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RESEARCH ARTICLE

# DESIGN AND CONSTRUCTION OF A SOYA BEAN OIL EXTRACTING MACHINE

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## ABSTRACT

The objectives of this work are to design a small scale screw press for soya bean oil extraction; to fabricate the components of the machine based on the design specifications and; to test the oil press after fabrication and assembly of the components. This machine was aimed at easing the pain, stress, intensive labour, and time consumption encountered in the existing soya bean oil pressing processes. The basic features of the soya bean oil extracting machine are the frame, electric motor, pressing drum, oil outlet, cake outlet, hopper, pulleys, transmission belts and bearings. In operation, the gradually built-up pressure along the screw drum travel conveys, crushes, grinds, presses and squeezes oil out of the prepared soya bean into the oil outlet via the oil channel. The residual cake from where the oil is extracted is extruded out of the cake outlet in form of flakes. Analysis of variance showed that cylinder speed made significant effects at $p \leq 0.05$ on the parameter evaluated and the separation of means using F-LSD showed significant difference on the parameter 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 4.68 meq/kg, total viable count (TVC) $0.2 \times 10^1$ CFU/mL and total coliforms count $0.0 \times 10^1$ 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 is an important crop in Nigeria. It has high nutritional qualities. Soya bean has a high protein content of 40% by weight, 32% carbohydrate, 20% fat, 5% minerals and 3% fiber, and other trace substances. It is used as sources of protein for human food, animal feeds and industries (Adekunle *et al.,* 1995). Soya bean is rich in oil, and is often called an "oilseed." The value of the soya bean, which contains about 20% oil and 40% protein, lies in the fact that there is a strong demand for both these ingredients, either directly or indirectly, in human foods. The separation of these two major components has given rise to the soya bean crushing industry. Soya bean oil is classified as polyunsaturated oil which includes about 15% saturates 24% monounsaturates and 61% polyunsaturates of which 53.2% is linoleic acid while the linolenic acid is about 7.8%. The nutritional advantages of this composition and its effects in regulating the plasma lipid and eicosanoids bio- synthesis are reviewed on the basis of results from several human clinical trials and studies. These studies have shown that soya bean oil is effective in lowering the serum cholesterol level, and likely can be used as potential hypocholesterolemic agent if used as a dietary fat and ultimately help prevent atherosclerosis and heart diseases. 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. 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. Therefore, there is need for the design of a soya bean oil extracting machine that is effective, efficient, low cost and easy to operate. This necessitated the design and construction of soya bean oil extraction machine using locally available materials.

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## MATERIALS AND METHODS

### Materials for Performance Test

The materials for performance test include soya bean seeds, which were obtained from the market in Makurdi, weighing balance, Vernier calliper, oven and volumetric cylinder.

## 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 frustrum, 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 determine 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 is determined from the equation.

$$V_h = \frac{1}{3}\left(\frac{b_1^3 - b_2^3}{b_1 - b_2}\right)h \quad \text{(Eric } et\ al.\text{, 1982)} \quad \ldots\ldots\ldots\ldots 1$$

Where,

$b_1 = length$ of larger part of the frustrum $= 400$ mm
$b_2 = length$ of smaller part of the frustrum $= 50$ mm
$h = Height\ of$ frustrum $= 300$ mm
$V_h = 18250000\ mm^3 = 0.01825\ m^3$

### Hopper Capacity, Hc

The hopper capacity is determined from the equation.

$$H_c = \rho V \quad \text{(Eric } et\ al.\text{, 1982)} \quad \ldots\ldots\ldots\ldots 2$$

Where; $\rho = Density\ of\ soya\ bean\ sample\ 750\ kg/m^3$,
$V = Volume\ of\ hopper = 0.01825\ m^3$
$H_c = 14\ kg$

### 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;

$$P = \frac{L}{M} \quad \text{(Khurmi and Gupta, 2005)} \quad \ldots\ldots\ldots\ldots 3$$

Where, L = Length of drum = 450 mm,
M = Number of flights = 9
Screw Pitch P = 50 mm

### Shear Failure Analysis of Pressing Drum

The shearing stress of the pressing drum is defined by;

$$\tau = \frac{16M_t}{\pi d^3} \quad \text{(Bhandari, 1994)} \quad \ldots\ldots\ldots\ldots 4$$

$$M_t = WR \quad \ldots\ldots\ldots\ldots 5$$

Where;

$\tau$ = 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, $\tau$ = 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;

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \text{(Bhandari, 1994)} \quad \ldots 6$$

Where;

$S_S$ = Maximum permissible shear stress,

$$Ss = \frac{Ultimate\ Strength\ in\ Shear}{Factor\ of\ Safety, FS} \quad \ldots\ldots 7$$

$K_b$ = 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.

### 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 ($P_E$).

$$P_T = P_D + P_E \quad \ldots\ldots\ldots\ldots 8$$

### Power to Drive the Pressing drum

Power to drive pressing drum;

$$P_D = T_D \omega_D \quad \ldots\ldots\ldots\ldots 9$$

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,
$\omega_D$ = Angular velocity of pressing drum.

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

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

Power to drive pressing drum, $P_D$ = 456 W

**Power to Extract Oil**

Power to extract oil is defined by;

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

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

Where;

$P_E$ = Power required to extract oil, W,
$\omega_D$ = 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
$\tau$ = Shear stress of *soya bean* = 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 of the Soya Bean Extracting Machine**

The extracting machine consists of the following basic units; feeding unit (hopper), pressing mechanism, driving mechanism, adjustable regulator and lock nut. The feeding unit is a hopper through which the seeds are introduced into the pressing chamber. The pressing chamber contains a screw auger drum. The screw drum is supported by bearing 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 auger drum and cylinder is adjusted by the screw drum regulator. Turning the handle anticlockwise moves the taper plug section of the screw drum axially further into the taper borne of the cylinder, thus reducing the thickness of the cake. Turning the screw drum regulator clock-wise withdraws the screw drum 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.

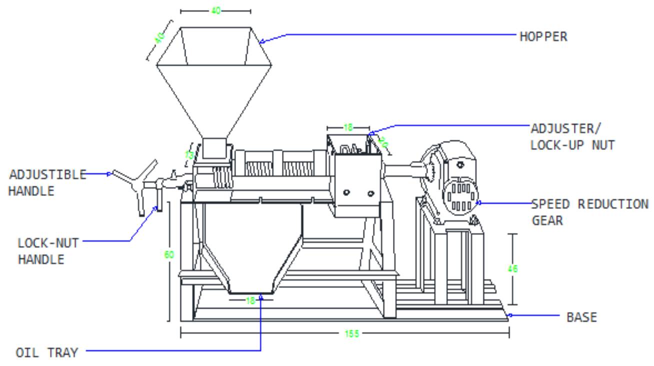


**Fig.1. Isometric View of the Soya Bean Oil Extracting Machine**

**Fig. 2. Picture of the Soya Bean Oil Extracting Machine**

**Method of Evaluation and Statistical Analysis**

**Selection, Preparation and Pre-treatment of Test Materials**

The sample 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 water oil.

**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. 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, extraction efficiency was calculated according to Adesoji *et al*. (2013) as:

$$O_E = \frac{100 W_{OE}}{X W_{FS}} \% \quad \text{................ 14}$$

Where;

$W_{OE}$ = Weight of oil extracted,
$W_{FS}$ = Weight of fed sample,
X = Oil content of Soya bean in decimal.

### Experimental Design

The experimental design for the statistical analysis follows a one-treatment effect (cylinder speed) in a Completely Randomized Design (CRD) with three observations (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;

$$Cfu = \frac{N}{VD} \qquad 15$$

Where; N= number of colonies, V= volume of diluents, D= dilution factor.

## RESULTS

Table 1 shows replicated results of rate of operation (kg/hr) of the soya bean oil-extracting machine at three different cylinder speeds, Table 2 shows the Analysis of variance (ANOVA) at P≤ 0.05 of the effect of cylinder speed on the rate of operation (kg/hr) and Table 3 represents the Means using F-LSD. Table 4 shows replicated results of oil yield (%) of the soya bean oil extracting machine at three different cylinder speeds, Table 5 is the replicated results of the volume of oil of the soya bean oil extracting machine obtained at three different cylinder speeds, Table 6 represents the Analysis of variance (ANOVA) at P≤ 0.05 of the effect of cylinder speed on the oil yield (%) and the Means using F-LSD is presented in Table 7.

**Table 1. Replicated results of rate of operation (kg/hr) of the soya bean oil extracting machine at three different cylinder speeds**

| Cylinder Speed (rpm) | Replications | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| 40 | 125 | 124 | 126 | 375 |
| 50 | 136 | 138 | 135 | 409 |
| 60 | 148 | 150 | 147 | 445 |

**Table 2. 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 3. 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-LSD$_{0.05}$** | 3.78 |

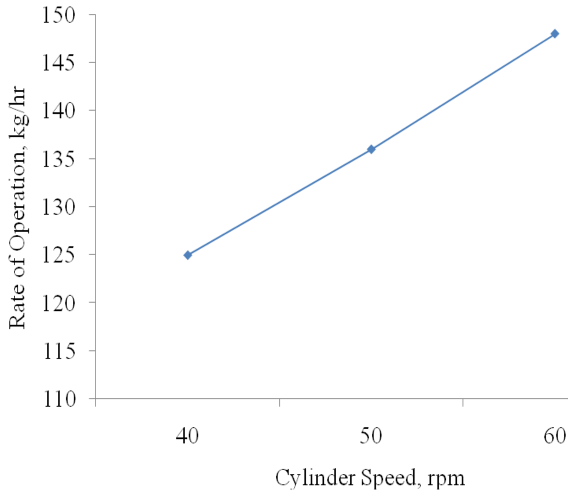


**Fig. 3. Effect of cylinder speed on the mean rate of operation (kg/hr)**

**Table 4. Replicated results of oil yield (%) of the soya bean oil extracting machine at three different cylinder speeds**

| Cylinder Speed (rpm) | Replications | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| **40** | 9.8 | 10.0 | 9.7 | 29.5 |
| **50** | 10.5 | 10.7 | 10.9 | 32.1 |
| **60** | 11.7 | 11.8 | 12.0 | 35.5 |

**Table 5. Replicated results of the volume of oil ($Cm^3$) of the soya bean oil extracting machine obtained at three different cylinder speeds**

| Cylinder Speed (rpm) | Replications | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | Total |
| **40** | 529 | 540 | 524 | 1593 |
| **50** | 567 | 578 | 589 | 1734 |
| **60** | 632 | 637 | 648 | 1917 |

**Table 6. 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 7. 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 |

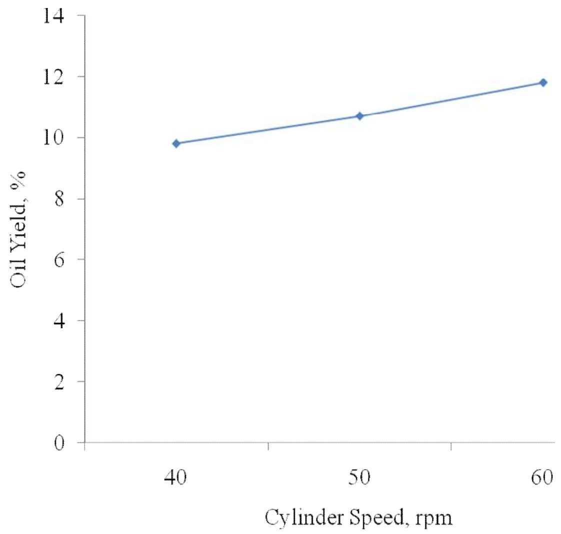


**Fig. 4. Effect of cylinder speed on the mean oil yield (%)**

**Table 8. 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 | $0.2 \times 10^1$ |
| Total Coliforms Count | Cfu/mL | $0.0 \times 10^1$ |

Results of the soya bean oil quality analysis are presented in Table 8. Figure 3 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.

## DISCUSSION

Results of the effects of speed on the rate of operation are shown in Tables 3. 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 2) 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. From the ANOVA (Table 6) 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 7 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 could reduce the oil yield, while 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.

In order to determine the stability and quality of soya bean oil extracts, 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 8. 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 (Soya bean oil - China dictionary, 2014). In this study, the peroxide value was found to be 4.48meq/kg, which is well below acceptable limit of 20meq $O_2$/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 191mgKOH/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 $0.2 \times 10^1$Cfu/mL of oil and total coliforms count was $0.0 \times 10^1$Cfu/mL of oil. The results are less than the standard set by the international commission on microbiological specification of food (ICMSF, 2000), and Health protection agency (2004) that the set limit of $10^6$Cfu/ml for aerobic count of foods and coliform count of less than $10^2$Cfu/ml. The reduction in the coliforms counts is as a result of the use of heat in the oil extraction process.

### Conclusion

The results obtained from the designed machine shows that mechanical extraction is a suitable method for extracting soya bean oil because of its high yield and high oil purity. In addition, 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. However, further studies on this machine should investigate the effect of other operational parameters such as cylinder-concave clearance on the quantity and quality of the extracted soya bean oil.

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