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RESEARCH ARTICLE

DEVELOPMENT OF A SOYA BEAN OIL EXTRACTING MACHINE

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ABSTRACT

An expelling machine for extracting oil from soya bean seeds was designed and fabricated for market-oriented production. The procedures employed the design stage, construction and testing. The machine components are: the speed reduction gear, expellant unit, drains collector, driving and driven pulleys, and the hopper. The expelling unit consists of a screw expellant shaft with expellant barrel. The soya bean seeds were pre-heated by roasting before extraction of the oil in it. The machine gave a better performance at the speed of 60 revolutions per minute. Analysis of variance showed that cylinder speed made significant effects at $p \le 0.05$ on the parameters evaluated and the separation of means using F-LSD showed significant difference on the parameters evaluated. The quality of extracted soya bean oil was also analysed. The oil was evaluated as follows: free fatty acid value 2.5 %, saponification value 191 mgKOH/g, iodine value 128 I_2 /100g, peroxide 4.68meqo$_2$/kg, total viable count (TVC) 0.2 x 10^1 CFU/mL and total coliforms count 0.0 x 10^1 CFU/mL. These values fall within the acceptable standard values. Based on the characteristics of the oil, it could be suitable for applications in pharmaceutical and food industries.

INTRODUCTION

Soya bean (*Glycine max*) is among the major industrial and food crops grown in every continent. The crop can be successfully grown in many states in Nigeria using low agricultural input. Soya bean (*Glycine max*) cultivation in Nigeria has expanded as a result of its nutritive and economic importance and diverse domestic usage. It is also a prime source of vegetable oil in the international market. Soya bean has an average protein content of 40% and is more protein-rich than any of the common vegetable or animal food sources found in Nigeria. Soya bean seeds also contain about 20% oil on a dry matter basis, and this is 85% unsaturated and cholesterol-free (IITA, 2009). Soya beans are crushed to obtain oil (for industrial and refined for food use) and soya bean meal/cake for animal feed. At present, soya bean oil is a major complement to palm oil in the domestic supply equation for edible vegetable oils and the major producers have reported a rise in demand for soya bean oil as Nigerians became more familiar with the higher quality and health benefits of soya bean oil. (IITA, 2009). In spite of all these benefits of soya beans and soya bean oil, there are series of inadequacies of its available processing methods. The traditional method of processing soya bean into its valuable components has long been in existence.

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It is however, laborious, time consuming and great amount of oil is lost. In the present world of technological advancement, different types of machines have been developed using modern methods for oil extraction from various oil seeds like soya beans. Although the modern systems of soya bean oil extraction have high efficiency, they are not readily available for use in the remote area. In urban areas where they are available, the cost of the machines and their operation and maintenance limit their uses.

The hot water flotation (HWF) method of edible oil extraction is traditionally used in the rural areas of many developing countries including Nigeria. Usually, decorticated oilseed is used. The oilseed kernels are heated and ground by pounding in a mortar and pestle. The ground seed was then suspended in boiling water and boiled for at least 30 min. Liberated oil floats to the surface. Further quantities of water were sometimes added after boiling to replace that lost by evaporation, and to encourage the oil to float to the surface. The oil was carefully scooped from the surface of the water using a shallow dish and was then heated over a fire to remove residual moisture. Therefore, there is need for the development of a soya bean oil extraction machine that is effective, efficient, low cost and easy to operate. This necessitated the development of soya bean oil extraction machine using locally available materials.

MATERIALS AND METHODS

Design Analysis

Design Consideration

Some of the criteria considered in the design include; use of local materials, adequate capacity, affordability, reduction in time and energy spent in extraction of oil manually, detachable components, using bolts and nuts to attach for easy repair and maintenance.

Design of Hopper

The hopper is a frustum, trapezoidal in shape. To determine the inlet and outlet dimensions of the hopper. The inlet dimension of the hopper should be the size of the area loading into the cylinder from the hopper which was determined to be 50mm×50mm. The outlet dimension of the hopper was estimated at eight times that of inlet, which is 400×400 mm.

Volume of Hopper, V_h

The volume of hopper was determined from the equation.

$$V_h = \frac{1}{3}\left(\frac{b_1^3 - b_2^3}{b_1 - b_2}\right)h \quad \text{.......} (1)$$

(Eric et'al, 1982)

Where, $b_1 = length$ of larger part of the frustum $= 400$ mm

$b_2 = length$ of smaller part of the frustum $= 50$ mm

$h = Height of$ frustum $= 300$ mm

$V_h = 18250000\ mm^3 = 0.01825\ m^3$

Hopper Capacity, Hc

The hopper capacity is determined from the equation.

$$H_c = \rho V \quad \text{.......} (2)$$

(Eric et'al, 1982)

Where; $\rho = Density of soyabean sample\ 750\ kg/m^3$,

$V = Volume of hopper = 0.01825\ m^3$

$H_c = 14\ kg$

Design of the Pressing Drum

Screw Pitch of the Pressing Drum

The pitch of a thread is the distance from a point on one thread to the corresponding point on an adjacent thread. Thus for a drum auger of length L and M number of flights, the pitch is given by;

$$P = \frac{L}{M} \quad \text{.......} (3)$$

(Khurmi and Gupta, 2005)

Where, L = Length of drum = 450 mm,

M = Number of flights = 9

Screw Pitch P = 50 mm

Shear Failure of Pressing Drum

The shearing stress of the pressing drum is defined by;

$$\tau = \frac{16M_t}{\pi d^3} \quad \text{.......} (4)$$

(Bhandari, 1994)

$$M_t = WR \quad \text{.......} (5)$$

Where;

τ = Shearing stress,

M_t = Torsional moment,

d = Core diameter of pressing drum = 96 mm,

R =d= Core diameter of pressing drum = 96 mm.

M_t = (63) 0.096 = 6.05 Nm

Shearing stress, τ = 34,833 N/m^2

The maximum allowable shear stress for steel screws is 55 Mpa (Bhandari, 1994). Therefore, since the maximum shear stress calculated for the screw press is far less than the maximum permmissible shear stress, the pressing screw will not fail hence, the design is considered safe.

Design of Shaft

Since mild steel is used for the shaft, maximum shear stress theory will be used for the design of the shaft diameter and it is given in the equation as;

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \text{.......} (6)$$

(Bhandari, 1994)

Where;

S_S = Maximum permissible shear stress,

$$Ss = \frac{Ultimate Strength in Shear}{Factor of Safety, FS} \quad \text{.......} (7)$$

K_b = Combined shock and fatigue factor applied to bending moment,
K_t = Combined shock and fatigue factor applied to torsional moment,
M_b = Maximum bending moment, Nm,
M_t = Torsional moment, Nm.

d = 13mm, but in order to satisfy all conditions of design and introducing factor of safety, nominal shaft diameter of 18.00mm is chosen. d =18mm

Power Requirement of the Machine

The total power requirement of the machine is the sum of the power to drive the pressing drum (P_D) and the power to extract the oil (P_E).

$$P_T = P_D + P_E \quad \text{.......... (8)}$$

(Khurmi and Gupta, 2005)

Power to Drive the Pressing drum

Power to drive pressing drum;

$$P_D = T_D \omega_D \quad \text{.......... (9)}$$

(Khurmi and Gupta, 2005)

But $T_D = W_D R_D$ .... (10)

Where;

W_D = Weight of pressing drum = 63 N,

R_D = Radius of pressing drum = 0.048 m,

ω_D = Angular velocity of pressing drum.

$$\text{Angular velocity, } \omega_D = \frac{2\pi N}{60} \quad \text{.......... (11)}$$

$$= \frac{2\pi \times 1440}{60} = 150.72 \text{ rad/s}$$

Power to drive pressing drum, P_D = 456 W

Power to Extract Oil

Power to extract oil is defined by;

$$P_E = T_S \omega_D \quad \text{.......... (12)}$$

(Khurmi and Gupta, 2005)

But

$$T_S = \frac{\pi (D_D)^3 \tau}{16} \quad \text{.......... (13)}$$

Where;

P_E = Power required to extract oil, W,

ω_D = Angular velocity of drum = 150.72 rad/s,

T_S =Torque of drum in relation with the shear stress of soya beans, Nm,

D_D = Diameter of drum =0.076 m

τ = Shear stress of fish= 88480 N/m^2 (determined experimentally).

T_s = 7.62 Nm

Power to extract oil, P_E = 1150 W

Total power,

$$P_T = P_D + P_E = 456 \text{ W} + 1150 \text{ W} = 1606 \text{ W} = 1.606 \text{ kW}$$

0.746kw = 1 horse power (HP)

$$\therefore 1.606 \text{ kW} = \frac{1 \text{ HP}}{0.746 \text{ KW}} \times 1.606 \text{ KW}$$

$$= 2.15 \text{HP}$$

Electric motor of 2.5 HP can conveniently power the machine.

Description and Operation of the Soya Bean Oil Extracting Machine

The machine consists of the following; feeding unit, (hopper) pressing mechanism, driving mechanism, adjustable regulator and lock nut. The feeding unit is a hopper through which the pods are introduced into the pressing chamber. The pressing chamber contains a screw auger drum. The drum screw shaft is supported by bearings at its ends and powered by an electric motor through a wheel belt and pulley drive at a regulated speed. The lower part of the pressing chamber is perforated with orifices to drain the oil into the collection pan. The cake is conveyed along the screw to the concave end and forced out of the chamber through the outlet chute. Clearance between screw shaft and drum is adjusted by the screw shaft regulator. Turning the handle anticlockwise moves the taper plug section of the screw shaft axially further into the taper borne of the drum, thus reducing the thickness of the cake. Turning the screw shaft regulator clock-wise withdraws the screw shaft and increases the cake thickness. The lock nut has to be released to allow the operating screw to move and should be relocked after each adjustment. Figure 1 is the isometric drawing of the soya bean oil extraction machine, while Figure 2 is the photograph of the soya bean oil extraction machine.

Performance Evaluation and Statistical Analysis

Selection, Preparation and Pre-treatment of Test Materials

The 5kg of soya bean was sorted, dehulled and heated to 100-105 °C for approximately 20 minutes. This process coagulates the proteins and disrupts the cell membranes thus allowing leakage out of bound oil. (Wilson, 1995)

Evaluation of the System

The constructed soya bean oil extractor was tested to evaluate its performance in the extraction process. Materials required include weighing balance, measuring cylinder, soya bean seeds, cake receiving container and oil receiving container.
The machine powered by a 2.5hp electric motor was set into operation and known weights (5000 g) of each prepared sample were fed into the machine through the feeding hopper. The helical screw drum conveyed, crushed, squeezed and pressed the sample in order to extract the oil.

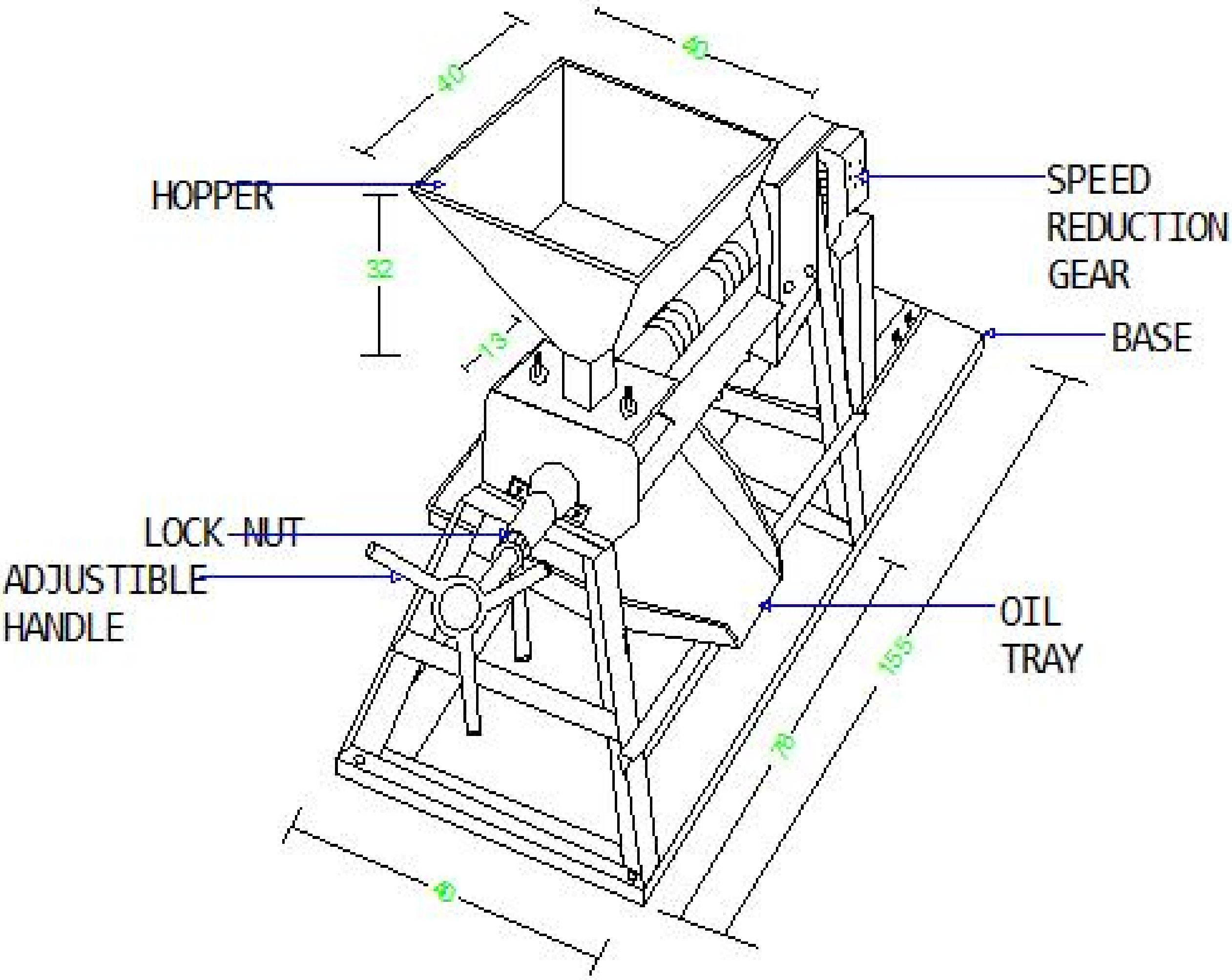

Fig. 1. Isometric View of the Soya Bean Oil Extracting Machine All Dimension in mm Scale; 1:10

Fig. 2. Photograph of the Developed Soya Bean Oil Extracting Machine

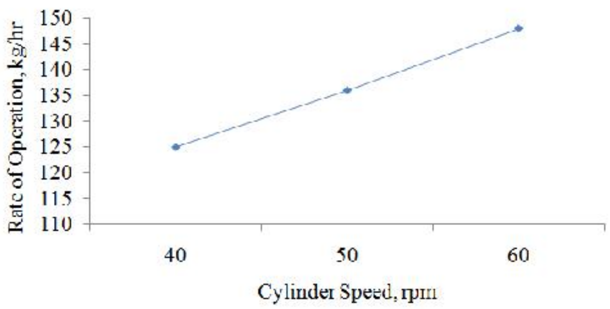

Fig. 3. Effect of cylinder speed on the mean rate of operation (kg/hr)

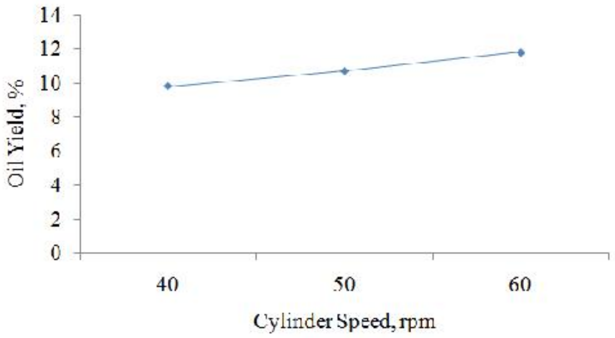

Fig. 4. Effect of cylinder speed on the mean oil yield (%)

The oil was separated from the press cake. The oil extracted and the press cake were collected and weighed separately. Clarification was done to separate the oil from its entrapped impurities. The clear oil was sieved and heated to remove moisture in the oil. From the values obtained, oil yield was calculated using the formula prescribed by Adesoji et al (2013) as:

$$O_Y = \frac{100\, W_{OE}}{W_{FE} + W_{RC}} \% \quad \text{...} (14)$$

Where; W_{OE} = Weight of oil extracted,

W_{FE} = Weight of soya bean extract,

W_{RC} = Weight of residual cake.

Experimental Design

The experimental design for the statistical analysis follows a one-treatment effect (cylinder speed) in a Completely Randomized Design (CRD) with three replications per experimental unit. All data collected were subjected to analysis of variance (ANOVA) to test for significant effects at 95 % confidence limit using the procedure recommended by Steel and Torrie (1980). When significant difference was observed, treatment means were separated using the F-LSD.

Analysis of Soya Bean Oil Quality

Chemical methods

The physicochemical properties of the oil were determined to assess its quality and purity. Four oil quality indices were used to determine the quality of the extracted oil. They are the free fatty acid content, saponification value, iodine value and peroxide value. The level of free fatty acids (FFA), saponification value (SV), iodine value (IV) and peroxide value (PV) were determined by titration according to the Official Methods and Recommended Practices of the American Oil Chemists' Society (AOCS, 1992).

Microbiological Analysis

Microbiological analysis was conducted for aerobic plate count method (Standard Plate Count agar) with four dilution and incubated at 37°C for 24-48 hours. Count was carried out using hand lens. The colony forming unit (g/mL) was calculated according to Vanderzant and Splittstoesser, (1992) from the equation;

$$Cfu = \frac{N}{VD} \quad \text{...} (15)$$

Where;

N= number of colonies,

V= volume of diluents,

D= dilution factor.

RESULTS

The Analysis of variance (ANOVA) at $P \leq 0.05$ of the effect of cylinder speed on the rate of operation (kg/hr) is presented in Table 1 and the Means using F-LSD is presented in Table 2. While the Analysis of variance (ANOVA) at $P \leq 0.05$ of the effect of cylinder speed on the oil yield (%) is presented in Table 3 and the Means using F-LSD is presented in Table 4. Results of the design calculations are presented in Table 5. Figure 2 shows the effect of cylinder speed on the mean rate of operation while Figure 4 shows the effect of cylinder speed on the mean oil yield.

Table 1. Analysis of Variance of the Effect of Cylinder Speed on Rate of Operation (Kg/Hr)

Sources of Variation	Df	SS	MS	Observed F	Required F (5%)
Treatment	2	816.89	408.45	216^*	5.14
Error	6	11.33	1.89		
Total	8	828.22			

*- significant; ns- not significant

Table 2. Effect of Cylinder Speed on the Mean Rate of operation

Cylinder Speed (rpm)	Rate of Operation (kg/hr)
40	125
50	136
60	148
$F\text{-}LSD_{0.05}$	3.78

Means having the same letter in the same row are not statistically different from each other at $P \leq 0.05$ using F-LSD.

Table 3. Analysis of Variance of The Effect of Cylinder Speed on Oil Yield (%)

Sources of Variation	Df	SS	MS	Observed F	Required F (5%)
Treatment	2	6.04	3.02	108^*	5.14
Error	6	0.17	0.028		
Total	8	6.21			

*- significant; ns- not significant

Table 4. Effect of Cylinder Speed on the Mean Oil Yield

Cylinder Speed (rpm)	Oil Yield (%)
40	9.8
50	10.7
60	11.8
F-$LSD_{0.05}$	0.056

Means having the same letter in the same row are not statistically different from each other at $P \leq 0.05$ using F-LSD.

Table 5. Results of Design calculations

Description	Result
Volume of hopper	0.0183m^3
Hopper Capacity	14kg
Force acting on pressing drum	63N
Screw pitch of pressing drum	50 mm
Shearing stress of pressing drum	34,833 N/m^2
Bending moment of shaft	7.88Nm
Torsional moment of shaft	6.05Nm
Shaft diameter	18.00 mm
Power requirement	2.5H.P

Table 6. Analysis of Soya Bean Oil Quality

Parameter	Unit	Test Value
Physicochemical properties		
Free Fatty Acid Value	%	2.5
Saponification Value	mgKOH/g	191
Iodine Value	Iodine/100g	128
Peroxide Value	$mEqO_2/kg$	4.68
Microbiological Analysis		
Total Viable Count (TVC)	CFU/mL	0.2×10^1
Total Coliforms Count	CFU/mL	0.0×10^1

DISCUSSION

Effect of Cylinder Speed on the Rate of Operation

Results of the effects of speed on the rate of operation are shown in Tables 2. Cylinder speed had a positive association with rate of operation, being 125 kg/hr at 40 rpm, 136 kg/hr at 50 rpm and 148 kg/hr at 60rpm. From the ANOVA (Table 1) there is a significant difference in the cylinder speed. There was significant difference in the rate of operation at all the speeds investigated from the separation of means.

Effect of Cylinder Speed on the Oil Yield

From the ANOVA (Table 3) there was a significant difference in the cylinder speed. From the means separation, there was significant difference in the oil yield at all the speeds investigated. The best oil yield of 11.8 % was obtained for 60 rpm speed. The lowest oil yield of 9.8 % was obtained for the condition of 40 rpm. It was observed from Table 4 that the oil yield increased with increasing cylinder speeds. This is in agreement with the statement of Bamgboye and Adejumo, (2007) who reported that a reduction in speed of rotation of the shaft, for example, could reduce the oil yield, increasing the oil content in the cake and solids in the oil. Akinoso et al, (2009) while evaluating the effects of compressive stress, feeding rate and speed of shaft screw press on palm kernel oil yield observed same trend of increase in oil yield with increased speed.

Analysis of Soya Bean Oil Quality

In order to determine the stability and quality of extracted soya bean oil, some quality assessment was conducted. It was observed that all the results obtained were tolerable to the standard values. These results are shown in Table 6. The value of free fatty acids (FFA) in extracted soya bean oil was found to be 2.5 %, which is within the standard value of 2 % to 3 % for soya bean oil. The iodine value was found to be 128 I_2/100g, which is within the standard value of between 120 to 137 I_2 /100g of the sample (Soybean oil - China dictionary, 2014). In this study, the peroxide value was found to be 4.68 $meqo_2$/kg, which is well below acceptable limit of 20 $meqo_2$/kg oil. This indicated that the soya bean oil extracted had low lipid oxidation rate. Saponification is the process of breaking down a neutral fat into glycerol and fatty acids by alkali treatment. The saponification value of soya bean oil obtained in this study was 191 mg KOH/g which is within the standard value range of 188-195 mg KOH/g for soya bean oil (Soybean oil - China dictionary, 2014). The results of the microbiological analysis of soya bean oil showed that the total viable count was 0.2×10^1 CFU/mL of oil and total coliforms count was 0.0×10^1 CFU/mL of oil. The reduction in the coliforms counts is as a result the use of heat in the oil extraction process.

Conclusion

The results obtained from the developed machine shows that mechanical extraction is a suitable method for extracting soya bean oil because of its high yield and high oil purity. Also, the use of an electric motor to operate the extractor produces less noise thereby reducing the cost of abating pollution. This process also generates little or no waste since the soya bean cake can be used as animal feeds thereby reducing cost of waste disposal. From the output of the machine it can be concluded that design and installation of a commercial plant is viable.

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