Mathematical modeling of mechanical horizontal screw oil extractor

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Abstract: A theory using mechanical expression was proposed from the physics of oil expression in a screw press to characterize a mathematical model. The general oil expression equation was solved for three machine parameters (choke clearances, screw shaft clearances and screw shaft speeds) which simulate the machine parameters effects in the overall screw expeller process. The mathematical model was validated by the experimental data obtained from pressing fish oil with a screw press, using regression analysis. The experimental oil extraction data was fitted to the model and the quality of fit evaluated. A good fit was indicated by correlation coefficient of 0.9983, coefficient of determination of 0.9967, absolute average percentage deviation of 4.8 %, coefficient of variation of 3.4 % and chi-square goodness of fit of 1.8. Good agreement was obtained between experimental and predicted data. The optimum oil yield (22.5 %) is equal to the maximum oil yield (22.5 %) obtained in the experimental study. The mathematical model was also used to satisfactorily predict the performance of commercial screw expellers. This theory however provided an alternative to the costly and time-consuming empirical studies in obtaining information on the performance of a press.

Keywords: mathematical, model, extraction, parameters

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1 Introduction

For obtaining oil from oleaginous materials, there are two important methods that can be applied: expression and extraction. Expression is the process of mechanically pressing liquid out of liquid containing solids whereas extraction refers to the process of separating a liquid from a liquid-solid system (Khan and Hana, 1983; Brennan et al., 1990). There are several types of machines commonly used in mechanical pressing method, i.e. hydraulic press machine and screw press machine. Hydraulic press machine is classified as a batch mechanical pressing machine while screw press machine is considered as a continuous pressing machine (Pighinelli and Gambetta, 2012).

One of the oldest and most popular methods of the oil production in the world is considered to be the mechanical expression of oil from the seeds using a screw press (Mrema and McNulty, 1985). The use of mechanical oil expellers presents several important advantages, that determine the popularity of this method: the equipment is simple and sturdy in construction, can easily be maintained and operated by semi-skilled supervisors, can be adapted quickly for processing of different kinds of oilseeds. The oil expulsion process is continuous with product obtained within a few minutes of start of the processing operation (Pradhan et al., 2011). Also, using the mechanical pressing, a chemical free protein rich cake is obtained, unlike the solvent extraction method (Haumann, 1997; Singh and Bargale, 2000).

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The disadvantage of the mechanical screw pressing method is that it recovers about 86%-92% of oil from oilseeds (Singh and Bargale, 2000). Mechanical screw-press performance, characterized by the oil recovery, for a given oilseed, depends on the preparation method of the raw material (Ionescu et al., 2014; Singh et al., 2002; Zheng et al., 2003) and on the operating parameters of the pressing machine (Jacobsen and Backer, 1986; Ionescu et al., 2014). The screw press, also called an expeller, is used for the expression of oil from oilseeds. It was developed by the trial-and-error approach towards the end of the last century. Many studies are now directed at understanding its mechanism of operation in order that better presses may be developed. Numerous attempts have been made to improve the efficiency of oil extraction through pressing. In general, three types of intervention have been studied: optimization of the operating parameters of the process, improvement of the geometric configuration of the press and pre-treatment of the seeds. However, many of these studies are the result of criteria based on experience and intuition of manufacturers and operators rather than on a rigorous theoretical analysis of the physical principles involved in the process (Singh and Singh, 1991; Bargale et al., 2000; Toscano and Pedretti, 2007). Although screw presses have been used for decades in the vegetable oil industry, no satisfactory mathematical models are available to describe the pressing process, especially in the case of solid-liquid separation processes (Chapuisa et al., 2014).

Virtually all previous attempts at simulation of press operation required prior knowledge of press characteristics such as the operating pressure, and since such parameters are usually unknown at the design stage, such works were of limited use to engineers working on screw press designs (Mrema and McNulty, 1985; Vadke et al., 1988). This paper presents a method for theoretical analysis and prediction of extrusion pressure, extrusion time and oil yield in a screw press of known specifications in order to facilitate a fully theoretical analysis and simulation of screw press operation. This type of information will be useful in the optimization and control of expeller operation.

1.1 Objectives of the study

1.1.1 Main objective

The main objective of the study is to develop a model equation for selecting optimum parameters for mechanical process of edible oil extraction.

1.1.2 Specific objectives

The specific objectives of the study are:

i. To develop a mathematical model for mechanical oil extraction,

ii. To carry out experimental runs within the range of the factors in the model,

iii. To validated the model using experimental data,

iv. To optimize the yield of mechanical oil extraction using the model.

1.2 Justification of the study

The mechanical oil extracting machine is of interest and relief to all operators of mechanized oil processing business outfit as it eliminates drudgery of the traditional methods of oil extraction and its associated losses. Determination of the optimal operational parameters of this machine will make its economical use in terms of labour, time and energy requirement thereby reducing cost of quality fish oil and fish meal production.

Improving the process efficiency and finding an alternative machine setting methods have always been of utmost importance in the study of mechanical oil extraction processes. There are numerous techniques through which the efficiency of the process can be improved and there are many components and combination of components that can be used in the process. Experimentation is not always the correct method for determining these optimum parameters. Experiments consume a large amount of time and also require a considerable amount of investment. Hence, it is necessary to have a better technique to implement such changes to a process and study the changes without having to conduct full scale experimentation-lab scale or on the actual unit. Process model is one way to accomplish this.

2 Theoretical Consideration and Model

Formulations

2.1 The basis

The oil-bearing material is fed into the pressing chamber where they are macerated. The macerated oilseed mass forms a stream of solid cum semi-solid material inside the press and is subjected to the pumping action of the rotating worm shaft inside the stationary press barrel. The stream of oilseed material behaves like a fluid under the pumping action of the rotating auger. Consequently, the solid flows in a manner similar to variable density flow in the annular space between two finite horizontal co-axial cylinders. Although, heat is generated by the shearing action of the worm shaft against the semi-solid mass, the steel press barrel is a good conductor of heat and it is expected to act as a temperature moderator such that once steady state is established, the temperature profile across the barrel length is nearly isothermal. Considerable mathematical simplification therefore accrues by reducing the flow problem to an isothermal variable density flow.

2.2 Modelling assumptions

For modelling of oil extraction processes, the following general assumptions have been taken into considerations.

i. The minced fish is homogeneous and saturated with oil.

ii. The fish sample is a three-phase system consisting of solid, liquid and air.

iii. Flow of oil out of the fish is pressure-induced because pressure is the liberating force.

2.3 General flow analysis

Figure 1 is a continuous helical flight on worm shaft. Figure 2 shows the material flow through a small section of worm channel, that is, the space between the shaft surface and the barrel wall. This miscella flow in turn changes the flow rate of the mixture in the axial direction. As the miscella (oil/water) and solid mixture passes through the section, it is subjected to radial pressure exerted by the shaft. The pressure causes flow of miscilla in the radial direction through the solid matrix and out through the barrel slots. The pressure distribution of the flow in the extruder is the total output obtained from the drag flow, back pressure flow and leakage. Assuming there is no leakage.

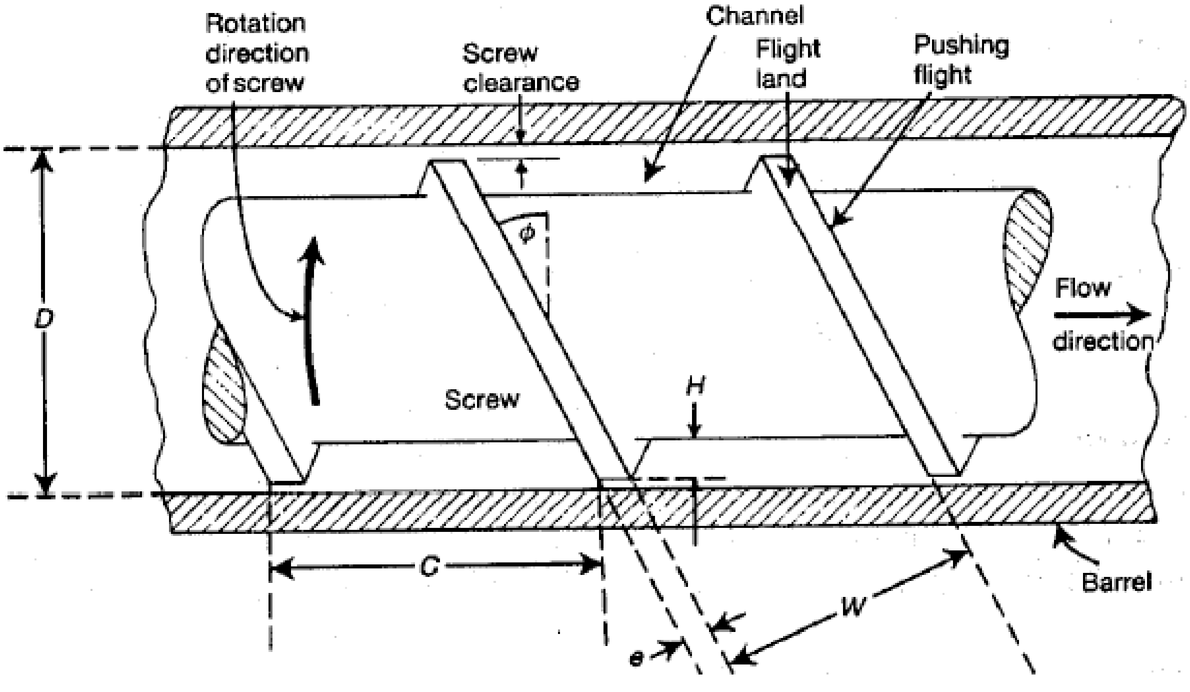

Figure 1 Continuous helical flight on worm shaft (Vadke et al., 1988)

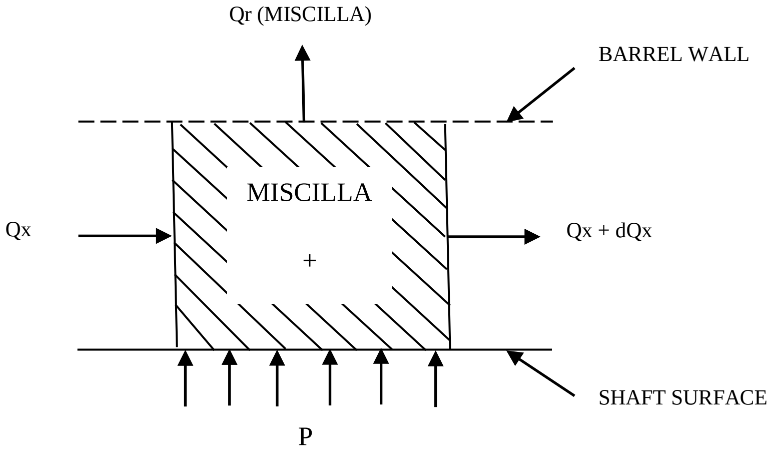

Figure 2 Flow of material through a section of worm channel (Vadke et al., 1988)

The extruder and die characteristics are defined by the equation (Crawford, 1998; Singh and Sharma, 2017);

$$Q = \frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset = \frac{\pi DH^3 \sin^2}{12\eta}\frac{P}{L} = Q_d - Q_p \quad (1)$$

Where; Q_d = Drag flow (m^3s^{-1}), Q_p = Pressure flow (m^3s^{-1}), D = Diameter of the screw (m), N = Screw revolution (rpm), H = Channel depth of the screw (m), Ø = Helix angle of screw (^{o}), L = Length of the screw (m), P = Operation pressure (Pa), η = Viscosity (Pas).

When there is no pressure build up at the end of the extruder, any flow is due to drag and maximum flow rate Q_{max} can be obtained. The equation then can be reduced to only the drag term as follows (Crawford, 1998; Singh and Sharma, 2017).

$$Q = Q_{max} = \frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset \quad (2)$$

Similarly, when there is a high pressure drop at the end of the extruder the output of the extruder, Q becomes equal to zero (Q = 0) and the maximum pressure is obtained from the equation (Crawford, 1998; Singh and Sharma, 2017).

$$\frac{1}{2}\pi^2 D^2 NH \sin\emptyset \cos\emptyset = \frac{\pi DH^3 \sin^2}{12\eta}\frac{P}{L} \quad (3)$$

The maximum pressure becomes (Crawford, 1998; Singh and Sharma, 2017);

$$P = P_{max} = \frac{6\pi DLN\eta}{H^2 \tan\emptyset} \quad (4)$$

2.4 Residence time distribution of the material in the screw press

When describing the extrusion process, it is of great importance to define the residence time for material particles in the extruder. On the basis of this time distribution, it is possible to establish the degree of mixing of the material, anticipate the course of plasticization as well as the extent and degree of uniformness in the deformation of the stream of liquid material during extrusion. Residence time is largely the result of the distribution of the velocities inside the device and the length of the screw. Although it is possible to calculate the residence time distribution for particular zones in the extruder from the flow velocities, practice shows that it is empirical evidence that provides the best results (Toscano and Pedretti, 2007).

Knowing that the length of the part of the compression chamber in which material compression really takes place (Lc) in m, and knowing that the rotation speed of the screw (N) in rps, it is possible to estimate the average compression time (Tc) of the fish using Equation 5 (Toscano and Pedretti, 2007).

$$T_c = \frac{L_c}{V} = \frac{L_c}{NP} \quad (5)$$

Where; T_C = Compression time (s), L_C = Length of the compression chamber (m), V = Linear speed (ms^{-1}), N = Screw rotational speed (rps), P = Screw pitch (m).

2.5 Model formulation

The essence of formulating a model for this type of study is to enable one study the extraction theory beyond the limiting experimental values and even to prescribe the optimal conditions of the extraction process without really having to embark upon endless practical experimentations. The extraction process estimating the quantity of oil, Y extracted from oil bearing material using the mechanical screw expeller at a given time depends on the choke clearance (c), screw clearance (s) and screw speed (N). In this model, the effect of the choke clearance was represented by the size (C), the effect of the screw clearance was represented by the screw size (D) and the effect of the screw speed was represented by the screw rotational speed (N). All these variables (C, D and N) are directly proportional to oil yield (Y).

The quantity of oil extracted using the mechanical screw press is mathematically expressed by Koo in 1942 as stated by Akinoso et al. (2009) as;

$$Y = C_0(\alpha)P^{1/2}T^{1/6}V^{-z/2} \qquad (6)$$

Where; Y = Oil yield in %, C_0 = Constant for the oil bearing material type, α = Initial oil content of the seed in % weight, P = Applied pressure in MPa, T = Time of pressing in hours, v = kinematic viscosity in m^2s^{-1}, z = exponent of kinematic viscosity (1/6-1/2).

Combining the maximum pressure equation (Equation 4) with the simple equation for oil yield prediction (Equation 6), the following equation was obtained;

$$Y = C_0(\alpha)\left(\frac{6\pi DLN\eta}{H^2\tan\emptyset}\right)^{1/2}T^{1/6}V^{-z/2} \qquad (7)$$

Collecting the viscosity terms together;

$$Y = C_0(\alpha)\left(\frac{6\pi DLN\eta V^{-z}}{H^2\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (8)$$

$$Y = C_0(\alpha)\left(\frac{6\pi DLNVV^{-z}}{H^2\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (9)$$

$$Y = C_0(\alpha)\left(\frac{6\pi DLNV^{1-z}}{H^2\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (10)$$

Introducing choke clearance effect as;

$$C_L = C \qquad (11)$$

$$Y = C_0(\alpha)C\left(\frac{6\pi DLNV^{1-z}}{H^2\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (12)$$

$$Y = \frac{C_0(\alpha)C}{H}\left(\frac{6\pi DLNV^{1-z}}{\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (13)$$

Collecting the viscosity terms together as a constant K to account for the nature of raw material, the equation reduces to;

$$Y = \frac{K(\alpha)C}{H}\left(\frac{6\pi DLN}{\tan\emptyset}\right)^{1/2}T^{1/6} \qquad (14)$$

Where; Y = oil yield (%), K = constant for oil bearing material type = 0.0322, α = initial oil content of the oil bearing material (fish) = 26.8 %, L = Length of the screw = 0.965 m, H = Channel depth of the screw = 0.0175 m, T = time of pressing = 20 s, Ø = Helix angle of screw = 10 degrees, D = Diameter of the screw (D1 = 0.086 m, D2 = 0.084 m, D3 = 0.082 m), C = Diameter of the choke (C1 = 0.086 m, C2 = 0.084 m, C3 = 0.082 m), N = Screw speed (N1 = 0.833 rps, N2 = 1.000 rps, N3 = 1.167 rps).

This implies that the yield depends directly or indirectly solely on screw length, screw diameter, choke diameter, screw speed, channel depth, screw helix angle and extraction duration. Since K is a constant accounting for the nature of raw material, it can vary for one and the same material depending on whether it is subjected to conditioning (time temperature treatment) or intact/undergone size reduction. Equation 14 was used to obtain the values of Y.

2.6 Model verification

In order to verify practically, the adequacy of the model, confirmation run experiments were performed. The test conditions for the confirmation runs were the combinations of variables at different levels within the limits of the factors under investigation. Verification entails comparing the mean values obtained from the verification runs to the predicted values of the developed model. The predicted values were compared with the actual experimental results by computing the residuals and their percentage errors.

2.7 Model validation

The adequacy and accuracy of the model equation was demonstrated by a comparison between the experimental values and the predicted values based on regression analysis (Mirhosseinia et al., 2008). To measure how well the suggested model was able to fit the experimental data, parameters such as correlation coefficient, coefficient of determination and probability value (p-value) were determined. The chi-square (χ^2) goodness-of-fit test was also performed to examine the validity of the model (Mooney and Swift, 1999).

The extraction process model was tested using the data generated from the bench-scale laboratory approach using the mechanical screw press. The model describing the quantitative extraction process of the mechanical screw press system was such that variations in the experimental values of oil yield and predicted values of oil yield from simulation are obtained. These variations for the sets of data in the variable parameters of choke clearance (C), screw clearance (D) and screw speed (N) for the observed and predicted were summed up as the absolute values of the average percentage deviation calculated as (Little and Hills, 1978);

$$\text{Deviation (\%)} = \frac{\text{Experimental values} - \text{predicted values}}{\text{Experimental values}} \times 100\,\% \tag{15}$$

The coefficient of variation was obtained from Equation 16 (Little and Hills, 1978).

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Expected (experimental) value}} \times 100\% \tag{16}$$

Standard deviation was calculated from Equation 17.

$$\text{Standard deviation}, S = \sqrt{\frac{\Sigma(y-\bar{y})^2}{n-1}} \tag{17}$$

Where; y = Observations, $\bar{y}$ = Mean, n = Number of observations.

The coefficient of determination and correlation coefficient were calculated from Equations 18 and 19 respectively (Little and Hills, 1978).

$$R^2 = \frac{(\Sigma xy)^2}{\Sigma x^2 \Sigma y^2} \tag{18}$$

$$R = \sqrt{R^2} = \sqrt{\frac{(\Sigma xy)^2}{\Sigma x^2 \Sigma y^2}} \tag{19}$$

Where; R^2=Coefficient of determination, R= Correlation coefficient, x=Experimental values, y= Predicted values.

The chi-square (χ^2) goodness-of-fit test was calculated from Equation 20.

$$\chi^2 = \sum \frac{(E-P)^2}{P} \tag{20}$$

Where; χ^2 = chi-square, E = Experimental values, P = Predicted values.

3 Results and discussion

The predicted results of the yield of oil extraction (%) from the theoretical model at different time intervals were plotted to form series of extraction curves for the predicted extraction results and presented in Figures 3-11. Table 1 is the experimental and predicted results of the cumulative yield of oil extraction (%) from the theoretical model and Table 2 shows the analysis of variance (ANOVA) of experimental and predicted values.

3.1 Oil yield prediction of the model

The governing equation was solved numerically with the varying process conditions resulting in the estimation of the oil yield. The variable conditions include choke clearance (C), screw clearance (D) and screw speed (N). The series of these extraction curves for the predicted extraction results are plotted and presented in Figures 3-11 for the three levels of choke clearance (C), screw clearance (D) and screw speed (N). The extraction curves show that the cumulative oil yield increased with time at all the treatment combinations.

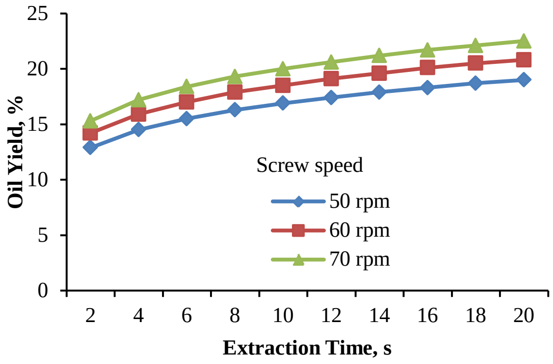

Figure 3 Predicted oil yield for 1 mm choke clearance and 1 mm screw clearance

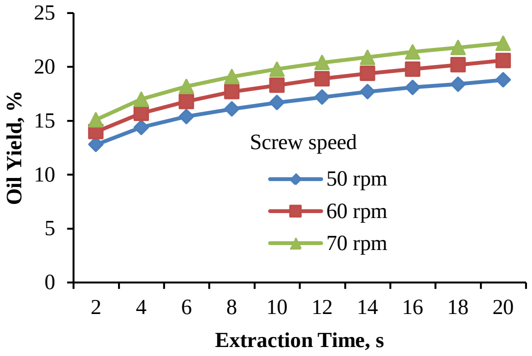

Figure 4 Predicted oil yield for 1 mm choke clearance and 2 mm screw clearance

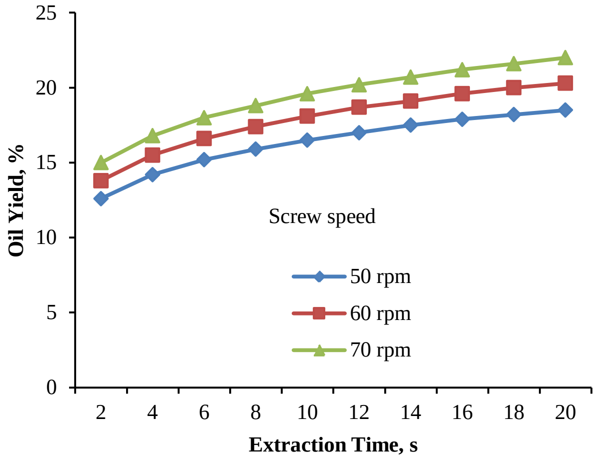

Figure 5 Predicted oil yield for 1 mm choke clearance and 3 mm screw clearance

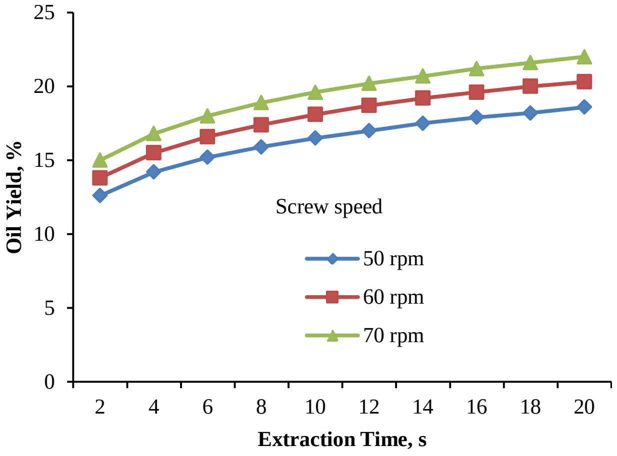

Figure 6 Predicted oil yield for 2 mm choke clearance and 1 mm screw clearance

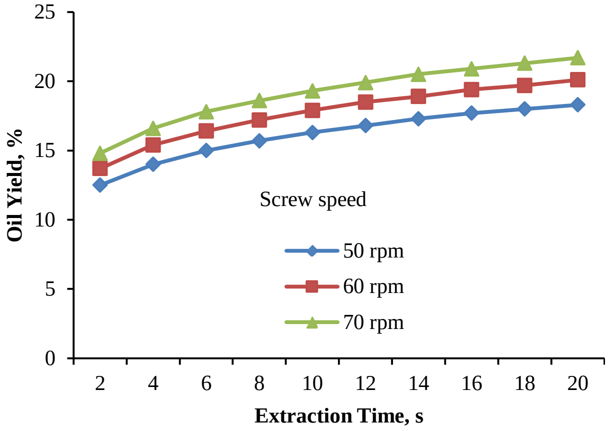

Figure 7 Predicted oil yield for 2 mm choke clearance and 2 mm screw clearance

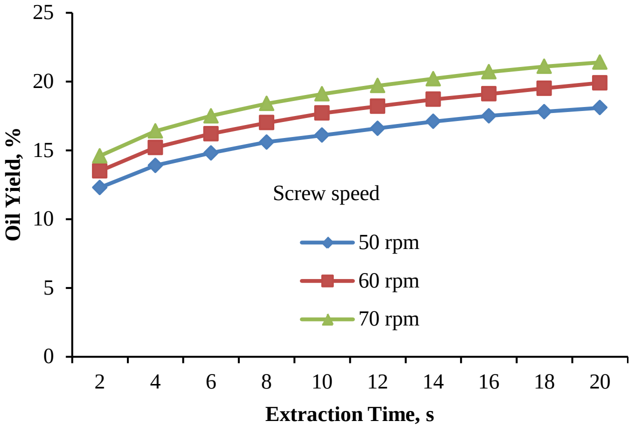

Figure 8 Predicted oil yield for 2 mm choke clearance and 3 mm screw clearance

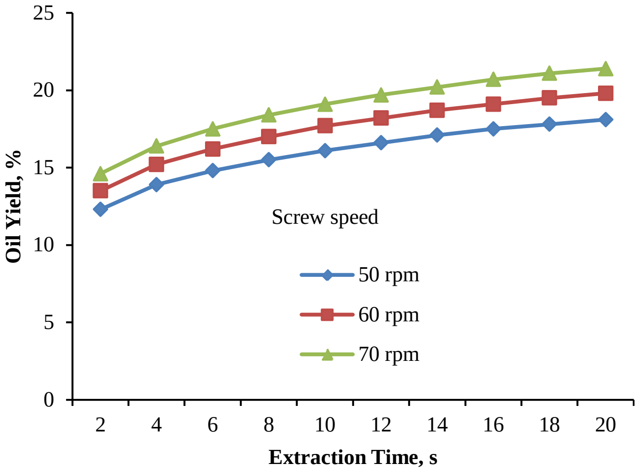

Figure 9 Predicted oil yield for 3 mm choke clearance and 1 mm screw clearance

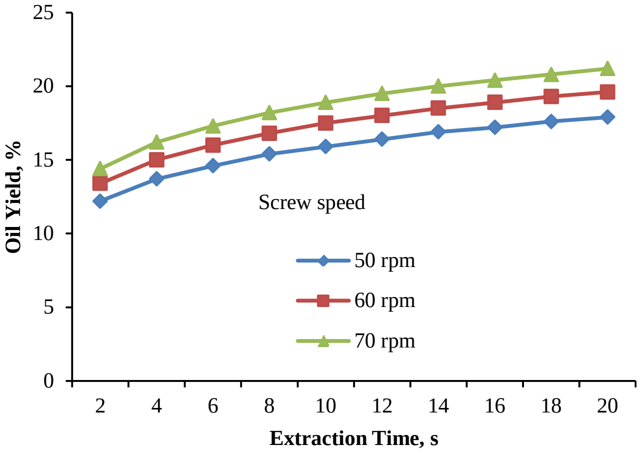

Figure 10 Predicted oil yield for 3 mm choke clearance and 2 mm screw clearance

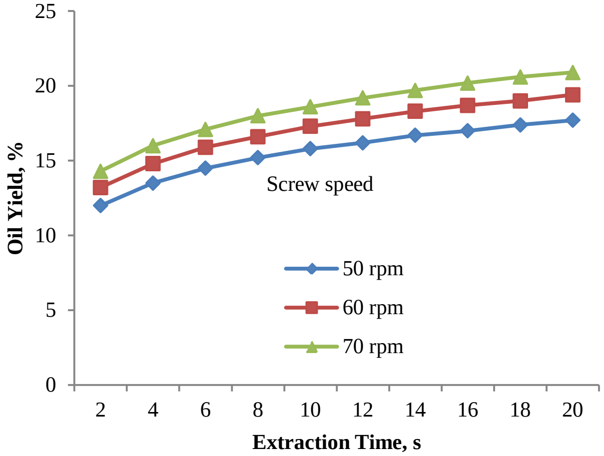

Figure 11 Predicted oil yield for 3 mm choke clearance and 3 mm screw clearance

3.2 Comparison of experimental results with predicted values from the simulation model

Table 1 is the experimental and predicted results of the cumulative yield of oil extraction (%) from the theoretical model. The table indicates that there is an agreement between the predicted and experimental results. The deviation ranged from - 2.2 % to 2.1 % with mean value of 0.9 %, the percentage deviation ranged from -11.8 % to 10.0 % with mean value of 4.8 % and the coefficient of variation ranged from 0.0 % to 8.3 % with mean value of 3.4 %. The coefficient of determination, R^2 and correlation coefficient, R of the model were 0.9967 and 0.9983 respectively.

The high correlation coefficients (0.9983) also confirmed that a close agreement between experimental data and the predicted values calculated using the models had been obtained. The closer the experimental and predicted results, the better they explain the adequacy of the model equation (Rossa et al., 2011).

The coefficient of determination in the model defined by R^2 expresses the degree of fitness of the model. The results gave a coefficient of determination (R^2) of 0.9967; indicating the adequacy of the applied model. This implies that 99.67 % of the variations could be explained by the fitted model, indicating a reasonable fit of the model to the experimental data. That is, the model can be used to navigate the design space with fewer errors. For fitness of the proposed model to the empiric, a coefficient of determination of 0.0 is the worst while 1.0 is the best. For a good fit of a model, R^2 should be at least 0.8 (Joglekar and May, 1987; Guan and Yao, 2008; Lee et al., 2010; Akintunde et al., 2015). Therefore, the R^2 value of the model is sufficiently high, to indicate that the model is workable and can be used for the estimation of the mean response and the subsequent optimization stages.

The ANOVA of the difference between the experimental data and the predicted values at $P \geq 0.01$ shows that the p-value of 0.629 obtained exceeds the p-value level of 0.01 and the calculated F-value of 0.24 obtained is far less than the theoretical (Tabulated) F-value of 7.17. This indicates that there was no significant difference between the experimental data and the predicted values at $P \geq 0.01$, thus the model is validated.

Table 1 The experimental and predicted results of the cumulative yield of oil extraction (%) from the theoretical model

S/N	Choke size, mm	Screw size, mm	Screw speed, rpm	Oil yield %		Deviation %	Percentage deviation %	Coefficient of variation %
				Experimental	Predicted			
1	C1	D1	N1	21.1	19.0	2.1	10.0	7.0
2	C1	D1	N2	21.8	20.8	1.0	4.6	3.2
3	C1	D1	N3	22.5	22.5	0.0	0.0	0.0
4	C1	D2	N1	20.5	18.8	1.7	8.3	5.9
5	C1	D2	N2	21.3	20.6	0.7	3.3	2.3

6	C1	D2	N3	22.1	22.2	-0.1	-0.5	0.3
7	C1	D3	N1	20.0	18.5	1.5	7.5	5.3
8	C1	D3	N2	20.7	20.3	0.4	1.9	1.4
9	C1	D3	N3	21.5	22.0	-0.5	-2.3	1.6
10	C2	D1	N1	19.5	18.6	0.9	4.6	3.3
11	C2	D1	N2	20.2	20.3	-0.1	-0.5	0.4
12	C2	D1	N3	21.0	22.0	-1.0	-4.8	3.4
13	C2	D2	N1	19.1	18.3	0.8	4.2	3.0
14	C2	D2	N2	19.7	20.1	-0.4	-2.0	1.4
15	C2	D2	N3	20.6	21.7	-1.1	-5.3	3.8
16	C2	D3	N1	18.8	18.1	0.7	3.7	2.6
17	C2	D3	N2	19.2	19.9	-0.7	-3.6	2.6
18	C2	D3	N3	19.8	21.4	-1.6	-8.1	5.7
19	C3	D1	N1	18.3	18.1	0.2	1.1	0.8
20	C3	D1	N2	18.9	19.8	-0.9	-4.8	3.4
21	C3	D1	N3	19.4	21.4	-2.0	-10.3	7.3
22	C3	D2	N1	18.0	17.9	0.1	0.6	0.4
23	C3	D2	N2	18.6	19.6	-1.0	-5.4	3.8
24	C3	D2	N3	19.0	21.2	-2.2	-11.6	8.2
25	C3	D3	N1	17.8	17.7	0.1	0.6	0.4
26	C3	D3	N2	18.0	19.4	-1.4	-7.8	5.5
27	C3	D3	N3	18.7	20.9	-2.2	-11.8	8.3
	Mean					0.9	4.8	3.4

Coefficient of Determination, R2 = 0.9967

Correlation Coefficient, R = 0.9983

Chi-square, χ2 = 1.8

Note: C1 = 86mm, C2 = 84mm, C3 = 82mm, D1 = 86mm, D2 = 84mm, D3 = 82mm, N1 = 50rpm, N2 = 60rpm, N3 = 70rpm

Table 2 ANOVA of experimental and predicted values

Source	DF	SS	MS	F-cal	F-tab	P
Parameters	1	0.46	0.46	0.24^{ns}	7.17	0.629
Error	52	102.17	1.96			
Total	53	102.63				

Note: ^{ns} Not significant

The chi-square (χ^2) goodness of fit test shows that there is not a significant difference between the predicted and actual values since the χ^2 value (1.8) is much smaller than the cut-off value of χ^2 for 99 % confidence level for 26 degrees of freedom (45.642). This indicates that the developed model is valid at 99 % confidence level.

The coefficient of variation (CV) indicates the degree of precision with which the experiments are compared (Claver et al., 2010). It is a measurement of reproducibility of the model. The CV of the model was obtained as 3.4 %. As a general rule, a model can be considered reasonably reproducible if its CV is not greater than 10 %. Therefore, the developed model could adequately represent the real relationship among the parameters chosen.

3.3 Optimization of the process

Optimizations were performed to measure the optimum levels of independent variables of choke clearance, screw clearance and screw speed, required to achieve the desired oil yield. The process providing the maximal oil yield involved press operation at low choke clearance, low screw clearance and high screw speed. To determine the exact optimum points for all the independent variables necessary to achieve the optimized condition, a numerical optimization was utilized.

From the model, under the optimum conditions, a maximum oil yield of 22.5 % was extracted at level of choke clearance 1 mm, screw clearance 1 mm and screw speed 70 rpm. The optimum oil yield (22.5 %) is equal to the maximum oil yield (22.5 %) obtained in the experimental study.

4 Conclusions

The oil extraction process in screw presses is governed by a couple of factors, some of them being quantifiable and some of them being less quantifiable, which demonstrates the complexity of the process and its mathematical expression. For screw presses with constant-diameter screw and pressing chamber equipped with circular holes for oil drainage and with a single cake outlet, the percentage of expressed oil along the pressing chamber has mainly an exponential variation, regardless of the material feeding rate or the cake outlet size.

Extraction yield is one of the most important variables in oil extraction process; therefore, the study of this parameter is of utmost importance. This study addresses modeling and optimization of the process parameters for oil extraction operation. The mathematical model was developed in order to relate the process control parameters to the process response characteristics. The mathematical model for the prediction of extraction yield in terms of the controlling parameters was established by combining the maximum pressure equation of Crawford (1998) with the simple equation for oil yield prediction of Koo in 1942 as stated by Akinoso et al. (2009).

The validity and accuracy of the oil extraction model were assessed by comparing the predicted and experimental results. The model fitted the data from the extraction tests with correlation coefficient of 0.9983, coefficient of determination of 0.9967, absolute average percentage deviation of 4.8 %, coefficient of variation of 3.4 % and chi-square goodness of fit of 1.8.

The closeness of the predicted values to the experimental values indicates that the formulated process model can be used to predict oil yield of oleaginous material in this extraction process. However, the deviations between the experimental and predicted values may have resulted because of, (i) variations introduced due to the inherent genetic factors of the oleaginous material (fish) like most agricultural products and (ii) lack of uniformity in the physical conduct of the experiment. The theory however, provides an alternative to costly and time-consuming empirical studies in obtaining information about the performance of a press.

Numerical optimization carried out determined the optimum parameters for extraction to be when the choke clearance, screw clearance and screw speed were 1 mm, 1 mm and 70 rpm, respectively. The model developed has provided a basis for selecting optimum process parameters for the recovery of oil using mechanical press.

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