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Using Regression Analysis to Model Wear in Flights in Palm Oil Mill Press Screws

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Abstract: *Using Rison Palm Oil Mill, Ubima in Rivers State of Nigeria as a case study, tests were conducted to generate data for modelling. Variable speed pulley systems were constructed to provide different operating speeds for the press. Flights wear rates at different press speeds and throughput capacities were measured. The throughput capacity of the twin-screw press was computed from timed samples of press cake and drained oil. Using computer regression packages, multiple regression models were formulated to determine the best wear model for the system. Multiple regression double-log model gave the best fitting curve for predicting flights wear in the system.*

Keywords: *Twin-screw press, wear, flights, modelling, speed; throughput capacity*

1. Introduction

Wear prediction in screw presses is difficult due to too many influencing variables to contend with; such variables as load, speed, screw material, in-process material, surface and environmental factors, as well as the presence of abrasive contaminants, corrosives, and vibration. One also needs to know how these factors interact in order to get the best of wear predictions (Khurmi, 2004). In modelling wear prediction in screw presses, it thus becomes necessary to categorise the numerous influencing factors in terms of (i) major factors; which include the load or throughput capacity as well as the speed, and (ii) minor factors; which cover all remaining variables.

The choice of tribological materials is a critical factor in press screws (Kragelsky, 1981). It is however assumed that whilst the best of engineering material is selected, usually based on the microstructure of the material, the speed of the press screw as well as the throughput capacity exert the greatest influence on the wear of flights. There can be no question of poor lubrication since enough oil from the in-process material (the digested material in the oil mill) invariably accounts for that. The model can therefore be generalised to include (Mendenhall, 1981): (i) the deterministic part; which takes care of the major variables or determinants, and (ii) the random error part; which takes care of other minor variables.

Several models were formulated in an attempt to determine the best combinations of press screw speed, N and the throughput capacity, Q that would result to minimum wear of the flights.

2. Problem Background

The mechanical milling of oil palm fruits started in Africa before the First World War (Hartley, 1977). Before then, many African countries had already evolved various traditional methods of extracting palm oil and palm kernels with small-to-medium oil palm fruit plantations. These traditional methods were commonly associated with low capacity production. The growing demand for palm oil, therefore, necessitated early research in modern processing techniques. Various palm oil extraction methods were successively introduced in order to improve on both quantity and quality. The curb press, otherwise called the case press, gave a more efficient performance with minimal wear and breakdown problems. With oil extraction efficiency of about 65 per cent however, the loss of extractable oil was still high (Hartley, 1977).

Two types of continuous screw press; the single-shafted and the double-shafted, has been used to express palm oil from the digested materials. Both types allow for the gradual passage of the mash through a cylinder while under compression by the screws against the cylinder walls and the cones at the end of the cylinder. The double-shafted screw press gives oil extraction efficiency as high as 95 per cent. Unfortunately, the press screw flights wear out rapidly and the high cost of importing new press screws has made it almost impossible for the local palm oil mills to survive. The remedy measure presently adopted is to weld-fill the worn out flights. This could only serve for few days after which it rapidly wears out.

This premature water or gas breakthrough is often referred to as coning on vertical flow, or cresting on horizontal flow. As illustrated in Figure 4, while coning involves the localised movement of gas or water towards the well, cresting involves the localised movement of gas or water along a significant, if not, the entire length of a horizontal well.

3. Descriptions

Figure 1 shows the sectional view of the twin-screw press. Two press screws are caused to rotate appositively inside a screen surface. Material entering the hopper is subject to gradually increasing pressure as it moves toward the exit end of the press, thereby forcing the liquid phase to extrude through the screen. Final pressing is controlled by hydraulically actuated cones that provide easy adjustment of moisture content. Wedge wire screens and hard surfaced wear areas are standardised. Outstanding characteristics of the twin-screw press include tight squeezing, automatic control, positive feeding, and low horsepower. The twin-screw press is used to extract palm oil from the mash (consisting of the oil bearing flesh, kernel nut and palm fruit fibers). Palm fruits are normally plucked from trees in bunches (Hartley, 1977). These are sterilised, debunched and digested. The digested mash is fed into the screw press where it is squeezed in-between the oppositely rotating twin screws. Liberated oil is drained from the bottom of the machine.

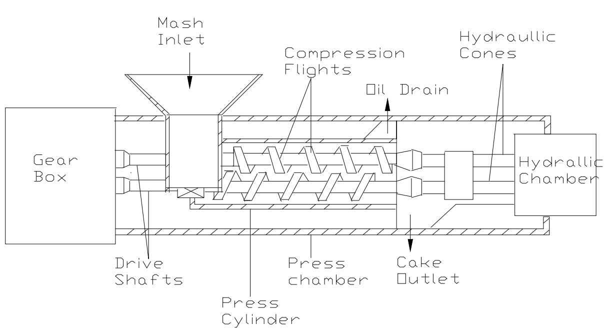

Figure 1. The sectional view of the twin-screw press

In order to examine the wear behaviour in the twin-screw press, measurements on the flights thickness were taken at one-week intervals. Wear rate was calculated as reduction in flights thickness over time. Figure 2 shows the wear trends of the five flights

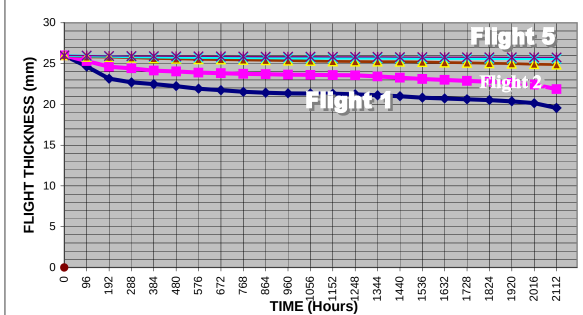

FIG.2.0 FUNCTIONAL WEAR RATE OF THE FIVE FLIGHTS

Figure 2. Functional wear rate of the five flights

4. Methodology

Tests were conducted to generate data for the analysis. Press speed was varied by use of variable speed pulley systems. The throughput capacity was computed from timed samples of press cake and drained oil. Average thickness and thus flights wear was recorded over time from which was calculated the average wear rate of the flights. Data in Table 1 was used for the regression analyses.

Table 1. Experimental data on twin-screw press

Index Nos.	N (rev/min)	V (m/s)	Q (m^3/s)	Y (m/s)
1	8	0.040	1.68×10^{-3}	7.30×10^{-10}
2	10	0.050	1.94×10^{-3}	8.50×10^{-10}
3	12	0.060	2.21×10^{-3}	9.52×10^{-10}
4	13	0.065	2.35×10^{-3}	9.90×10^{-10}
5	14	0.070	2.49×10^{-3}	1.02×10^{-9}
6	15	0.075	2.64×10^{-3}	1.04×10^{-9}
7	16	0.080	2.75×10^{-3}	1.09×10^{-9}

Keys: N = rotational speed of the flights; V = forward speed;
Q = throughput capacity; Y = wear rate of flights

5. Regression Analysis

Several models were constructed to examine the combined effect of the throughput capacity and the press speed on wear rate of the flights.

5.1 Linear Model of Press Speed

A linear model was constructed to examine the combined influence on flights wear by the throughput capacity and the press speed. Figure 3 gives the response curve of the model. The computer printout gave the following model equation:

$$Y = 1.123559E\text{-}9 + (2.08893E\text{-}10)N - (0.00000122)Q \quad \ldots..\ (1)$$

where, Y is wear rate of flights

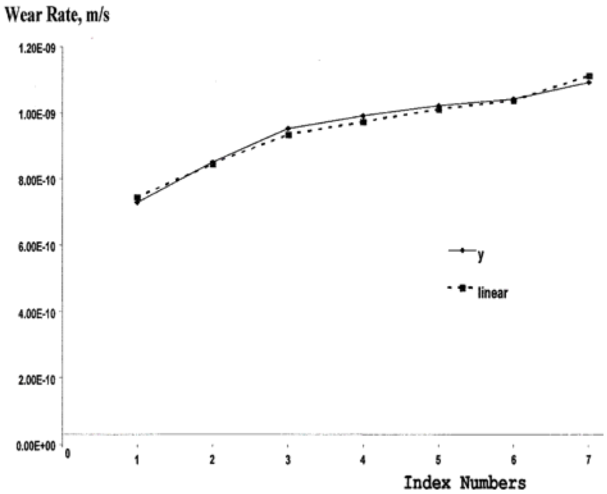

Figure 3. Response curve for Linear model of N and Q

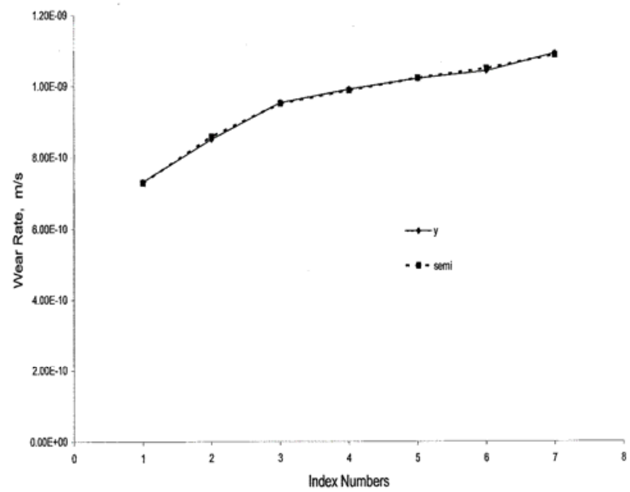

Figure 5. Response curve for Semi-Log model of N and Q

5.2 Exponential Model of press Speed

An exponential model was also considered. Figure 4 shows the response curve of the model. Computer printout of the model gave the following equation;

$$\ln(Y) = -20.46383 + (0.26040)N - (1564.32274)Q \quad \ldots\ldots(2)$$

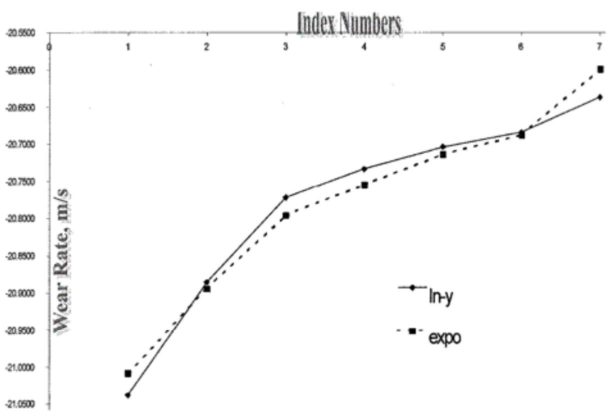

Figure 4. Response curve for Exponential model of N and Q

Semi-Log Model of Press Speed

A semi-log model was also formulated. Figure 5 shows the response curve of the model. The model equation is as follows:

$$Y = -7.89472E\text{-}9 + (1.198751E\text{-}9)\ln(N) - (9.5929E\text{-}10)\ln(Q) \quad \ldots.(3)$$

Double-Log Model of Press Speed

A double-log model was formulated to examine the wear behaviour of the flights under different press speed and throughput capacity. The response curve is shown in Figure 6. The model equation is;

$$\ln(Y) = -37.85916 + (1.99383)\ln(N) - (1.98366)\ln(Q) \quad \ldots.(4)$$

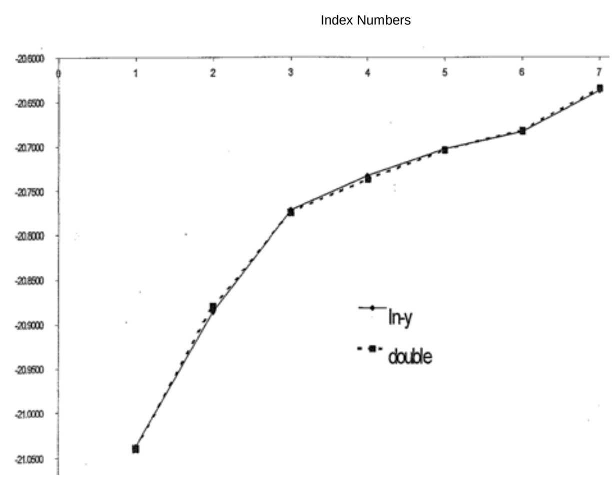

Figure 6. Response curve for Double-Log model of N and Q

6. Results and Discussion

The primary goal of any regression analysis is to make a decision on whether to reject or accept the hypothesis. However, even with the best of decisions, some levels of error are bound to occur. Error occurs when a null hypothesis is rejected which is in fact true. The probability, α of committing this type of error is known as level of significance.

Thus, confidence interval = $(1 - \alpha)$ %, represents an interval of sample numbers within which reasonable conclusions about the population parameters can be drawn. The rejection region is usually a set of computed values of the test statistics for which the null hypothesis is rejected. The value at the boundary of the rejection region is called the critical value. Critical values for relevant parameters will be defined as we proceed.

Table 2 shows the result of the multiple regression models. Considering a 95% confidence interval or 0.05significance level (Terry, 1982), the models can be analysed as follows:

Table 2. Regression analysis result

	Linear		Exponential		Semi-Log		Double-Log	
Combined Effects of N and Q								
F-value /Probability	131.69 / 0.0002		64.02 / 0.009		1387.11/ 0.0001		3618.78 / 0.0001	
R-Square values	0.9850		0.9697		0.9985		0.9994	
Individual Contributions of N and Q	N	Q	N	Q	N	Q	N	Q
t-value / Probability	1.80 / 0.1466	-1.42 / 0.2276	1.41 / 0.2313	-1.15 / 0.3144	5.12 / 0.0069	-2.95 / 0.0419	12.39 / 0.0002	-8.88 / 0.0009
Regression Coefficients (N/ Q)	2.08893 E-10 / –1.22E –6		2.604E -01/ –1564.323		1.198751E-9 / - 9.5929E-10		1.99383 / -1.98366	

6.1 F-value

F-value of linear model is 131.69 with a significance probability of 0.0002, which is less than 0.05. Thus, the model is significant. This means that the combined effects of the press speed, N and the throughput capacity, Q on the wear rate of flights is statistically significant. F-value of the exponential model is 64.02 with a significance probability of 0.009, which is also less than 0.05 and thus significant. The semi-log model has an F-value of 1387.11 with significance probability of 0.0001. This also shows that the combined effect on flights wear by N and Q is significant. The double-log model shows that the combined effect of N and Q on the wear rate of flight is quite significant, having an F-value of 3618.78 with a significance probability of 0.0001.

6.2 R-Square value

The R-square value shows the extent with which the estimated values approach the observed. A critical value of 0.75 or 75% is normally accepted. The plain curves in the response curves represent the observed values, and the doted curves represent the estimated values of wear rate using computer regression packages, hence the models.

R-Square value of the linear model is 0.9850. Thus, the model explains about 98% variations in the response curve. The model can, therefore be used for prediction purposes, having explained more than 75% variations in the response curve. The exponential and semi-log models with R-square values of 0.9697 and 0.9985, explain about 96% and 99% variations in the response curves, respectively. Thus, the models can also be used for prediction purposes. The double-log model is however more suitable for prediction purposes, having explained about 99% variations in the response curve.

7. Individual Contributions

7.1 t-value

The *t*-value gives a measure of marginal contributions to wear by the individual parameters. A critical probability of 0.20 is usually within safe limits (McClave, 1982). The *t*-value of N is 1.80 for the linear model, with a significance probability of 0.1466. This shows that the marginal influence of the press speed on flights wear is quite significant. The marginal effect of throughput capacity, Q on wear appears insignificant with the model. This does not however, mean that Q has no effect on wear. The variation in Q can be occasional, with greater impact on wear. The exponential model shows that the marginal effects of N and Q on wear are insignificant thereby giving an unreliable result. The semi-log and the double-log models show that both N and Q have significant marginal effects on wear of the flights, with significance probabilities of 0.0002 and 0.0009, 0.0069 and 0.0419, respectively.

7.2 The Regression Coefficients

The Regression Coefficients of N and Q are 2.08893E-10 and –0.00000122, respectively for the linear model. This gives a positive relationship between the press speed and the wear rate, and a negative relationship with the throughput capacity. Precisely, one unit increase in press speed results in about 2.08893E-10 units increase in wear rate; also a unit increase in Q results in about 0.00000122 decrease in wear rate. This is obvious since the screw press has a specific design capacity, and Q was varied by adjusting the forward speed of the hydraulic cones. An increase in the hydraulic cone speed will ultimately increase the throughput capacity, with the press cake coming out at a faster rate. This is likely to reduce the squeezing pressure which in turn has a reducing effect on wear of the flights. Much increase in Q will however, reduce the oil extraction efficiency of the system.

The exponential model has regression coefficients of 0.26040 and –1564.32274 for N and Q, respectively. This shows a positive relationship between the press speed and the wear rate, and a negative relationship with the throughput capacity. The semi-log model shows a positive relationship with N and a negative relationship with Q. The double-log model has a regression coefficient of 1.99383 and –1.98366 for N and Q respectively, showing a positive relationship with the press speed, and a negative relationship with the throughput capacity and flights wear.

7. Conclusions

The linear model takes into account about 98% of variations in the response curve. This is a promising result. It however tends to suppress the influence of throughput capacity on flights wear. The exponential model explains about 96% of variations in the response curve. This is acceptable for prediction purposes. It however gave an unreliable result on marginal contributions to flights wear by both the press speed and the throughput capacity.

The semi-log model explains about 99 per cent variations in the response curve. It also gave a fairly good account on the individual contributions to wear by N and Q. The double-log model also explains about 99% variations in the response curve. It also gives a good account on the marginal contributions to flights wear by the press speed and the throughput capacity.

Comparing the individual contributions to wear, the respective regression coefficients show that a slight change in press speed or throughput capacity gave a more sensitive response to wear under the double-log model. Thus, the double-log model is strongly recommended. The predicting model is thus,

$$\ln(Y) = -37.85916 + (1.99383)\ln(N) - (1.98366)\ln(Q) + \text{Random Error} \quad \text{.... (5)}$$

The random error term represents small contributions to wear by minor influencing variables.

References:

Hartley, C.W.S. (1977), *The Oil Palm*, New York: Longman Inc.

Khurmi, R.S. (2004), *Machine Design*, India: S. Chard Conpany, Ltd.

Kragelsky, V. (1981), *Tribology Handbook*, Moscow: Mir Publishers.

McClave, J.T. and Dietrich, F.H. (1982), *Statistics*, San Francisco: Dellen Publishing Company

Mendenhall, W. (1981), *Mathematical Statistics with Applications*, 2nd Edition, Boston: Duxbury

Terry, S. (1982), *Statistics by Example*, California: Dellen Publishing Company.

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