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Design, Manufacturing and Testing of a Hydraulic Press to Produce Oil from Egyptian Jatropha Seeds

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ABSTRACT

Increase of fossil fuel consumption rates, depletion of conventional fuel, harmful exhaust emissions increase and global warming. This concludes to search for alternative fuels. This study was performed to produce a suitable alternative fuel. The produced oil from non-edible jatropha seeds becomes researcher's interest because of the higher price of edible vegetable oils. Design, manufacturing, and testing of an efficient system to produce the oil from Egyptian jatropha seeds was carried out. This hydraulic press squeezes jatropha seeds to produce the oil. It is designed to obtain the maximum oil yield. Physical and chemical parameters such as specific gravity, kinematic viscosity, calorific value, flash number and cetane number of the extracted oils were measured. Time of oil extracted from jatropha seeds is 720 minutes at a yield of 11%. The extracted Jatropha oil gave light color because of its low FFA of 5%. The density and viscosity of the extracted oil decreased as the temperature increases. The flash point of the oil is higher than diesel oil. Calorific value of the produced jatropha oil was 39201 kJ/kg. Jatropha biodiesel oxidation instability increased for hydraulic extraction due to its content of oleic and linoleic acids.

1 . Introduction

The researchers have been directed to find suitable alternative fuels due to fuel crisis and global warming. Jatropha plants are cultivated in sewage bonds and desert. Extraction of jatropha oil can be produced either chemically or by mechanical presses. Biodiesel has become environmentally friendly and more attractive since it is obtained from renewable resources, in addition to its benefits [1,2].

Various types of oil expellers were used for jatropha oil extraction. Sundhara and Komet expellers were utilized. Jatropha oil extraction was done mechanically (by pressing the kernels), chemically, and enzymatically. The mechanical press prototype had cast iron heavy parts and iron sheets. The mechanical press was driven electrically. The oil is extracted from the seeds using traditional manual methods in rural areas. A single screw mechanical expeller was used as Komet expeller. Chemical

methods were used for oil extraction like aqueous enzymatic treatment. Ultra-sonication had been used as an effective method for jatropha oil yield increase of 74% [3–6].

Soxhlet is used as a reference conventional extraction method. Other methods are compared to Soxhlet. Most extraction methods were like Soxhlet, but they require a long time and large amount of solvents. Most extraction processes are simple in performance and did not require specialized personnel. These methods are cheap, so they have been favored to be used widely in industries and laboratories [7–9]. Mechanical processes followed by solvent ones can be used in oil extraction from seeds. Soybeans have lower oil content, but sunflower seeds, palm and rapeseed have higher oil contents [10–12].

Pretreatment of jatropha curcas seeds for oil extraction consumes approximately 24% of the total internal energy in solvent extraction and 66% in mechanical extraction. Seed pretreatment degrades quality energy before oil extraction. Mechanical extraction is more energetically efficient method.

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Solvent extraction of *Jatropha curcas* oil is 79% efficient, but that of mechanical extraction of 96% [13]. Biodiesel was produced from *jatropha* oil. Chemical and physical properties such as density, kinematic viscosity, flash point, pour point and cloud point were evaluated for *jatropha* oil and compared to conventional fossil diesel. *Jatropha* oil properties allow to be used in conventional diesel engines without any modifications [13,14].

The ram press produced oil in rural areas with small amounts. The strainer press produced oil more effectively and uses manual operation. The cylinder press extracted the oil from *Jatropha* seeds on a large scale with oil yields of about 89.4% [15]. Performance of a screw press machine for *Jatropha* seeds extraction was studied under different machine capacity and seed moisture content. The oil yield, extraction efficiency, specific energy, and operational cost were studied. The highest value of oil yield and extraction efficiency were 43 kg/hr and 81%, respectively [2,16–18]. *Jatropha* seeds were the ideal sustainable and low-cost source of oil feedstock for biodiesel production [19].

The behavior of oil expression was very sensitive to seeds preparation. The presence of seed shells built a porous solid. The specific mechanical energy of oil expression was less than 5% of the energy content of the oil [20]. Oil extraction from *jatropha* seeds by mechanical pressing was carried out using twin-screw press. The operating conditions such as screw configuration, screw rotation speed and press temperature influenced oil yield. The highest oil yield was 71% [21].

Hydraulic press was used to investigate the effect of process parameters on oil recovery. Oil extraction was done for compression speed of 0.05–2.5 MPa/s, applied pressure of 5–25 MPa, pressing temperature of 25–105 °C, pressing time of 1–30 min, and preheating time of 0–30 min. Oil recovery increased with the increase in temperature and pressing time. The optimum oil recovery was obtained when *Jatropha* seeds were pressed at 15 MPa and temperature of 90 °C for 10 min of pressing [22,23].

Jatropha seeds were pressed under height of 80 mm using the pressing vessel diameter 60 mm. The dependency between compressive force and deformation was described and the mass of emerged oil was measured [24]. The seeds must be previously crushed with a hammer mill to particles smaller than 2 mm diameter and dry heating treatment at optimization conditions [25].

The literature gives studies on the effect of seed pretreatment on hydraulic pressing of *Jatropha* oil. This research aimed to study the effect of hydraulic extraction process on fatty acid content, oil yield and oil properties. The target of this work is to design and manufacture a hydraulic press to press Egyptian *jatropha* seeds with lower cost and local materials. Hydraulic press was designed and tested. The aim of the hydraulic press is to extract *jatropha* oil from the seeds with higher yield. The selected materials were tested for the applied load. Hydraulic press parts were manufactured for easy maintenance and movement. Produced oil properties of the extracted oil were evaluated to show the effect of the extraction method on physical and chemical properties.

2 . Research Approach and Methodology

The design of hydraulic press relies on Pascal's principle. The system is a press acting as a pump that has humble mechanical force acting over a small cross-sectional area. The other part is a press having a larger area that generates a large mechanical force correspondingly. If the pump is separated from the press cylinder, only small diameter tubing which resists pressure more easily is needed. The pressure on a restricted fluid is transmitted without being diminished and acts with equal force on equal areas at 90° to the container wall. When the press is pushed internally, the incompressible oil is displaced, and the volume displaced by the small press is equal to the volume displaced by the large press. This causes a difference in the displacement which is proportional to the ratio of the press head area. Thus, the small press must be moved a large distance to allow the large press to move significantly. In this study, the applied force increased on the larger press area, the applied force over a distance should be decreased.

Jatropha oil extraction using hydraulic pressing was investigated. A sieve plate covered with fine mesh was used. The pressing chamber has a controlled temperature from 30 to 100 °C with a fixed diameter. The press pressure is up to 100 MPa. The hydraulic plunger supplied with sensors for temperature, pressure and position measurements. The piston was lowered on the top of the seeds. The seeds were laid in the press chamber then the piston was pressed on the seeds. The pressing temperature can be equilibrated for at least 30 min on the seeds without mechanical pressure which is raised up to 4 MPa for 10 sec after that. The pressure was extended linearly at the desired speed until it reached to the final pressure. This extraction yield was 10% of the extracted oil [26].

2.1 . Design and Manufacturing of the Hydraulic Press

The exerted pressure with a machine is termed a press. The presses operated on the principles of hydrostatic pressure called hydraulic. Screw presses used the transmitting power and mechanical presses to transmit power [27–30]. In the hydraulic press, fluid under pressure produced the generated, transmitted and amplified force. The liquid system provided a medium of power transmission and amplification. A smaller piston area transfers the fluid to a cylinder of larger piston area and thus amplifying the force under high pressure.

The hydraulic press contained a pump produced the motive power for the fluid. The power transmission through the pipes, connectors and control devices were caused by the hydraulic fluid. The motor converts the hydraulic energy into useful work [27–30]. A more positive response with the change in input pressure is the main advantages of hydraulic presses. The applied force can be accurately controlled. The force magnitude was shown during the entire working stroke of the ram travel. The large nominal required force was shown by hydraulic presses[31].

The fluid power in the systems is required [32]. The primary aim in the system design is to transpose the desired system performance into system hydraulic pressure and volume flow rate. It was desired to match the characteristics with the available system input to sustain operation. The maximum load is a

principal parameter in the design (150 kN). Other vital factors are the distance that the load resistance has to move (piston stroke = 600 mm), the system pressure, the cylinder area (piston diameter = 80 mm), and the volume flow rate of the working fluid. The hydraulic cylinder, the frame, and the hydraulic circuit are the critical components in the design as given in Figure 1.

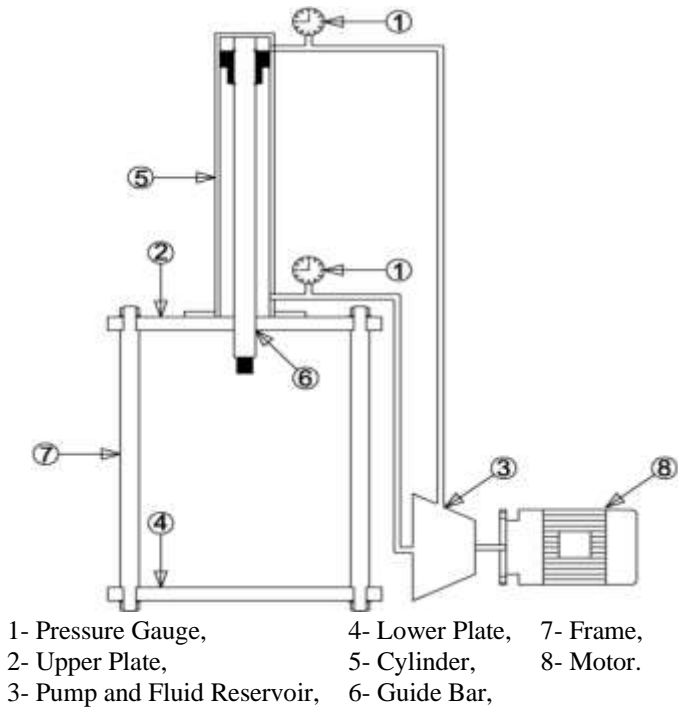


Figure 1: A Schematic diagram of the hydraulic press.

The hydraulic cylinder is tubular in structure and the piston slides inside it. The design included the cylinder minimum wall thickness, the end cover plate, the flange thickness, the specifications and size of bolts. The bore area of the cylinder and the minimum wall thickness were known from the output force required from the hydraulic cylinder. From Khurmi and Gupta[33] the maximum wall thickness (t) of the hydraulic cylinder was computed to be 0.0167 m from

$$t = r_i((\delta_t / (\delta_t - 2p))^{1/2} - 1) \quad (1)$$

Where

- r_i = Internal radius of cylinder (m), 50×10^{-3} m,
- p = internal fluid pressure (N/m^2), 3.82, and
- δ_t = tangential stress (N/m^2), 480×10^6 .

Therefore, the minimum wall thickness is 0.017 m and it is considered adequate for the design.

The bolts and the uniform internal pressure distributed over the area support the thickness (T) of the end cover plate. This thickness is given by Khurmi Gupta[33] as

$$T = K D (P / \delta_t)^{1/2} \quad (2)$$

Where

- D = Diameter of end cover plate (m), 0.1,
- K = Coefficient depending upon the material of plate, 0.4,
- P = Internal fluid pressure (N/m^2), 38.2, and
- δ_t = allowable design stress of cover plate material, $480 N/m^2$.

The estimated plate thickness, accordingly, is 0.0118 m.

The cylinder cover may be fastened by bolts or studs as shown in Figure 2. The following Eq. (3) was used in order to find the correct size and number of bolts [33]:

$$(\pi D_i^2 / 4) P = (\pi d_c^2 / 4) \delta_{tb} n \quad (3)$$

Where

- P = Internal fluid pressure (N/m^2),
- D_i = internal diameter of cylinder (m),
- d_c = core diameter of bolt (m), 16×10^{-3} m, and
- δ_{tb} = permissible tensile strength of the bolt.

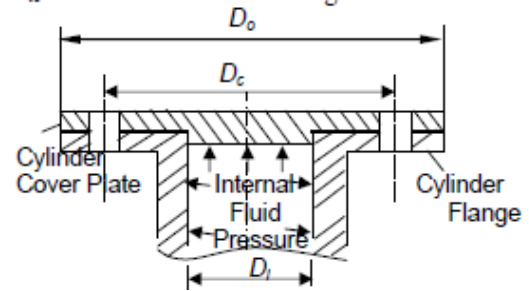


Figure 2: Arrangement for securing the cylinder cover plate with bolt.

The number of bolts can be found from the size of the bolt as known in Eq. (3). The number of bolts was computed to be 4. The circumferential pitch, D_p of the bolt of 0.0191 m determined the tightness of the joint between the cylinder and the end-cover plate as

$$D_p = D_i + 2t + 3D_c \quad (4)$$

Where

- t = Thickness of cylinder wall (m), 17×10^{-3} m.

The minimum thickness (t_f) of the flange as determined from bending consideration aids in the design of cylinder flange. The two considered forces are fluid pressure and that used to separate the flange due to sealing resisted by the stress produced in the bolts. The force needed to separate the flange was computed to be 58.72 kN as computed from

$$F = (\pi/4) D_1^2 P \quad (5)$$

Where

- D_1 = outside diameter of seal, 134×10^{-3} m.

The flange bending about section A-A along which the flange is weakest, as in Figure 3, enables to calculate the thickness of the flange (t_f). This bending is brought up due to the force in the two bolts and the fluid pressure inside the cylinder.

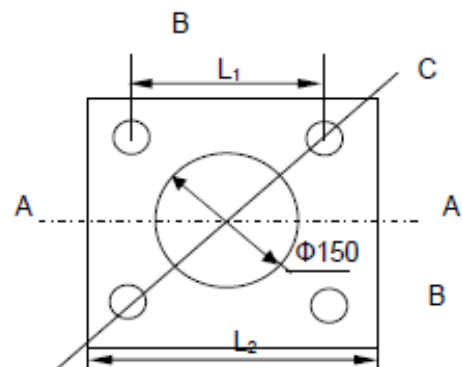


Figure 3: Square flange.

A flange thickness of 0.0528 m is thus, estimated from

$$T_f = (6M)/(b \delta_f) \quad (6)$$

Where

T_f = Flange thickness,

b = width of flange at section A-A, 22.2×10^{-3} m,

δ_f = shear stress of flange material, 480 N/m^2 , and

M = resultant bending moment, 5144.78 Nm .

The applied load was sustained by the required piston rod column size. The applied load is in alignment with the cylinder bore center line. The force applied to the rod column, the mounting situation of the cylinder and the stroke had effects on the applied load. Following Sullivan [32], the piston rod column size and the cylinder length under end thrust condition were computed. The size of the piston rod has a diameter of 0.09 m and is considered adequate for the design.

Internal and external leakages in the press under operating conditions of pressure and speed were prevented by seals. The selected static seal used the groove and ring principle. The groove dimension was calculated such that the O ring selected to be compressed from 15 to 30% in one direction and equal to 70-80% of the free cross-sectional diameter. The O ring can be compressed in one direction and expanded in the other. The groove dimension of $4 \times 3 \text{ mm}$ was specified for the seal.

Mounting points that maintain proper relative positions of the units and parts mounted on it under all specified working conditions were provided by the frame. The general rigidity of the machine was provided from reference [34]. The design consideration is that of direct tension imposed on the pillars. Other frame members such as the platens (as in our case) are subjected to simple bending stresses.

The direct contact on the compressed object was evaluated by the upper and lower platens. The equal and opposite couple acting on the longitudinal plane led to a bending stress applied to the platens. The bending moment (M) and shear force (V) created in the beam were found to be 45 kN/m and 150 kN , respectively, as calculated from Beer and Johnston procedure [35].

The maximum bending moment M was utilized to compute modulus of section of the platens. The minimum depth (thickness), d , was computed to be 0.048 m from

$$d = ((6M)/(\delta b))^{1/2} \quad (7)$$

Where

M = Maximum bending moment, 45 kN/m ,

$b = 600 \times 10^{-3} \text{ m}$, and

$\delta = 480 \times 106 \text{ N/m}^2$.

The maximum fluid discharge pressure from the pump was required to estimate the frictional loss in the system. It was about $47.16 \times 106 \text{ N/m}^2$. The lever of length of 0.8 m actuated the pumping action. The lever was calculated by assuming a maximum theoretical effort and taking the moment about the fulcrum.

2.2. Hydraulic press specifications

Specifications and dimensions of the present hydraulic press are listed in Table 1.

Table 1: Specifications and dimensions of the present hydraulic press.

No.	Type	Specification
1	Maximum load	150 KN
2	Internal fluid pressure	3.82 N/m^2
3	Tangential stress	$480 \times 10^6 \text{ N/m}^2$
4	Shear stress of flange	$480 \times 10^6 \text{ N/m}^2$
5	Maximum bending moment	45 KN/m
6	Pumping pressure	$47.16 \times 10^6 \text{ N/m}^2$
7	Piston stroke	600 mm
8	Piston diameter	80 mm
9	Thickness of cylinder wall	$17 \times 10^{-3} \text{ m}$
10	Core diameter of bolt	$16 \times 10^{-3} \text{ m}$
11	Internal radius of cylinder	$50 \times 10^{-3} \text{ m}$
12	Length of the lever	0.8 m
13	Width of flange	$22.2 \times 10^{-3} \text{ m}$
14	Thickness of cylinder wall	$17 \times 10^{-3} \text{ m}$
15	O-ring seal dimension	$4 \text{ mm} \times 3 \text{ mm}$
16	Outside diameter of seal	$134 \times 10^{-3} \text{ m}$

The present hydraulic press is composed of three main parts: base, housing, circular plates, and press. These components are illustrated in Figure 4. The housing was supported on its base and the seeds were then fed into the housing. The housing has holes on all its sides to extract the oil from them. The oil was collected from the holes underneath the base. The oil yield from the hydraulic press was considerably lower than that from other methods. The yield of hydraulic press extraction was reduced to about 50 % of total oil in the seeds because jatropha cakes absorb oil after removal of the applied force.



(a) L Housing (c) Circular plates (d) Hydraulic press
Figure 4: Hydraulic press components.

2.3. Gas Chromatography (GC) measurement

This is a technique used for measuring the fatty acid composition in oil sample which used mixture separation according to their boiling point. Oil was prepared by methylation process. In methylation process, Methanolic Sodium Hydroxide was prepared by dissolving 2 g of sodium hydroxide (NaOH) in 100 ml methanol. A clear solution was obtained by stirring the mixture for 2 minutes. Oil sample of 0.2 g was blended with 6 ml of Methanolic sodium hydroxide solution. Then the mixture was refluxed for 10 minutes. Then, 10 ml of a mixture solution, consisted of 30 ml concentrated Hydrochloric acid (HCl) and 20 ml methanol, was added and refluxed for another 10 minutes. Then, 10 ml of hexane was mixed and refluxed for 2 minutes and allowed to cool. Finally, a distilled water of 0 ml was added, and the mixture was left to separate. The upper layer was collected and dried by calcium chloride. This sample is ready for GC analysis, [36,37].

The gas chromatography unit of Hewlett Packard model 5890 consists of a flame ionization detector, an oven and a fused silica capillary column was used for GC analysis. A small syringe is used to inject the oil. The injector is contained in an oven whose temperature is enough to boil the sample. The sample is carried into the column by a helium carrier gas and its temperature was varied from 50 to 250 C [37,38]. The retention indices of the fatty acids methyl esters are calculated using fatty acids methyl esters standards (C4-C22) from Sigma Aldrich Company standards. The triglyceride as saturated (Cn: 0), monounsaturated (Cn: 1) and polyunsaturated with two or three double bonds (Cn: 2, 3) were contained in the Fatty acid. Vegetable oils are potential feedstock's for biodiesel production, but the fuel quality can be affected by the oil composition.

3. Results and Discussion

3.1. Free Fatty Acid (FFA) percentage

The extraction method changes the oil color and hence its quality. The extraction temperature influences physical and chemical properties of the oil. The extracted oil oxidation is according to the applied extraction temperature. Higher extraction temperature for long time results in darker color extracted oil. Extraction temperature effects on oil color and FFA %, and this is affected on the biodiesel production process.

FFA percentage in the oil was estimated by titration. In this process, 4 grams of sodium hydroxide (NaOH) were dissolved in one liter of distilled water to get (0.1 NaOH) solution. The end point was determined by Phenolphthalein indicator. One ml of jatropha oil was dissolved in 10 ml of isopropyl alcohol. The mixture was then warmed and stirred until all the oil dissolved in the alcohol and the mixture turns clear. Two drops of phenolphthalein were added. NaOH solution is added drop by drop to the mixture, with stirring all the time until the solution stays pink for 10 seconds. FFA percentage calculation from titration method was estimated from Refs. [39,40]. For hydraulic extraction, 6.5 ml of 0.1 NaOH solutions was estimated to produce 5% FFA

$$FFA\% = (28.2 V_{\text{titr}} n) / w \quad (8)$$

Where,

V_{titr} = Volume in ml of titration solution,

N = normality of NaOH solution ($n=0.025$), and

w = weight of the oil sample in grams (1ml = 0.92 g).

Thus,

$$FFA\% = 0.766 V_{\text{titr}} \quad (9)$$

3.2. Gas Chromatography analysis

Vegetable oil should have lower saturation and Poly unsaturation. Jatropha oil contains linoleic, oleic, palmitic and stearic fatty acids. Oil extraction by hydraulic press is a standard process because the seeds were pressed without heat as given in Table 3. Extraction temperature affects oleic acid content which is high for hydraulic extraction. Jatropha oil can be classified as oleic–linoleic oil. Jatropha seeds have higher oleic fatty acid than other vegetable oils as shown in Table 3 and Figure 5. Rich polyunsaturated acids in the oil such as linoleic and linolenic acids gave poor oxidation stability biodiesel. Higher degree of unsaturation led to have higher freezing point, poor flow characteristic at lower temperatures and need preheating before combustion. Jatropha oil of mono unsaturation is higher than other vegetable oils, so this oil is a good candidate for biodiesel production. Oil oxidation depends on the fatty acid composition. Jatropha oil with higher content of unsaturated fatty acid has a relatively short induction period. Peak values in Figure 5 show areas which give relation between time and relative abundance as shown in Table 3.

Table 3: Fatty acid composition of jatropha oil.

No.	Fatty acid	Hydraulic extraction
1	Palmitic (16:0)	17.69
2	Stearic (18:0)	3.16
3	Oleic (18:1)	22.64
4	Linoleic (18:2)	51.63

Jatropha biodiesel is unstable and easily oxidized in air. GC was tested in GC unit at Central Lab., National Research Centre.

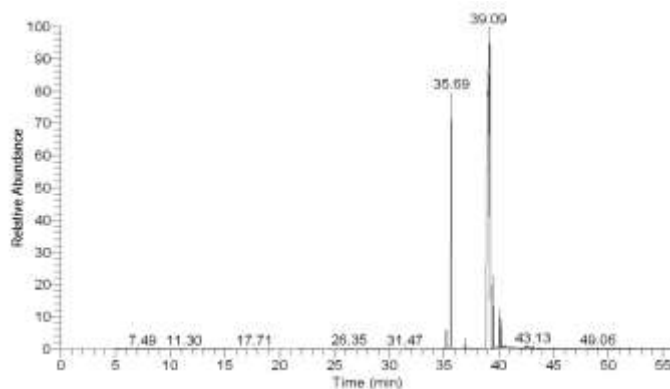


Figure 5: GC for oil extraction by hydraulic press.

3.3. Influence of extraction time on oil yield

Extraction process time is a vital parameter in determining the best extraction method. Extracted oil from the seeds under pressure had more than 4 hrs. A sample of one kg jatropha seeds was used for calculating the consumed time. It takes more than

12 hrs for pressing 1 kg of Jatropha seeds. The extraction time is 750 minutes for oil extraction. The maximum extraction yield is 11% for. The percentage of oil content in jatropha seeds can be calculated from Refs. [41,42].

$$\text{Percentage of oil yield} = \frac{(\text{Weight of oil obtained})}{(\text{Weight of seeds})} \times 100 \quad (10)$$

3.4. Effect of Temperature on oil density

The variations in densities at different temperatures of extracted jatropha oil are shown in Figure 6. The results indicate that oil extraction temperature has a significant effect on the density. The measured value of oil density by the test method (ASTM D-1298) of jatropha oil at a temperature of 20 C is 916 kg/m³ for hydraulic as compared to only 829 kg/m³ for diesel oil. The density of the oil decreased with the increase in temperature. The density is inversely proportional to the oil temperature. The density can be correlated as a linear relationship ($\rho = -0.5247 T + 923.79$) with oil temperature. Jatropha oil density variation at different temperatures was referenced to diesel oil (825 kg/m³).

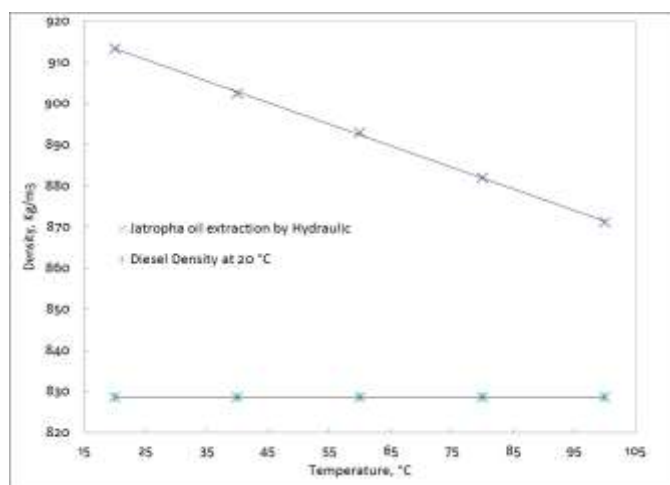


Figure 6: Effect of temperature on oil density.

3.5. Effect of Temperature on oil viscosity

Viscosity of jatropha oil is much higher than hydrocarbon diesel oil. The measured value of dynamic viscosity by test method ASTM D-445 for Jatropha oil at 40 °C is 7.5 Cp for as compared to only 1.188 Cp for diesel oil at the same temperature. Jatropha oil viscosity variation at different temperatures was referenced to diesel oil (1.188 Cp). However, the viscosity decreases with increase in oil temperature. This can be inferred by comparing the values of oil viscosities at 40, 60, 80, 60 and 100 C for Jatropha oil. Preheating of bio oil fuel lines is one of the solutions to overcome the problems related to the higher oil viscosity in diesel engines. The viscosity can be correlated and fitted for the extraction processes. The viscosity decreases as a power function according to the increase in oil temperature ($\mu = 84.624 T^{-0.809}$). Correlation of viscosity at different temperatures is helpful in predicting and calculating viscosity of extracted oil from Egyptian Jatropha seeds. The variations in viscosity at different temperatures of jatropha oil are indicated in Figure 7.

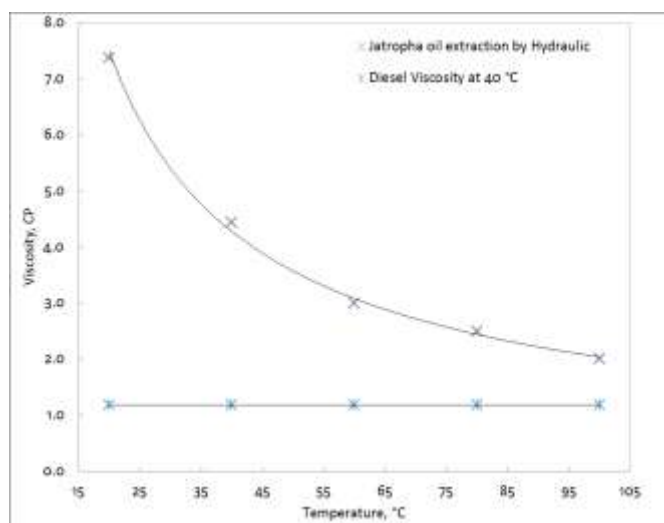


Figure 7: Effect of temperature on oil viscosity.

3.6. Effect of hydraulic extraction on jatropha oil properties

Calorific value of jatropha oil extracted by the hydraulic process was 39201 kJ/kg, as stated in Table 7. The fuel calorific value is defined as the available heat to produce the required engine output power. Therefore, the calorific value is important in the choice of an alternative fuel for a diesel engine for higher engine performance. Measured cetane number for jatropha oil extracted by the hydraulic process is 39. Cetane number is a measure of fuel combustion quality in diesel engines. Cetane number and ignition delay affect engine performance, cold starting, and warm up. The higher Cetane number led to shorter ignition delay and engine performance reduction. The flash point of jatropha oil extracted hydraulically is 146 °C. Flash point is critical for storage and safety handling of the oil. Flash points of jatropha oil is higher than crude diesel, so, jatropha oil is relatively less hazardous, safe in handling and storage with respect to diesel fuel as recorded in Table 7.

Table 7: Chemical and physical properties of Jatropha oil compared to pure diesel.

No.	Oil properties	Test method	Jatropha oil extracted	Diesel oil
1	Flash point, °C	ASTM D-92	146	75
2	Cetane number	ASTM D-13	39	45
3	Calorific value, kJ/kg	ASTM D-240	39201	42000

4. Conclusions

The main goal of this research is to design, manufacture, and test a hydraulic press to produce higher yield and optimum physical and chemical properties of oil extracted from Egyptian jatropha seeds. The present results led to these conclusions:

1. Time of oil extraction process from jatropha seeds is 720 minutes at a yield of 11%.
2. Higher extraction temperature caused darker color of the oil because of oxidation. Jatropha oil extracted by hydraulic pressing gave lighter oil color because of the lower FFA of 5% for the produced oil. This method is characterized for higher oil production .
3. The density and viscosity of the extracted oil decreased with temperature increase. The deduced correlations of viscosity and density in relation with temperatures can be correctly used in predicting the viscosity and density for the extracted oil from Egyptian Jatropha seeds.
4. Flash point of jatropha oil extracted by hydraulic press is higher than fossil diesel oil, so, handling and storage of the oil is relatively less hazardous as compared to diesel fuel. The calorific value of jatropha oil extracted by the hydraulic process was 39201 kJ/kg.
5. Jatropha oil contains oleic, linoleic, palmitic and stearic fatty acids. Jatropha biodiesel oxidation instability increased for hydraulic extraction due to its content of oleic and linoleic acids.

Conflict of Interest

The authors declare no conflict of interest.

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