PREDICTING PERFORMANCE IN A CENTRIFUGAL SUNFLOWER SEED HULLER USING FORWARD-STEPWISE REGRESSION TECHNIQUE

U.S. Mohammed[1], V.I.O. Ndirika[2], L.G. Abubakar[3] and *O.L. Akangbe[4]

[1]Department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria

[2]Department of Agricultural Engineering, Michael Okpara University of Agriculture, Umudike, Umuhia, Nigeria

[3]Agricultrual Engineering Programme, Abubakar Tafawa Balewa University, Bauchi, Nigeria

[4]Department of Mechanical Engineering, Igbinedion University, Okada, P.M.B. 0006, Benin City, Edo State, Nigeria. olaosebikanakangbe@yahoo.com .

ABSTRACT

Multifactor relationships for estimating hulling efficiency and kernel breakage in a centrifugal type sunflower seed holler were generated using forward stepwise multiple regression technique. The effects of the generated relationships in predicting hulling performance was highly significant ($p < 0.01$). Impeller peripheral speed was found to be the most important factor influencing hulling performance. Both speed and impact surface type had positive contributions to hulling performance while product feed rate had negative contribution.

KEYWORDS: *Hulling, Performance, Sunflower, Impact, Speed, Feed.*

INTRODUCTION

Sunflower seeds are usually hulled by employing a number of techniques which involve the application of impact, either directly or indirectly. Attempts at hull removal using techniques involving the application of friction have also been reported [1, 2]. Impact by centrifugation appears to be the most popularly adopted technique [3, 4]. However, attempts at complete hulling of sunflower seeds have not been totally successful [5].

Hulling by centrifugation requires subjecting the seeds to high centrifugal forces to achieve high forces of impact by which the seeds are hulled when directed against hard surfaces of impact. Increasing the force of impact has been reported to result in increased kernel breakage while improving hulling efficiency [6, 7]. A number of factors have also been reported to influence hulling performance, including impeller peripheral speed, product feed rate, impeller vane angle, material and type of the surface of impact, crop variety, impeller diameter, product moisture content [3, 4, 6, 7 – 11], and impeller / vane material.

A twin unit sunflower seed huller was developed. The description and working principles of this equipment are as reported by [12]. The present study was undertaken to evaluate contributions of different crop and machine factors to the equipment's performance.

MATERIALS AND METHODS

Five factors were considered for this study, namely Impeller peripheral speed, Impact surface type, Product Feed Rate, Impeller Vane Angle, and Crop Variety. The levels at which these factors were varied for the study are presented in Table 1. The two crop varieties used are the promising varieties of sunflower seeds in Nigeria.

The mild steel impact ring was 3 mm thick plate, 70mm wide. The rubber surface was 10 mm thick and 70mm wide. Product feed was by gravity, controlled using a feed control flap. Separate impellers with the indicated feed angles (Table 1) were used for the study.

The equipment was evaluated for hulling efficiency and kernel breakage as expressed below

$$\eta_B = 100\left(\frac{Q_{BK}}{Q_0}\right) \quad (1)$$

$$\eta_H = 100\left(1 - \frac{Q_U}{Q_O}\right) \quad (2)$$

Where, η_B = Kernel Breakage, %

η_H = Hulling Efficiency, %

Q_{BK} = Quantity of broken kernels, g

Q_U = Quantity of seeds not hulled, g

Q_O = Quantity of products collected at all outlets, g

A total of 120 tests were conducted in three repetitions (360 experimental runs). Forward–stepwise regression technique was used to fit the test data to a multiple linear regression trend of the form

$$\eta_i = \alpha_O + \alpha_1\chi_1 + \alpha_2\chi_2 + \alpha_3\chi_3 + \alpha_4\chi_4 + \alpha_5\chi_5 + \varepsilon_i \quad (3)$$

Where, $\chi_1, \chi_2, \chi_3, \chi_4$ and χ_5 are the independent variables, η is the equipment's performance, and $\alpha_1, \alpha_2, \alpha_3, \alpha_4$, and α_5 are slope coefficients for respective influencing factors.

1. RESULTS AND DISCUSSIONS

1.1. Hulling Efficiency

The forward stepwise regression procedure [13] introduces a new independent variable into the regression model at each step, choosing always the variable with the largest and significant estimates (or beta coefficient). The procedure is terminated when the estimates for the remaining variable(s) are not significant, at the 5% level.
Three variables were introduced into the hulling efficiency equation, namely Speed, impact surface and Product federate, in that order, based on the comparative relative contribution of each of these variables to predicting hulling efficiency, the levels of significance of their beta coefficients being also significantly high (Table 2). Up to 45% of the hulling efficiency trend can be explained using speed alone (Table 2). An incremental 35% R^2 change was obtained when impact surface was introduced into the model. Only 4% improvement in R^2 value was obtained with the inclusion of product feed rate in the model and the effect was highly significant (Table 2). The inclusion of crop variety and vane configuration in the model, in the stated order, only resulted in less than 1% improvement in the R^2 value (0.1% and 0.05%, respectively) and the effects were not significant ($P = 0.0774$ and $P = 0.272$, respectively). As such, the model obtained at step 3 (Table 2) was accepted as the best fitting model for hulling efficiency. The model statistics are presented in Table 3

$$\eta_H = 19.7 + 0.018S_p + 15.4I_s - 0.02F \tag{4}$$

Where,

η_H = hulling efficiency, %

S_p = Impeller peripheral speed, m/min

I_s = Impact surface type

= 1, for mild steel

= 2, for rubber surface

F = Product feed rate, kg/h.

The effect of the model in predicting hulling efficiency is highly significant {$F(3,349) = 617.9353$, $p = 0.000000$, Multiple $R = 0.91736890$, $R^2 = 0.84156570$, and Adjusted $R^2 = 0.84020380$}. When the slope coefficients of the included independent variables were examined, probability statistics for their calculated t-values indicated that the variables are very relevant in predicting hulling efficiency (Table 3). When these variables were further examined for redundancy (Table 4), less than 1% (0.897, 0.724 and 0.101% for speed, impact surface and product feed rate, respectively) of what is explained by each of these variables is explained by other variables in the equation. Standard residual plots (Figures 1 & 2) indicate that the data are normally distributed and there is a good model spread. As such, equation 4 was accepted as a good predictor of hulling efficiency.
Speed has a positive contribution to hulling efficiency, which implies that hulling efficiency increases as speed increases. The impact surface type also has a positive contribution to hulling efficiency. This is in the sense that different surfaces of impact, in addition to the hardness of the surface, possess properties that enhance particle rebound. Multiple impact on the surface of impact results in increased hulling efficiency. Feed rate however has a negative contribution to hulling efficiency. As feed rate reduces, hulling efficiency increases

1.2. Kernel Breakage

All the variables studied could be introduced into the kernel breakage model based on the magnitudes and levels of significance of their data coefficients (Table 5). The speed variable alone accounted for an R^2 value of 0.509. Up to 27% improvement on this was obtained with the inclusion of impact surface in the kernel breakage model. Feed rate gave a lower but highly significant improvement on the strength of the model. Only slight improvements (less than 2%) were obtained with subsequent variable inclusions (Table 5). As such, the variable inclusion procedure was terminated at the third step (Table 5). Model statistics for kernel breakage are presented in Table 6.

$$\eta_B = -10.1981 + 0.0151 S_p + 11.0317 I_s - 0.0138 F \quad (5)$$

Where,

η_B = Kernel breakage, %

S_p = Impeller peripheral speed, m/min

I_s = Impact surface type

= 1, for mild steel

= 2, for rubber surface

F = Product feed rate, kg/h.

The effect of the model in predicting kernel breakage is highly significant { F (3,349) = 481.9068, p = 0.000000, Multiple R = 0.89751922, R^2= 0.80554075, Adjusted R^2= 0.80386918}. T-statistics for the included variables (Table 6) show that they are very relevant in predicting kernel breakage. Redundancy analysis (Table 7) shows that only between 0.1 and 0.9% of the effects explained by any of the three included variables is explained by other variable in the equation. Standard residual plots (Figures 3& 4) indicate that the data are normally distributed and the model spread is good. As such, equation 5 was accepted as a good predictor of kernel breakage.

Both speed and impact surface have a positive contribution to kernel breakage. As the impeller peripheral speed increases, there is corresponding increase in final particle acceleration result in increased severity of impact with consequent Kernel Breakage.
Increased particle rebound occasioned by the different properties of the surface of impact also increases the severity of particle impact, resulting in kernel structure failure.
More particles rebound occur on the rubber surface, resulting in more kernel breakage. Kernel breakage is less when multiple impacts are limited. Product feed rate has a negative contribution to kernel breakage. The higher the product feed rate, the lesser the kernel breakage.

2. CONCLUSION

Hulling Performance in a centrifugal type sunflower seed huller was evaluated at varying levels of impeller peripheral speed, impact surface type, product feed rate, crop variety, and impeller vane angles, using the forward stepwise multiple regression technique. Three variables (Speed, impact surface and product feed rate) were successfully included in the hulling efficiency and kernel breakage trends. Both speed and impact surface type had positive contributions to hulling efficiency and kernel breakage. Product feed rate had a negative contribution. The effect of the impact surface type can be explained in terms of multiple impacts occurring as a result of the frequency of particles rebound on the different surfaces of impact. Better hulling efficiencies can be obtained at the higher speeds of operation. Impeller peripheral speed is the most important factor influencing hulling performance.

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Table 1: Levels of Variables used for Performance Evaluation Tests

Factor	Factor Levels 1	2	3	4	5
Impeller Peripheral Speed, S_p (m/min)	1561	1955	2349	2659	3053
Impact Surface Type, I_s	Mild Steel	Rubber			
Feed Rate, F (kg/h)	79	344			
Impeller Vane Angle, V (°)	0	55	90		
Crop Variety, Cr	Funtua	Isaanka			

Table 2: Summary of Stepwise Regression for Hulling Efficiency

Summary of Stepwise Regression; Dependent Variable = ηH

	Step +In/-Out	Multiple R	Multiple R^2	R^2 Change	F to Enter or Remove	p-level	Variables Included
S_p	1	0.672607	0.452400	0.452400	289.9785	0.000000	1
I_s	2	0.894603	0.800315	0.347915	609.8114	0.000000	2
F	3	0.917369	0.841566	0.041251	90.8676	0.000000	3
Cr	4	0.918140	0.842981	0.001415	3.1363	0.077442	4
V	5	0.918438	0.843527	0.000547	1.2122	0.271659	5

Table 3: Regression Summary for Hulling Efficiency

Regression Summary for Dependent Variable (ηH)
R= 0.91843750 R= 0.84352744 Adjusted R= 0.84127280 F(5,347)=374.13

	Beta	Standard Error	B	Standard Error	t(347)	p-level
Intercept			19.74052	1.456354	13.55475	0.000000
S_p	0.718005	0.021331	0.01755	0.000521	33.66019	0.000000
I_s	0.590901	0.021312	15.35443	0.553799	27.72564	0.000000
F	-0.203734	0.021246	-0.01998	0.002083	-9.58936	0.000000
Cr	0.037720	0.021248	0.98015	0.552134	1.77520	0.076742
V	-0.023381	0.021236	-0.00819	0.007443	-1.10100	0.271659

Table 4: Redundancy Analysis on Hulling Efficiency Trend – Redundancy of Independent Variables

Redundancy of Independent Variables; Dependent Variable = ηH
R-square column contains R-square of respective variable with all other independent variables

	Tolerance	R^2	Partial Correlation	Semipartial Correlation
S_p	0.991029	0.008971	0.874952	0.714778
I_s	0.992757	0.007243	0.830053	0.588757
F	0.998990	0.001010	-0.457698	-0.203631
Cr	0.998753	0.001247	0.094868	0.037696
V	0.999896	0.000104	-0.059002	-0.023380

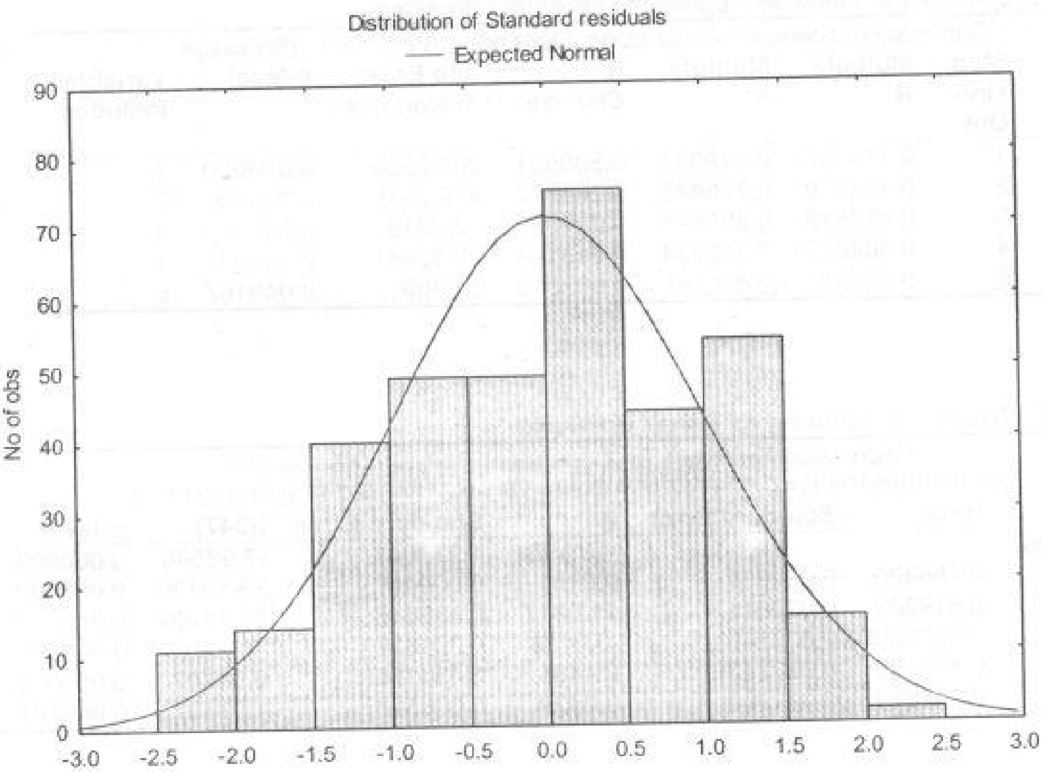

Figure 1: Distribution of Standard Residuals for Hulling Efficiency

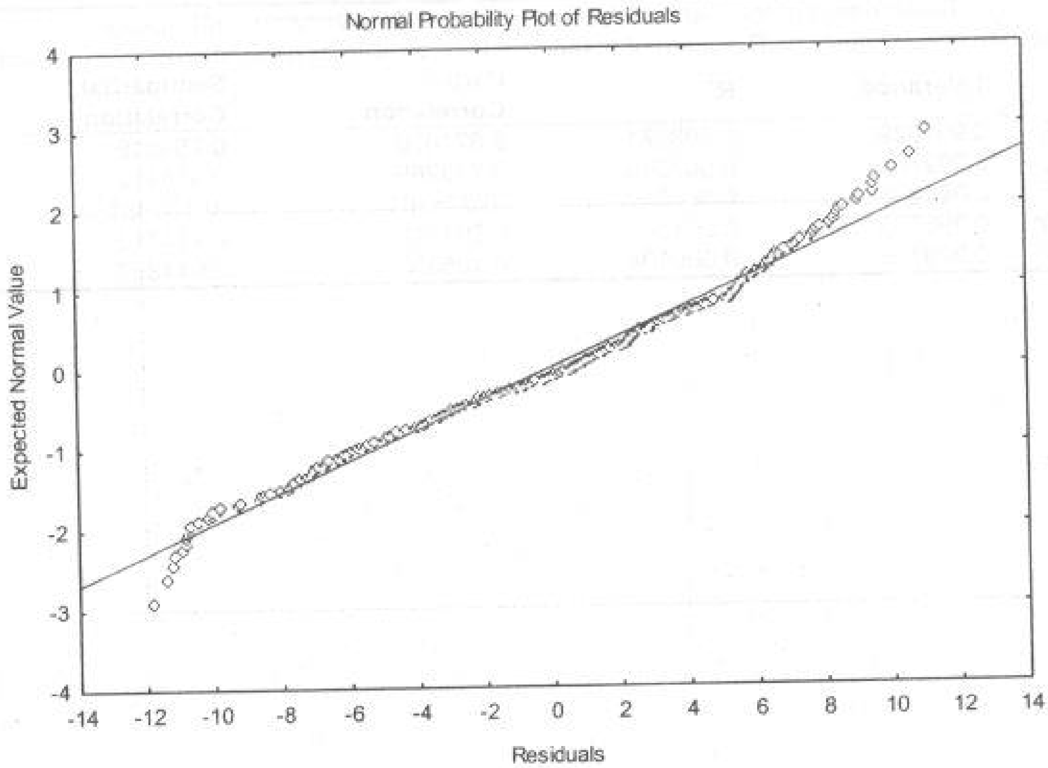

Figure 1: Normal Probability Plot of Residuals for Hulling Efficiency

Table 5: Summary of Stepwise Regression for Kernel Breakage

Summary of Stepwise Regression; Dependent Variable = ηBreakage							
	Step +In/-Out	Multiple R	Multiple R^2	R^2 Change	F to Enter or Remove	p-level	Variables Included
S_p	1	0.714095	0.509931	0.509931	365.2258	0.000000	1
I_s	2	0.881160	0.776443	0.266512	417.2515	0.000000	2
F	3	0.897519	0.805541	0.029097	52.2216	0.000000	3
Cr	4	0.904839	0.818734	0.013194	25.3294	0.000001	4
V	5	0.905951	0.820747	0.002013	3.8969	0.049167	5

Table 6: Regression Summary for Kernel Breakage

Regression Summary for Dependent Variable (ηBreakage)
R= 0.90595108 R= 0.82074736 Adjusted R= 0.81816447 F(5,347)=317.76

	Beta	Standard Error	B	Standard Error	t(347)	p-level
Intercept			-10.1981	1.277047	-7.98566	0.000000
S_p	0.756420	0.022831	0.0151	0.000457	33.13126	0.000000
I_s	0.518202	0.022811	11.0317	0.485615	22.71707	0.000000
F	-0.172078	0.022740	-0.0138	0.001827	-7.56723	0.000000
Cr	0.114783	0.022743	2.4436	0.484155	5.04707	0.000001
V	0.044870	0.022730	0.0129	0.006526	1.97407	0.049167

Table 7: Redundancy Analysis on Kernel Breakage Trend – Redundancy of Independent Variables

Redundancy of Independent Variables; Dependent Variable = ηBreakage
R-square column contains R-square of respective variable with all other independent variables

	Tolerance	R^2	Partial Correlation	Semipartial Correlation
S_p	0.991029	0.008971	0.871670	0.753019
I_s	0.992757	0.007243	0.773269	0.516322
F	0.998990	0.001010	-0.376361	-0.171991
Cr	0.998753	0.001247	0.261512	0.114712
V	0.999896	0.000104	0.105383	0.044867

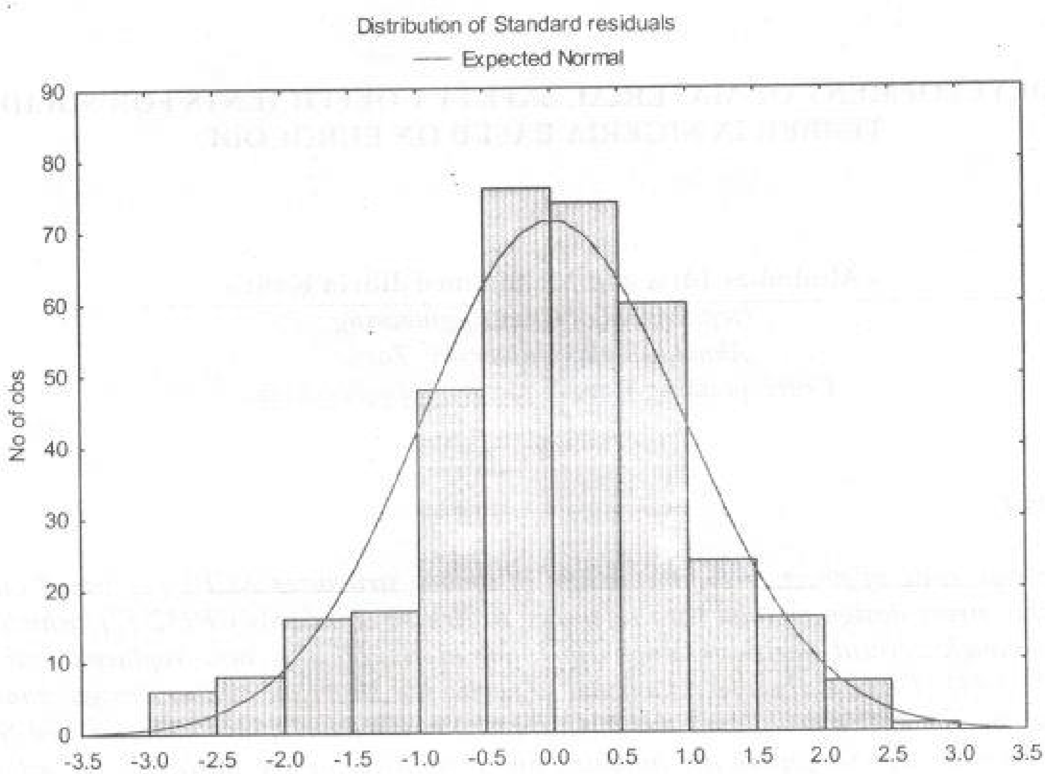

Figure 3: Distribution of Standard Residuals for Kernel Breakage

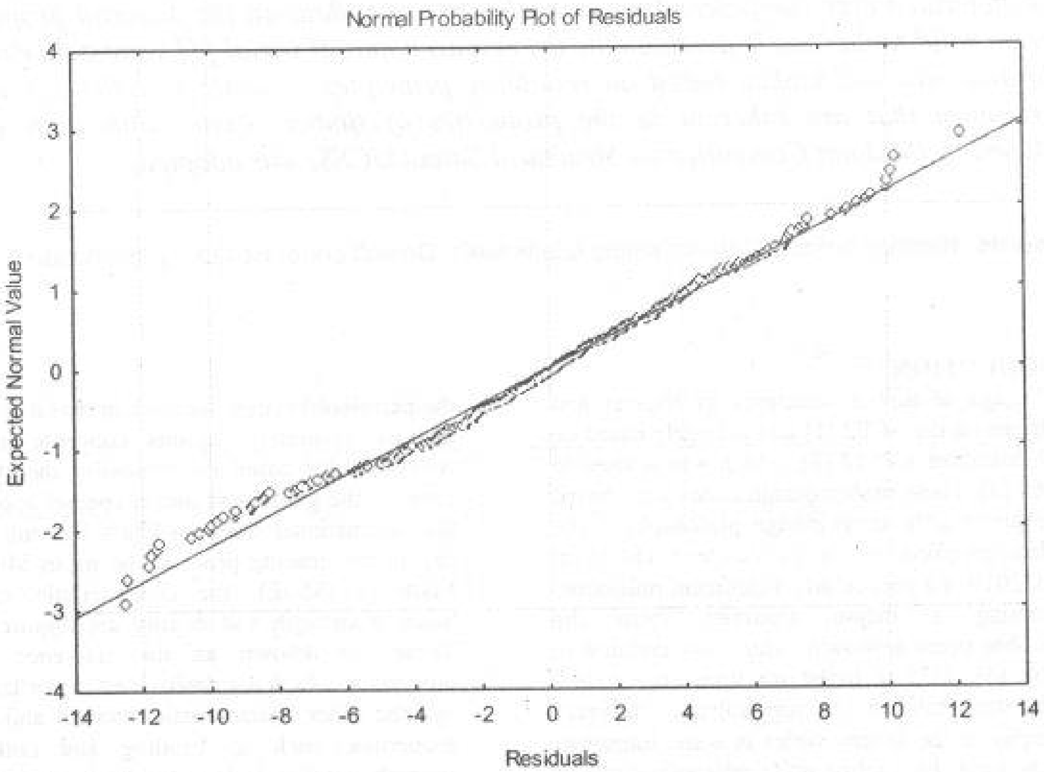

Figure 4: Normal Probability Plot of Residuals for Kernel Breakage