use of drilled die principle to achieve the pelleting (Veronica, 2018; IITA, 2005; Akintunde, 2006; Olukunle, 2000; Orimaye, 2019).

A pelletizing and drying machine usually manufactured by artisan in Enugu province although widely used by local farmers and small-scale fish feed manufacturers in the south eastern region but has shown some lapses in performance due lack proper design considerations, design of experiment and process optimization. The common problems with these machines are unsatisfactory/incomplete pelleting, varying or inconsistently shaped pellets and the fact that feed may be reduced to a uniform cylinder with considerable wastage before satisfactory pelleting could be achieved. The pelleting unit comprises of hopper, which was welded to a cylindrical base- the barrel. The hopper is fabricated from 2mm thick mild steel sheet. The barrel is a thick galvanized pipe with a thickness of 10mm and inner diameter of 100mm. The barrel housed the screw conveyor (auger) made of bright mild steel shaft wound with stainless steel rod to form the screw worm. The auger conveyor consists of two parts which converts the formulated feed materials into granular form first before compressing it into a semi-solid plasticized mass. The pelletized feed is forced out through the die. The feed material is conveyed and pressed by a screw inside a tube or barrel leading to a rise in temperature as operation in the presence of water to promote gelatinization of starched component and stretching of expandable components. The expanded feed product is shape by the opening in the die. The shaped feed falls into drying chamber by gravity. The heating element in the dryer heats up the feed to reduce the moisture content, and the blower at end point as the dryer cool the feed temperature before it discharges for the fish consumption or for storage.

Hence, Performance testing of this fish feed pelleting machine gave 62%, and 22%, as its pelleting efficiency and mechanical damage, respectively. This performance was low and unsatisfactory. The shortcomings are attributed to insufficient design analysis stemming from inability to determine the shape and appropriate number of balls for any given operation, frictional characteristics of the pelleting surface, effect of speed variation on the performance indicator (as constant output speed of 25rpm through direct coupling was used) and failure to consider feed and operational parameters in the development of attrition pelleting machine. Investigations reveal that feed and machine moisture content, geometric mean diameter, and other operational factors, pelleting thickness and mass of loaded together with feed pelleting conveyor speed and diameter of pelleting die affects its four performance parameters at the same level. In other words, high levels of these six operational parameters results to high values of the four performance indicators. The performance parameters are the efficiency, mechanical damage, throughput, as well as the amount of energy used on a per-unit basis of the pellet. The efficiency is the ratio of the total mass of the feed form to that of loaded feed. Mechanical damage is the amount of useful feed lost. Throughput is the quantity of the feed pelleted and released per unit of time by the mechanism. The quantity of energy consumed by the machine is known as its specific energy consumption. consumed by the machine to pellet a unit mass of feed. It is desired to operate this machine with maximum efficiency and throughput, at minimum mechanical damage and specific energy consumption possible. For this reason, it is of economic sense to apply a multi-response optimization technique that uses small number of experimental runs to evaluate the effect of all these factors simultaneously (instead of one-factor-at-a-time experimental approach which is time consuming and costly) to determine the optimal settings of these operational parameters that will satisfy these four responses.

2. Materials and methods

2.1 Description of the fish feed pelletizer

Fig. 1 shows the assembled and exploded view of a fish feed pelletizing and drying machine.

1. Die plate, 2. Hopper, 3. Discharge collector, 4. Barrel, 5. Support, 6. Conveyor shaft, 7. Extrusion chamber, 8. Electric motor, 9. Electric motor base, 10. Speed reducer, 11. Intermediate shaft, 12. Barrel support, 13. Pulley, 14. Blower, 15. Blower housing, 16. V-belt, 17. Bearing, 18. Conveyor belt, 19. Main frame, and 20. Dryer box.

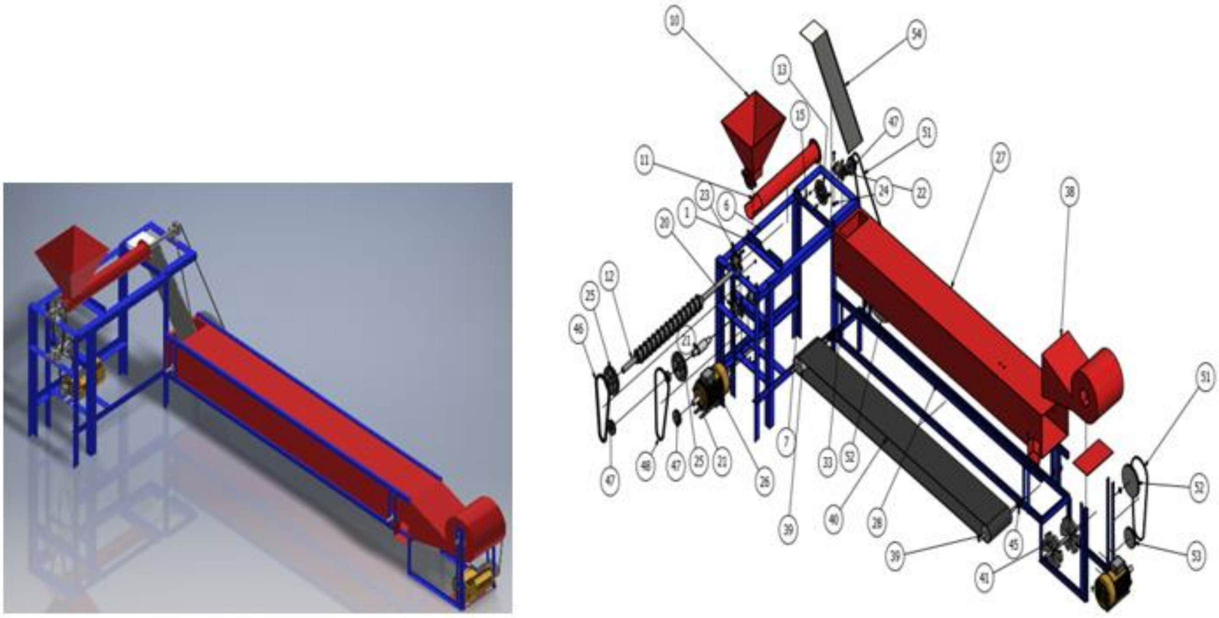

Fig. 1: Fish feed pelletizer

2.2 Design of experiments for the fish feed pelletizer analysis

The determination of the empirical relationships between the operational (factors) and performance (responses) parameters of the fish feed pelletizer and their optimal settings in this study started within RSM experimental design before the actual experimental evaluation and model fitting and optimization. The experimental design was developed based on the number of variables available, the availability of resources, data collection sources, time constraints, and cost considerations. Effects of the operational parameters of the machine; screw speed (SS), feed moisture content (MC), feed rate (f_R), die thickness (D_T), die diameter (D_D) and particle size (P_S) on the performance parameters, also throughput capacity (TP), pelletizing efficiency (η_p), specific energy consumption(SE) and mechanical damage(MD) were studied.

MINITAB (version 17) was used to create and randomize a thirty-four (34) two-coded levels (+1 and -1) half factorial design layout, with “+1” and “-1” indicating the high and low levels of the factors, respectively, and “0” indicating the factors' midpoint. Two level fractional factorial design (2^{k-q}) was employed because of its economic viability, desirable properties, orthogonality, and it permits marginally small experimental runs to be analyzed for high factorial points. Experimental study variable number (K = 6), for independent variables including screw speed (ss), feed moisture content(MC), feed rate(f_R), Die thickness (D_T), die diameter(D_D) and particle size (P_S) was used for the design. The coded symbols of these factors are x_1, x_2, x_3, x_4, x_5 and x_6 respectively. The number of experimental runs was determined from Equation (1)

$$n = 2^{k-q} + n_c \qquad (1)$$

where n_c is the number of centre points, k is the number of factors in the design q is the number of fractions, and n is the number of experimental runs. Table 1 is the generated factorial design layout for this study.

Table 1: Randomized design layout for the study

Experimental Runs		**Coded Values**					
Std Order	**Run Order**	**X_1**	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**
1	1	-1	-1	-1	-1	-1	-1
2	2	1	-1	-1	-1	1	-1
3	3	-1	1	-1	-1	1	1
4	4	1	1	-1	-1	-1	1
5	5	-1	-1	1	-1	1	1
6	6	1	-1	1	-1	-1	1
7	7	-1	1	1	-1	-1	-1

8	8	1	1	1	-1	1	-1
9	9	-1	-1	-1	1	-1	1
10	10	1	-1	-1	1	1	1
11	11	-1	1	-1	1	1	-1
12	12	1	1	-1	1	-1	-1
13	13	-1	-1	1	1	1	-1
14	14	1	-1	1	1	-1	-1
15	15	-1	1	1	1	-1	1
16	16	1	1	1	1	1	1

2.3 Multifactor-response analysis procedure for the fish feed pelletizer

Experimental testing of factor changes with performance metrics were used to identify the actual limitations of the operational factors under investigation. The exact high and low levels for each component were chosen based on the answers' lack of fluctuation or asymptote behaviour before or after some combination of the factors. The other five components were held constant at their design values in each of the tests for determining the actual levels for any of the factors. These design values are 400rpm, 10%, 300Kg/h,6mm, 3mm and 0.3mm for the screw speed (ss), feed moisture content(MC), feed rate(f_R), die thickness (D_T), die diameter(D_D) and particle size (P_S) respectively. Throughput, pelletizing efficiency, specific energy consumption and Mechanical damage of pellets were found by putting a known mass of feed into the machine for pelleting, the machine was tested for each combination of factors. After each operation, a stop watch was used to record the pelleting time and an electronic digital balance was used to weigh the pelleted feed. The four performance parameters were calculated using Equations (2) to (5) based on the experimental findings of their modifications. The natural values of these answers were then calculated using the transformation equations 6, which connect the coded and real values of the components.

$$md = \frac{WE}{WT} \quad (2)$$

$$\eta_E = \frac{WR}{WT} \times \frac{100}{1} \quad (3)$$

$$tp = \frac{M_c}{T} \quad (4)$$

$$S_E = \frac{power\ of\ motor(kw) \times timetaken\ (hr)}{mass\ produced\ in\ kg} \quad \frac{kwh}{kg} \quad (5)$$

$$X = \frac{x - \left(\frac{x_{max} + x_{min}}{2}\right)}{\left(\frac{x_{max} - x_{min}}{2}\right)} \quad (6)$$

where W_E is the mass of the feed retained, W_T is the total feed weight, W_R is the weight of feed recovered, M_C is the amount of the materials passing through the machine, T is time taken in hour. X is the coded variable; x is the independent variable in natural units while x_{max} and x_{min} are the maximum and minimum values of the independent variables, respectively.

The data obtained from the experimental assessments of this machine's operation at each actual factor limits combination as contained in the developed factorial design (Table 1) were analysed the MINITAB to fit mathematical functions relating the factors and each of the responses based on first-order main effect formulation The developed linear response function of this machine were later confirmed unfit for under approximation using of their exhibited statistical residual diagnostic measures and plots. The Regression analysis of model coefficients, analysis of variance (ANOVA), and lack-of-fit tests are examples of measurements. The plots utilized for the statistical verification of the fitted functions were normal probability plots of residuals, histograms of residuals, dot plots of residuals vs observation order, and dot plots of residuals versus fitted response. The discrepancy between the observed responses and the model projected value is known as residual. Thus, the factorial design was augmented/simulated to an orthogonal thirty-four (34) run, central composite circumscribed response surface design for fitting second-order response models of the pelletizer. The response surface design comprises of the initial 16 factorial points, centre and star points valued at 0 and 2.123 respectively (Table 2).

3. Results and discussion

3.1 Parametric evaluation of the fish feed pelletizer

The multi response experimental evaluation of the fish feed pelletizer revealed the limits within which its six operational and performance parameters vary significantly as shown in Table 2 while Table 3 constitutes the matching of the actual and coded settings of the limits. The results of the multifactor-response evaluation of this machine based on the factorial design reflecting the coded values of the factors and the corresponding actual response values of this machine as applied in the model development is as shown in Fig. 3.

Table 2: Limits of the fish feed pelletizing machine operational parameters

S/N	Factor Description	Factor Symbols		Factor Values	
		Coded	Actual	High (+1)	Low (-1)
1	Screw Speed (rpm)	x_1	S_S	900	400
2	Feed Moisture Content (%)	x_2	M_C	50	10
3	Feed Rate (kg/h)	x_3	F_R	500	300
4	Die Thickness(mm)	x_4	D_T	10	6
5	Die Diameter (mm)	x_5	D_D	7	3
6	Particle size (cm)	x_6	P_S	0.7	0.3

Table 3: Analysis table for the first order RSM study

Experimental Runs		Coded Values						Responses			
Std Order	Run Order	X_1	X_2	X_3	X_4	X_5	X_6	TP	η_p	SE	MD
1	1	-1	-1	-1	-1	-1	-1	10	63	28.5	8.9
2	2	1	-1	-1	-1	1	-1	14	73	24	8.1
3	3	-1	1	-1	-1	1	1	18	73	16	8.6
4	4	1	1	-1	-1	-1	1	16	67	25.6	8.2
5	5	-1	-1	1	-1	1	1	14	73	24	7.9
6	6	1	-1	1	-1	-1	1	11.5	89	26	7.3
7	7	-1	1	1	-1	-1	-1	14	66	27	7.8
8	8	1	1	1	-1	1	-1	18.5	64	26	6.7
9	9	-1	-1	-1	1	-1	1	10	63	28.5	8.2
10	10	1	-1	-1	1	1	1	14	73	24	7.9
11	11	-1	1	-1	1	1	-1	18	72	16	6.2
12	12	1	1	-1	1	-1	1	16	67	25.6	6.4
13	13	-1	-1	1	1	1	-1	14	73	24	7.6
14	14	1	-1	1	1	-1	-1	11.5	89	26	8.2
15	15	-1	1	1	1	-1	1	14	66	27	5.9
16	16	1	1	1	1	1	1	18.5	64	26	5.4

3.2 Development of response models of the fish feed pelletizer

The first order response models of this fish feed pelletizer developed using the multifactor-response performance test results are shown in Equations (7) to (10). Statistical evaluation revealed unsuccessful approximation of the four responses of the improved pelletizer with these linear functions (Equations 7 to 10). This is because the models exhibit significant lack of fit with poor Error standard deviation and coefficient of determination (ESD) as shown in Table 4.

$$TP = 14.594 + 0.469x_1 + 2.406x_2 + 0.344x_3 - 0.219x_4 + 2.281x_5 - 0.156x_6 \quad (7)$$

$$\eta_p = 70.99 + 1.19x_1 - 3.63x_2 + 1.57x_3 + 0.61x_4 - 0.44x_5 - 0.34x_6 \quad (8)$$

$$SE = 24.638 + 0.763x_1 - 0.988x_2 + 1.113x_3 - 0.000x_4 - 2.137x_5 + 0.000x_6 \quad (9)$$

$$MD = 7.456 - 0.181x_1 - 0.556x_2 - 0.356x_3 - 0.481x_4 - 0.156x_5 - 0.031x_6 \quad (10)$$

Table 4: Coefficients of determination and ESD for first order models

Responses	S	R-sq	R-sq(adj)
$Tp\ (kg/h)$	1.93335	84.43	74.06
$\eta_p(\%)$	7.77435	34.31	0.00
$SE\ (kg/KJ)$	3.04243	58.58	30.96
$MD\ (\%)$	0.69287	72.89	54.82

The initial two level half-fractional factorial designs were expanded by adding extra centre points and axial points, totaling fifty-four (54) experimental runs with an axial point value of (2.366), allowing study of curvature and second order interactions. The simulated response surface study matrix for fitting second order models of the improved pelletizer is shown in Table 9 while the models derived are given as Equations (6) to (9) for the throughput capacity, pelletizing efficiency, specific energy consumption and mechanical damage, respectively.

$$TP = 16.9163 + 1.0372x_1 + 2.2847x_2 + 0.3809x_3 + 0.3215x_4 + 1.5297x_5 + 0.3914x_6 - 0.8646x_1 * x_1 - 0.7753x_2 * x_2 - 0.1733x_3 * x_3 - 0.0161x_4 * x_4 - 0.6118x_5 * x_5 + 0.1054x_6 * x_6 + 0.2422x_1 * x_2 + 0.0291x_1 * x_3 + 0.0203x_1 * x_4 - 0.4541x_1 * x_5 + 0.0284x_1 * x_6 - 0.0097x_2 * x_3 + 0.0491x_2 * x_4 - 0.1091x_2 * x_5 - 0.0091x_2 * x_6 - 0.0116x_3 * x_4 + 0.0528x_3 * x_5 + 0.0491x_3 * x_6 - 0.0034x_4 * x_5 - 0.0097x_4 * x_6 + 0.0522x_5 * x_6 \quad (11)$$

$$\eta p = 81.410 + 2.6327x_1 - 2.9971x_2 + 0.2009x_3 + 0.2493x_4 - 0.2631x_5 - 0.0422x_6 - 2.8173x_1 * x_1 - 1.1202x_2 * x_2 - 1.1202x_3 * x_3 - 1.5686x_4 * x_4 - 2.0483x_5 * x_5 + 1.3257x_6 * x_6 - 4.149x_1 * x_2 + 0.146x_1 * x_2 + 0.146x_1 * x_3 + 0.157x_1 * x_4 - 4.311x_1 * x_5 + 0.013x_1 * x_6 - 0.019x_2 * x_3 + 0.073x_2 * x_4 + 1.164x_2 * x_5 - 0.011x_2 * x_6 + 0.063x_3 * x_4 - 0.083x_3 * x_5 - 0.188x_3 * x_6 - 0.408x_4 * x_5 + 0.056x_4 * x_6 - 0.217x_5 * x_6 \quad (12)$$

$$SE = 22.9407 + 0.0154x_1 - 0.1008x_2 + 0.3412x_3 - 0.1620x_4 - 1.1246x_5 + 0.4126x_6 + 0.5953x_1 * x_1 + 0.2907x_2 * x_2 + 0.2631x_3 * x_3 + 0.2729x_4 * x_4 + 0.3434x_5 * x_5 + 0.4783x_6 * x_6 + 0.8831x_1 * x_2 - 0.2850x_1 * x_3 + 0.3406x_1 * x_4 + 1.4881x_1 * x_5 - 0.3100x_1 * x_6 + 0.2750x_2 * x_3 - 0.3681x_2 * x_4 - 0.2244x_2 * x_5 + 0.3838x_2 * x_6 - 0.2313x_3 * x_4 + 0.2250x_3 * x_5 + 0.2394x_3 * x_6 - 0.2756x_4 * x_5 - 0.1513x_4 * x_6 + 0.2212x_5 * x_6 \quad (13)$$

$$MD = 9.3035 - 0.1058x_1 - 0.5789x_2 + 0.0222x_3 + 0.1016x_4 + 0.3304x_5 - 0.0592x_6 - 0.3926x_1 * x_1 - 0.2676x_2 * x_2 - 0.2497x_3 * x_3 - 0.2764x_4 * x_4 - 0.2140x_5 * x_5 - 0.2944x_6 * x_6 + 0.0308x_1 * x_2 - 0.0183x_1 * x_3 + 0.0847x_1 * x_4 + 0.0284x_1 * x_5 - 0.0880x_1 * x_6 + 0.1683x_2 * x_3 - 0.0846x_2 * x_4 - 0.0411x_2 * x_5 + 0.0255x_2 * x_6 - 0.0278x_3 * x_4 + 0.2285x_3 * x_5 + 0.0121x_3 * x_6 + 0.1003x_4 * x_5 - 0.0160x_4 * x_6 - 0.0722x_5 * x_6 \quad (14)$$

The inspection and analysis of variance for these second order models of the fish feed pelletizing machine performance parameters shown in Tables 5 to 8. This is because the values of 'R2'and 'adj- R2' increased while the value of 'S' reduced in each model as a result, it can be concluded that the interaction and square terms enhanced the models' adequacy. having correlation coefficients of 0.9986, 0.9971, 0.995 and 0.9841 which is close to one as desired of good model.

Table 5: ANOVA for the second order model of the pelletizing efficiency η_p (%)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	28	2838.92	101.39	309.25	0.000
Linear	6	694.9	115.816	353.25	0.048
Square	6	926.7	154.45	471.09	0.000
Interaction	15	1199.02	79.935	243.81	0.000
Error	25	8.2	0.328		
Lack-of-Fit	17	8.13	0.478	55.59	0.063
Pure Error	8	0.07	0.009		
Total	53	2847.12			

Table 6: ANOVA for the second order model of the specific energy, $SE\ (kJ/kg)$

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	28	242.549	8.6625	178.19	0.000
Linear	6	68.594	11.4323	235.16	0.023
Square	6	45.389	7.5649	155.61	0.009
Interaction	15	128.183	8.5455	175.78	0.080
Error	25	1.215	0.0486		
Lack-of-Fit	17	1.215	0.0715		
Pure Error	8	0	0		
Total	53	243.765			

Table 7: ANOVA for second order model of the Mechanical Damage, MD (%)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	28	48.1161	1.7184	55.3	0.000
Linear	6	20.2958	3.3826	108.86	0.000
Square	6	23.8096	3.9683	127.71	0.000
Interaction	15	3.9521	0.2635	8.48	0.000
Error	25	0.7768	0.0311		
Lack-of-Fit	17	0.7442	0.0438	10.75	0.901
Pure Error	8	0.0326	0.0041		
Total	53	48.8929			

Table 8: ESD and coefficients of determination for second-order models

Responses	S	R-sq	R-sq(adj)
$TP\ (kg/h)$	0.171007	99.86	99.7
η_p(%)	0.572589	99.71	99.39
$SE\ (kJ/kg)$	0.220486	99.5	98.94
MD (%)	0.176274	98.41	96.63

Table 9: ESD and coefficients of determination for second-order models

Responses	S	R-sq	R-sq(adj)
TP (kg/h)	0.171007	99.86	99.7
p (%)	0.572589	99.71	99.39
SE (kJ/kg)	0.220486	99.5	98.94
MD (%)	0.176274	98.41	96.63

Individual terms in the model are said to be statistically insignificant to the responses if $P-val > 0.05$ and therefore, those statistically insignificant terms were eliminated from the model to give Equations (15) to (18).

$$TP = 16.9163 + 1.0372ss + 2.2847mc + 0.3809FR + 0.3215DT + 1.5297DD + 0.3914PS - 0.8646SS*SS - 0.7753MC*MC - 0.1733FR*FR - 0.6118DD*DD + 0.1054PS*PS + 0.2422SS*MC - 0.4541SS*DD - 0.1091MC*DD \quad (15)$$

$$\eta p = 81.410 + 2.6327SS - 2.9971MC + 0.2009FR + 0.2493DT - 0.2631DD - 2.8173SS*SS - 1.1202MC*MC - 1.1202FR*FR - 1.5686DT*DT - 2.0483DD*DD - 1.3257PS*PS - 4.149SS*MC - 4.311SS*DD + 1.164MC*DD - 0.408DT*DD - 0.217DD*PS \quad (16)$$

$$SE = 22.9407 + 0.0154SS + 0.3412FR - 0.1620DT - 1.1246DD + 0.4126PS + 0.5953SS * SS + 0.2907MC * MC + 0.2631FR * FR + 0.3434DD * DD + 0.4783PS * PS + 0.3406SS * DT + 1.4881SS * DD - 0.3100SS * PS - 0.3681MC * DT + 0.3838MC * PS - 0.2313FR * DT + 0.2394FR * PS - 0.2756DT * DD - 0.1513DT * PS \quad (17)$$

$$MD = 9.3035 - 0.1058SS - 0.5789MC + 0.1016DT + 0.3304DD - 0.0592PS - 0.3926SS * SS - 0.2676MC * MC - 0.2497FR * FR - 0.2764DT * DT - 0.2140DD * DD - 0.2944PS * PS + 0.0847SS * DT - 0.0880SS * PS + 0.1683MC * FR - 0.0846MC * DT + 0.2285FR * DD + 0.1003DT * DD - 0.0722DD * PS \quad (18)$$

3.3 Multi objective optimization of the fish feed pelletizer

The rigor associated with most other optimization approaches is eliminated when using the desirability function approach. It is a multi-response, multi-factor optimization approach that is based on the Derringer Harrington concept. It determines the optimal factor settings for a multivariate objective function solution by optimizing a collection of answers. The objective is to maximize throughput capacity and pelletizing efficiency and minimize specific energy consumption and mechanical damage. A bound of six (6) parameters were defined on the total sum of the high level of coded factors investigated as linear inequality constraints required in optimization of this nature. Also, as part of linear inequality constraints required, bounds based factor levels was placed on individual factors. The coded high level of each factor is +1 and the total sum of the four factors at this level cannot exceed six. The response optimizer feature of MINITAB 17 was used, and the optimization plot obtained in Figure 2 indicated that the individual and composite desirability values are both close to one, indicating that the optimization outcome is very desired.

This optimization plot predicted 272rpm,63.5%, 431Kg/h, 8.33mm, 9.5mm and 0.58cm as the optimal settings of screw speed, moisture content, feed rate, die thickness, die diameter and particle size of the pelletizer respectively. The optimal response values were also shown as 16.2307kg/h, 80.638%, 17.12kJ/Kg and 6.32% for the fish feed pelletizing machine throughput, pelletizing efficiency, specific energy consumption and mechanical damage respectively and this was confirmed experimentally. Thus, optimization of the fish feed pelletizer improved its throughput by over 26% 22%, 11% and 6% when compared with its un-optimized version as well as the works of Adeyemi (2012), Salami (2013), Emmanuel and Segun (2018) respectively. Its efficiency also improved by over 10% while the mechanical damage reduced by over 27%. Thus, this study improved the operation of this pelletizer.

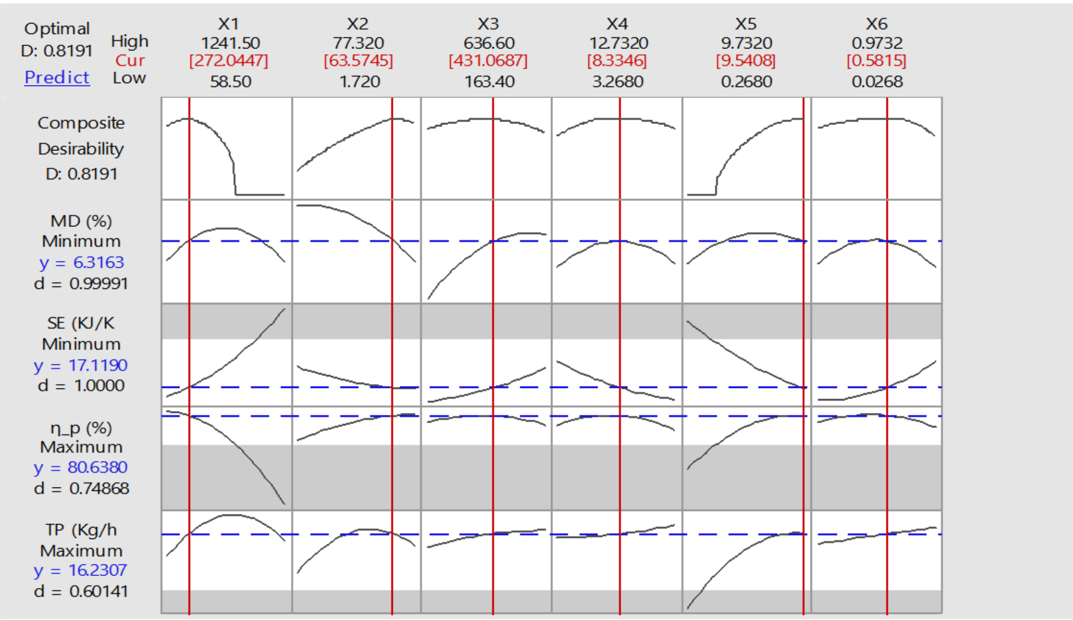

Fig. 2: Desirability optimization plot of the fish feed pelletizer

4. Conclusions

This study involves application of response surface-based desirability function analysis in performance characterization, modeling and optimization of a fish feed pelletizing and drying machine. It revealed 40-900rpm, 0.3-0.7mm, 10-50%, 300-500kg/h, 6-10mm and 3-7mm as respective limits within which the screw speed, particle size, feed moisture content, feed rate, die thickness and diameter influence the machine's performance significantly. The response models of this machine developed in this study with 80% prediction accuracy also showed significant effects of both main and quadratic levels of these parameters as well as their interactions on its performance indicators. The respective optimal settings of these operational parameters were also revealed as 272rpm, 77.320%, 636.60Kg/h, 12.7mm, 9.732mm and 0.9cm. The fish feed pelletizing machine operates with throughput, pelletizing efficiency, specific energy consumption and mechanical damage of 16.23kg/h, 80.63%, 17.12kJ/Kg and 6.32% respectively at these optimal factors' levels. This amount to over 26%, 10%, 12% and 27% improvement in these responses, respectively. Thus, application of this empirical simulation results of this study is recommended for advancement of design and operations of the fish feed pelletizer.

References

Adeyemi, S.O. and Akombo, P. M., (2012) Diet and dietary habits Of Labeo Senegalensis in a tropical freshwater ecosystem. Animal Research International, 9(1): 1502-1505.

Akintunde, B.O, Oyawale, F.A. and Toyosi, A.T. (2006) Design and fabrication of a cassava peeling machine" Nigerian Food Journal, 23(1): 231-238.

Emmanuel, O. and Segun, B. (2018) Design of experiments optimization study on the fat coating machine for extruded fish feed. Development of Animal and plant waste processing machine, 2(6): 338-342.

Food and Agriculture Organization of The United Nations (2002) Food energy - methods of analysis and conversion factors. Food and Nutrition Paper 77.

International Institute of Tropical Agriculture (2004) Nigerian's cassava industry. Statistical handbook, IITA, Ibadan.

Karthik, M., Sheila, R., Ingolf, R. and Girish C. (2016) Optimizing nutritional quality of aquafeeds. Aquafeed Formulation. pp 239-264.

Mohanty, S.N., Swamy D.N. and Tripathy, S.D. (1990) Protein utilization in inland major carp fry, Catlacatla (Ham.) and Labeo rohita (Ham.) fed four protein diets. Journal of Agriculture in Tropics, 5: 173-179.

Ogino, C. and Saito, K. (1970) The utilization of dietary protein by young carp. Bulletin of the Japanese Society of Scientific Fisheries, 36(3): 250-254.

Olukunle, O. (2000) Fishing. John Archers Limited, Nigeria, pp 1-5.

Orimaye, O.S., Ojo, O.I and Oluwole, P.A. (2019) Design, Fabrication and Performance Evaluation of Indigenous Fish Feed Pelletizing Machine for Low Income Farmers in Nigeria. Journal of Engineering Research and Reports, 4(3): 1-31.

Salami S.A., Oladunjoye, I.O., Olayeni, T.B. and Aratunde. A.E. (2013) Nutritional Value of Cattle Rumen Epithelial Scrapings Meal (CRESM) for Broiler Chicken. Poultry Industry.

United Nations Development Programme (1978) Digestion Physiology and Anatomy. College of Fisheries, University of Washington, Seattle, Washington, U.S.A.

Veronica, I.M., Bernard, O., Vincent, O. and Chika, C.O. (2018) A Design and Fabrication of Fish Feed Pelleting Machine. International Journal of Scientific Research and Management, 6: 78-84.