Design and Fabrication of Cottage Model Jatropha Oil Extractor for Small Scale Farmers

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Abstract: - **This paper presents the design and fabrication of Jatropha oil extractor. Jatropha seeds have been identified as one of the best sources of oil for biodiesel production, hence the need to mechanize the process. The aim of this research to develop a machine that can efficiently extract oil from Jatropha seeds, so as to remove the drudgery involved in traditional manual extraction operation. In carrying out this project, physio-mechanical properties of Jatropha seed were determined to assist in the design of the machine. The prototype of jatropha oil extractor was designed and fabricated at central workshop of faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria. The cost of the entire research was about ₦198,000, including pre-design investigations.**

Key words: **bio-diesel, Jatropha, physio-mechanical, investigations, extractor & fabricated**

I. INTRODUCTION

Energy plays a vital role in the economic, social and political development of a nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life of a people,[11].

As the world is currently moving fast towards globalization, industrial and technological advancement; sufficient generation and utilization of energy sources that are clean and eco-friendly has become an important issue,[10]. However, most of these energy sources are non-renewable and are getting fast depleted. Finding fossil fuel now involves deep sea exploration, as most oil shores are already being depleted, which has resulted in geometric increase in drilling cost,[7]. Eventually, the scarcity of the raw sources has led to geometric increase in the price of fossil fuels in the market over the years. The combustion of the fossil fuels also contributes high percentage to the emission of the largest greenhouse gases like carbon dioxide into the atmosphere which is increasing global warming. Many countries are now moving towards generation and use of cleaner energy resources as an alternative energy source,[8].Among the alternatives being considered are methanol, ethanol, biogas and vegetable oils.

Biodiesel is an alternative fuel made from renewable biological sources such as vegetable oils both (edible and non-edible oil) and animal fats,[5]. Jatropha vegetable oil is one of the prime non edible sources available in India. The vegetable oil used for biodiesel production might contain free fatty acids which will enhance saponification reaction as side reaction during the trans-esterification process,[3].

II. THE CONCEPT OF MACHINE DESIGN

The design of machines is a process by which the designer (an Engineer) applies his skill, knowledge and point of view to the creation of machines to perform functionally, economically and satisfactorily in accordance with some codes and standards,[9].Machine design is done through a methodology that involves recognition of need, problem formulation and analysis, feasibility study, creative design, preliminary design and development, detailed design, prototype building & testing , finally product release/marketing. Design is the central activity in engineering professional practice,[12].

III. OBJECTIVES

The objective of this research work is to develop a local, cost effective and efficient machine model which is capable of extracting oil from Jatropha seeds.

IV. SCOPE

The scope of this research is as follows:

i. Experimental determination of physio-mechanical properties of Jatropha seeds that is relevant to the design of an efficient oil extractor.
ii. Design of machine, using the physio-mechanical properties determined in i above as design input in accordance with engineering codes and standards.
iii. Construction of device designed in ii above using local technology and sourced materials.

V. RESEARCH METHODOLOGY

Materials used for this research include:

- Jatropha seeds
- Electric powered oven
- Digital moisture meter
- Digital micrometer screw gauge
- Angle of repose box
- Sieve
- Digital scale
- Vernier caliper
- Inclined plane
- Rupture force testing machine(universal model)

This research was carried out using a five step methodology as follows:

- Determination of the physio-mechanical properties of Jatropha seeds, that are relevant to the design of an efficient biodiesel producing machine.
- Design of basic components of an efficient biodiesel producing machine.
- Engineering drafting of the components.
- Construction using local technology and sourced materials.
- Testing of the constructed machine and report writing.

VI. DETERMINATION OF PHYSIO-MECHANICAL CHARACTERISTICS OF JATROPHA RELEVANT TO DESIGN OF BIODIESEL PRODUCING MACHINE

In order to determine the engineering properties of Jatropha prior to the design of extractor, 5kg of matured Jatropha seeds were harvested from Agbarha-otor in Delta State, their initial moisture content was determined in accordance with American Society of Agricultural Engineers standards,[2]. The required quantity of sample were taken and dried in an electric-fired oven until 10% moisture content was attained. The drying took approximately 2 hour. A digital micrometer screw gauge was used to measure the linear dimensions namely;

- length (L) = 15mm
- width (W) =10mm
- thickness (T) =7mm
- angle of repose = 32^0 of the Jatropha seeds.

The effective diameter (De), sphericity (Φ) and surface area (S) were calculated from the three linear dimensions given aboveusing the following expressions;

✓ effective diameter **De** = $(LWT)^{⅓}$ 1

De= $(15* 10 *7)^{⅓}$ = 10.2 mm

✓ Sphericity $\Phi = \frac{(LWT)^{\frac{1}{3}}}{L} \equiv \frac{De}{L}$ 2

$$\Phi = \frac{(15*10*7)^{\frac{1}{3}}}{15} = 67.8\ \%$$

✓ Surface area $S = \pi De^2$ 3

$S = 3.142 * 10.2^2 = 327\ mm^2$

The different stages of Jatropha seed processing are represented flow chart in Figure 1.

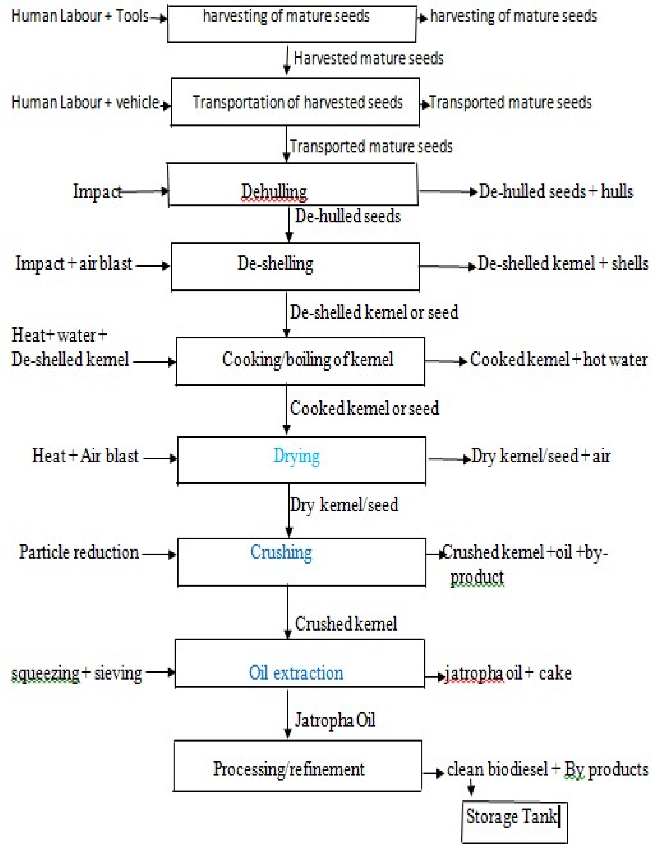


Fig.1. Jatropha seed process flow chart

VII. DESIGN CONSIDERATIONS

- The machine should be safe and simple to operate such that local Jatropha farmers can use it without difficulty.
- The machine should be affordable in terms of purchase and maintenance cost.
- The machine should be durable.
- The machine should be able to oil efficiently from Jatropha seeds.
- The machine should be such that its spare parts will be readily available to Jatropha farmers without having to travel long distances.
- The energy requirement of the machine should be minimal.
- The machine should be portable and easy to transport.
- Materials for construction were selected based on strength, safety, anti-corrosion characteristics and durability.

VIII. HOPPER DESIGN

The angle of repose determined for 32^0. To ensure easy flow of Jatropha seeds, then minimum permissible angle of inclination of the hopper must be greater or equal to the angle of repose of seeds,[1]. Hence, the angle hopper is inclined to an angle of 32^0. The hopper is fitted with a feed gate mechanism to control the flow of jatropha seeds from the hopper to the processing chamber,

Volume calculation for circular truncated conical hopper was done using as follows;

$$V = \frac{1}{3}\pi \left(r_1^{\,2} + r_1 r_2 + r_2^{\,2}\right)h \qquad 4$$

Where;

V →Volume of truncated conical hopper in m^3

π → 3.142

r_1→ lower radius = 100mm

r_2→ upper radius = 100mm

h→ vertical height from r_1 to r_2 = 450mm

V = 61,261,056.75 mm^3≡0.062 m^3

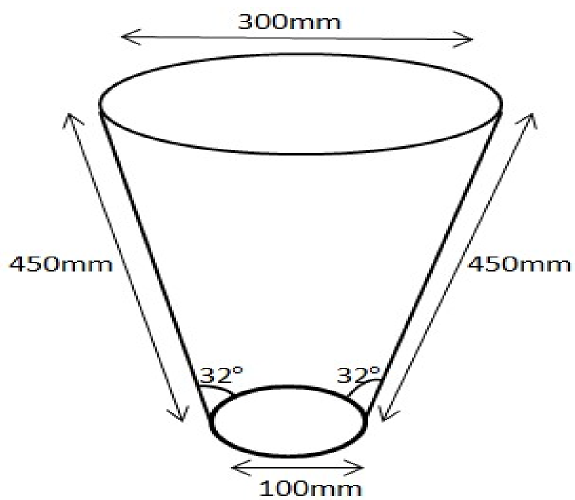


Figure 2. Schematic diagram of hopper

Force of material on shaft:

Bulk density (ρ) $\frac{\text{Mass of seeds in hopper}}{\text{Volume of seeds in hopper}}$

Assume the hopper carries 10kg of Jatropha seeds; bulk density = $\frac{10}{0.062}$ =161.3kg/m^3

IX. COMPRESSION TEST

In order to determine the force required to rupture Jatropha seeds at 10% moisture content, prior to design of machine components, a compression test was carried out at Material Testing Laboratory of Agricultural Engineering Department, Niger Delta University. The machine used was the Universal Testing Machine (UTMTestometricM500 – 100AT model). The test was done on three axes which are the major axis, the minor axis and the intermediate axis. The dimension of each axis was determined before starting the test. The material was placed between a fixed jaw and a 10 kN load cell and at loading rate of 10 mm per minute was applied.

There is a display a screen on the test rig that visualizes the whole process. After all the necessary procedures, compression commenced. Compression stopped automatically when rupture occurred, this was indicated by the clicking sound made by the machine. At this point the force displayed was taken and recorded as rupture force of Jatropha seeds sample = 240.30 N.

X. BELT AND PULLEY DESIGN

The belt and pulley was designed using Fenner industrial Belt Drives standard,[4].

Motor power: 5hp = 3750 w = 3.75 Kw

Motor speed: 1440 rpm

Speed ratio: 1:4

Belt type: V- belt (A belt section)

- Service Factor = 1.0 (the machine will run for less than 10 hours per day)
- Belt Designed power= 1.0*3.75 kw =3.75kw
- Driven Speed: At 1:4 speeds gives 360 rpm obtainable with the stock pulleys.
- Pulley Diameter: the diameter of small pulley (driver) and large pulley (driven) are :

  d= 100mm

  D= 400m

- Centre Distance: is Found using the formula

$$C = 2 * \sqrt{D + dxd} \qquad (5)$$

$$C = 2 * \sqrt{(400+100)X}\ 100$$

C= 447.2mm

(a) Correction factor =0.89

(b) number of belt =

$$\frac{\text{corrected designedpower}}{\text{Correctionfactor}}$$

$$\frac{3.75}{0.89} = 4.2 \text{ kW}$$

One belt will supply 1.42 KW powers which is greater than the corrected designed power (3.75 kw); hence a single belt will be sufficient for the Processing chamber Mechanism.

Belt Characteristics;

- Belt description = A1750 (13 x 8mm)

- Processing chamber mechanism pulley (driven) = 400mm
- Motor pulley (driver) = 100 mm

XI. SHAFT DESIGN

The shaft was designed using the American Society of Mechanical Engineers (ASME) code equation for solid shaft is given by [2].

$$D^3 = 16/\pi S_s \sqrt{(K_b M_b)^2 + (K_1 M_t)^2} \quad (6)$$

D→diameter of shaft (mm)

M_b → maximum bending moment Nm

M_t → Torsional moment Nm

Ss→ allowable shear stress =40x 10^6MN/m^2(for shaft with keyway)

Kb→combined shock and fatigue factor applied to bending which is 1.5 for gradually applied load,[2].

K_t→combined shock and fatigue factor applied to a torsional moment, which is 1.0 for gradually applied on rotating shaft,[2].

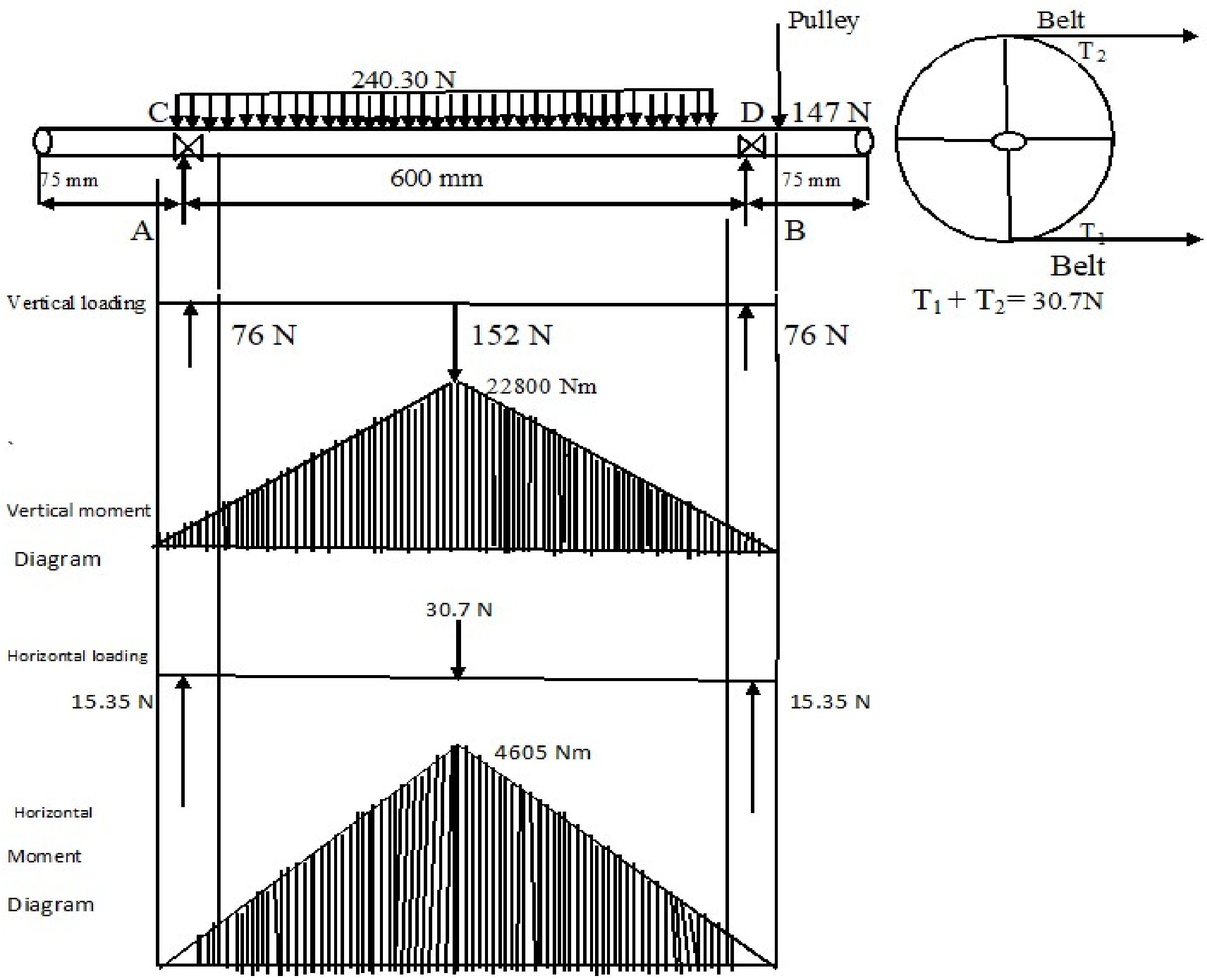


Fig.3. Shaft (Beam) loading diagram

R_A& R_B = reactions at A and B respectively

$R_A + R_B$ = total load acting on points C and D downward the shaft beam

Maximum bending moment= Mb (max) =

$\sqrt{228002 + 46052}$ = 23260.4Nm

= 23.2604 KNm

Recall that (6) above;

$$D^3 = \frac{16}{\pi Ss} \sqrt{(K_b M_b)^2 + (K_1 M_t)^2}$$

Putting all relevant parameters and solving same, we have;

$$D^3 = \frac{16}{\pi 40x10^6} \sqrt{(1.5*23.2604)^2 + (1*0.1518)^2}$$

= 0.0164 m = 16.4 mm

D = 16.4 mm

a factor of safety of 1.5 was applied being Steady torque shaft[2]

Hence; 16.4 * 1.5 = 25mm

Commercial shaft size of 30mm was selected for use.

XII. TORSIONAL RIGIDITY OF SHAFT

This is based on the permissible angle of twist, given as

$\theta = 584Mt * L / Gd^4$ for solid shaft 7

Where Mt = torsional moment on shaft 0.1518Nm (determined)

θ angle of twist (degree)

L = length of the shaft between point in the applied load and resisting torque (mm)

G = torsional modulus elasticity given as 80 * 10^4 N/m^2

d = shaft diameter 30mm≡ $0.03m$

Substituting the values into the equation above, we have

$$\theta = \frac{584 * 0.1518 * 1}{80 * 109 * (0.030)4}$$

$\theta = 0.00137^0$ per m

0.00137 perm < 3 ^{0}per mhence the shaft is torsionally rigid in accordance with there commendations of [2], for line shafting.

XIII. STRESS ANALYSIS AND DESIGN FOR SAFETY OF SHAFT

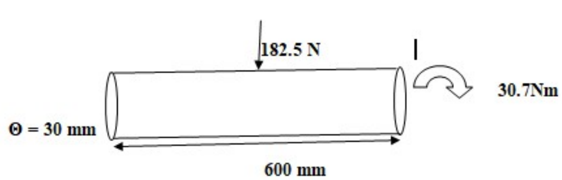
Here, we shall employ Von Misses–Henky failure theory for ductile steel; which states that failure will occur when

$$Sn^* > \frac{Sy}{N}$$

Where Sn* = von misses stress given as

$$Sn^* = \sqrt{sn^2(max) - Sn(max) * Sn(min) + S^2(Min)} \quad \frac{Sy}{N} =$$ yield strength= 100MN/m^2 for Steel

N= factor of safety = 3 for repeated unidirectional load/mild shock



We have to first calculate the maximum and minimum normal stresses, denoted as S_n (max) and S_n (min) respectively, on Torsional and bending moment basis.

$$S_n\,(max) = \frac{Sx + Sy}{2} + \sqrt{\left(\frac{Sx + Sy}{2}\right) + T^2{}_{xy}}$$

$$S_n\,(min) = \frac{Sx + Sy}{2} - \sqrt{\left(\frac{Sx + Sy}{2}\right) + T^2{}_{xy}}$$

$S_x = \frac{Mc}{I}$ →which is the stress at a critical point in tension or compression normal to the shaft

$$S_{x=}\ \frac{182.5 * 0.6 * 15 * 10 - 3 * 64}{\pi\,(30 * 10 - 3)4} = 41385826.8Nm$$

= 41 MNm

Shear stress $T_{xy} = \frac{Tr}{J}$

$$T_{xy} = \frac{30.7 * 15 * 10 - 3 * 32}{\pi\,(30 * 10 - 3)4} = 5790176.8\ Nm = 5.5$$ MNm

$$S_n\,(max) = \frac{41}{2} + \sqrt{\frac{(41)^2}{2} + (5.5)^2} = 50\ MNm$$

S_n (min) = (20.5) – 50 = –29.5 MNm

$$S_n^* = \sqrt{(50)^2 - (50 * -29.5) + (-29.5)^2} = 12.4\ MNm$$

$$\frac{Sy}{N} = \frac{100}{3} = 33.33\ MN/m^2$$

$S_n^* < \frac{Sy}{N}$ i.e. 12.4 MN/m^2 < 33.33 MN/m^2. Hence, failure will not occur according to Von misses Henkey theory. Therefore the shaft design is safe

XIV. DETERMINATION OF CRITICAL SPEED OF SHAFT

The critical speed is the speed at which a shaft must not be driven For a Single attached mass,[2]. It usually determined during shaft design. It is denoted as W_c and expressed as

$$Wc = \sqrt{\frac{(5)}{4} * \frac{(g)}{\delta_{max}}}$$

Where W_c critical speed (rpm)

g = acceleration due to gravity = 9.8m/s

δ_{max} = maximum static deflection, given as

$$\frac{32 * Mb * xn \quad (L - xn)}{E\pi d^4}$$

$$= \frac{32*23260*150*\ (750-150)}{80*109*\pi*(30)4} = 3.3 \times 10^{-7} \text{ mm}$$

$$W_c = \sqrt{\frac{(5)}{4} * \frac{(9.8)}{3.3\,x10-7}} = = 6092.7 \text{rad/sec} = 58186.3 \text{ rpm}$$

Wc = the designed speed of the shaft which is 360rpm is far less than the critical speed, 58186.3 rpm. Hence it is safe in accordance with [2].

XV. DETERMINATION OF LATERAL RIGIDITY OF SHAFT

The lateral rigidity was designed using $\frac{Mb}{EI}$

Where E = modulus of elasticity = N/m²

I = rectangular moment of inertial = M^4

M_b= maximum bending moment Nm

$$I = \frac{\pi * d^4}{64} = \frac{\pi * (30)^4}{64}$$

Thus,

$$= \frac{Mb}{EI} = \frac{23260}{80*109*39765.9} = 7.3 * 10^{-12} \text{ mm}^5$$

The value 7.3 * 10^{-12} $mm^5$is negligible, hence the shaft is laterally rigid, in accordance with, [2].

XVI. DRAFTING

The graphical details of the rice de-stoning machine were drawn using 3D AutoCAD software; as shown in Figures 4 to 6.

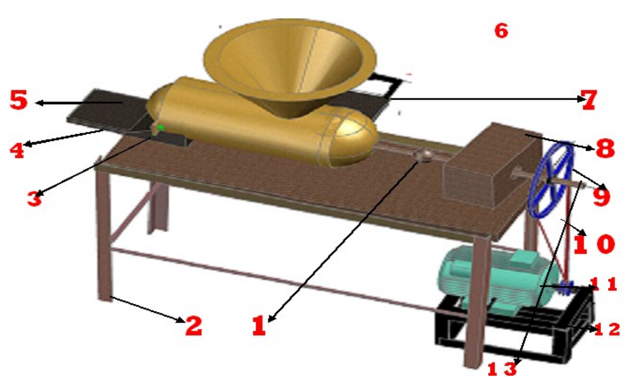


Fig. 4 Isometric view of expeller

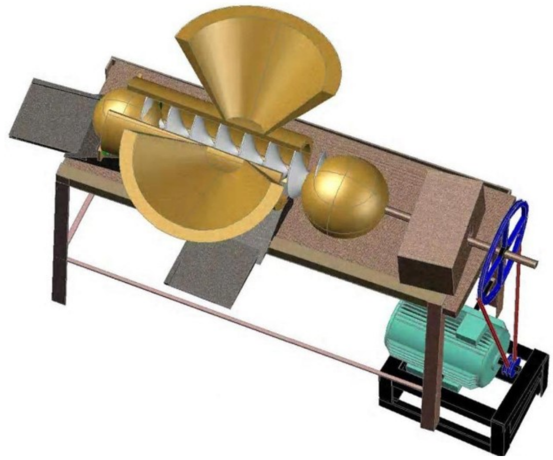


Fig. 5 Sectioned Isometric view of expeller

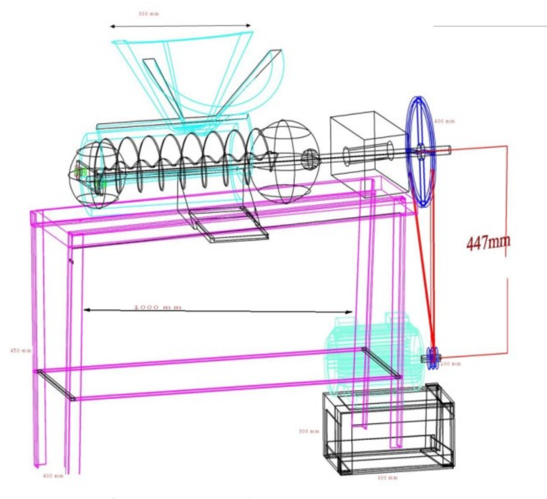


Figure 6 Orthographic view of expeller

XVII. FABRICATION OF TEST RIG

The Main operations that were used for fabrication include;

i. Purchase of Construction materials from, metal market.
ii. Marking out and cutting of construction material.
iii. Machining/machine tool processes.
iv. Assembly of fabricated and purchased components.
v. Surface finishing.
vi. Painting/Spray painting/ Coating/ Metal treatment.
vii. Testing, evaluation, installation and marketing of product (machine).

Table 1. Component part list

S/N	Component/Part	Specification/material
(1)	Shaft knuckle joint	Hardened steel
(2)	Frame	1000 X 400mm/galvanized steel angle bars
(3)	Jatropha Cake Adjustester	Threaded mild steel stud
(4)	Jatropha Cake discharge hopper	Steel plate

(5)	Processing chamber	Galvanized thick steel cylinder
(6)	Jatropha seed recharge hopper	Steel plate
(7)	Jatropha oil discharge hopper	Steel plate
(8)	Speed reduction gear	Cast casing
(9)	pulley	Cast iron
(10)	Belt	V-belt,A1750 type
(11)	Motor (power unit)	Rotational speed: 1440 rpm/3PH/50Hz Type: Ac induction motor
(12)	Motor seat	galvanized steel angle bars
(13)	Shaft	30 m Diameter shaft/Mild steel

XVIII. CONCLUSION

The jatropha oil extractor was designed and fabricated at central workshop of faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria. The cost of the entire research was about ₦198,000, including pre-design investigations. The machine is ready for use and readily available for purchase via the contacts on the title page of this paper, (Contact address, phone number and Email).

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