# Biodiesel Oil Derived from Biomass Solid Waste

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***Abstract*** **- Oils of a significant value both as fuels as well as for cosmetic applications can be extracted from the fruits of the jojoba plant. After extracting the oil, the remains of the fruit can still be further utilized as a solid fuel in furnaces or feedstock to animals. In the present work, the solid waste jojoba remains have been processed chemically to extract more biodiesel oil. The physical and chemical properties of jojoba solid waste, before and after extracting the biofuel have been measured and presented. Also the properties of raw biofuel extracted from the solid and its methyl ester have been measured and presented. It has been shown that 10% by mass of oil can be extracted from the solid waste. The biofuel produced has been tested in a diesel engine and the solid waste has been also burnt in a furnace for more energy production.**

***Keywords*** **--** Jojoba, Biofuel Oil, Solid Waste, Biomass

## 1. Introduction

Global warming issues have forced exploration of bioenergy as an alternative to oil and coal [1]. Biomass can also include biofuels, gaseous fuels for engines and turbine applications. The framework under which all this takes place is different from one region of the world to another. Biomass is used in everything from the fireplaces of third world nations to modern steam cycle systems that create both heat and power in industrial countries. Biomass energy is considered a renewable or sustainable energy because of its closed carbon cycle. Since trees use as much carbon dioxide during their growth as they add to the atmosphere when burned, there is no net gain in carbon dioxide, the leading offender of the greenhouse gases.

Biomass is considered as solar energy stored in organic matter. As trees and plants grow, the process of photosynthesis uses energy from the sun to convert carbon dioxide into carbohydrates (sugars, starches and cellulose). Carbohydrates are the organic compounds that make up biomass. When plants die, the process of decay releases the energy stored in carbohydrates and discharges carbon dioxide back into the atmosphere. Biomass is a renewable energy source because the growth of new plants and trees replenishes the supply [2].

The use of biomass for energy causes no net increase in carbon dioxide emissions to the atmosphere. As trees and plants grow, they remove carbon from the atmosphere through photosynthesis. If the amount of new biomass growth balances the biomass used for energy, bioenergy is carbon dioxide "neutral." That is, the use of biomass for energy does not increase carbon dioxide emissions and does not contribute to the risk of global climate change [3]. In addition, using biomass to produce energy is often a way to dispose of waste materials that otherwise would create environmental risks.

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One of the most promising plants for the production of biofuels is Jojoba as it is not edible and it has cosmetics applications. The jojoba shrub was grown in Africa and also grown in the Sonora Desert at the south of the USA. The plant name is written in Latin as (jojoba) and it was called (jojoba) in French, (khokhoba) in Spanish and (hohoba) in English. Considerable amount of data have been collected about jojoba and its cultivation for investment in Egypt and he termed the oil as "green gold". The term "green gold" stems from the fact that the seeds are used to produce oil while the residue can be used as fodder or solid fuel implying that there is no waste. Each acre which accommodates 900-1000 shrubs can produce about 540-600 kg of seeds when the plant is four years old; but the production increases gradually till it reaches 1350-1500 kg when the plant is ten years old. Jojoba seeds contain 50% of its weight as oil, so the Egyptian acre can produce 270-300 kg of oil after four years but will increase to 675-750 kg of oil after ten years of cultivation. The viscosity of jojoba raw oil is high and thus warrants treatment of oil before it becomes a viable engine fuel.

Abdel Kader [4] synthesized the jojoba oil in the laboratory and showed that methyl ester formation was 60% to 65% complete at respective molar ratios of methanol/jojoba oil 4.6:1. The alkaline catalyst used was (NaOH) and was added with a percentage of 1% which proved to produce maximum yield. At 60$^{o}$C, 65% jojoba methyl ester (JME) was produced in 2 hours. In addition, these studies concentrated on measuring the ignition delay period of jojoba methyl ester and different blends of jojoba methyl ester (JME) and gas oil at different conditions in shock tube. It was found that JME liquid and its blend with light diesel fuel exhibit shorter ignition delay than light diesel fuel. It can be also used in diesel engines with blend of diesel or as pure biofuel [5].

The jojoba raw oil is derived from the solid jojoba fruits by mechanically pressing them. After the pressing, the raw oil is extracted and the solid waste is used as animal feedstock. One of the objectives of the current work is to produce a biodiesel from a solid waste which can be used in diesel engines. The description of the chemical process is given and the physical / chemical properties of the solid and liquid fuels are highlighted.

## 2. Experimental procedure for extracting the oil from the solid jojoba flakes

Figure 1 illustrates the schematic for the extraction process. The quantity of 100g of Jojoba flake is first weighed and crushed then mixed with 50 ml of n-Hexane by using mortar and pestle. The crushed sample of 100g has been taken in cellulose thimble and kept inside the soxhlet. 200 ml of N-Hexane taken in the round bottom flask and boiled from the bottom using hot plate to start the distillation. The evaporated solvent gets liquefied at the condenser and gets collected in the soxhlet for extraction. Once the soxhlet gets filled with the solvent (n-Hexane), the extract and

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solvent mixture would be collected down by siphon tubing effect to the bottom flask for repeated distillation. Several cycles were repeated for 12 hours until the extraction was completely over that could be roughly estimated from intensity of the yellow coloration of the solvent against blank. The solvent could be evaporated from the mixture and the oil would be collected as it has higher boiling point than the solvent. The net result is the production of extracted 11mL of oil from the 100g of Jojoba flakes.

## 3. Results and Discussion

### 3.1 Chemical and physical properties of jojoba raw oil extracted from solid flakes

Table 1 illustrates the properties of solid jojoba flakes before the extraction. As may be seen it contains carbon, hydrogen, nitrogen and oxygen. This gives an indication of the possibility of burning such solid waste and producing some energy from the combustion. The extracted oil properties are shown in Table 2 and 3. Regardless of the oil viscosity, the oil produced offer good alternative to liquid diesel fuel from the heating value, density and cetane number (a measure of ignition quality). The jojoba methyl ester has been prepared by adding 10% methanol with catalyst and heating /stirring and then quenched by water. The mixture then separated to three layers. The top layer is the methyl ester with least density followed by water then the glycerides. Figure 2 illustrates the effect of heating time and methanol amount added to produce the jojoba methyl ester on the yield ratio of the ester. It can be seen from Fig. 2-a that the heating time of 1 hour was optimum in giving the highest yield. Figure 2-b shows the amount of 10% methanol produces the highest yield compared to other fractions. Figure 3 depicts the Thermo-Gravimetric Analysis results for the burning of the solid flakes in a Nitrogen or Air medium. The un-extracted line represents the solid jojoba flakes before extracting the oil, while the extracted line represents the solid jojoba flakes after extracting the oil. The drop in the weight of the sample is due to the burning of such weight. The first drop of weight - when the temperature reaches about 110 $^{o}$C - is due to the evaporation of any moisture content. This represents the moisture content inside the solid flakes. When the temperature becomes very high, e.g. 900 $^{o}$C in the medium of Nitrogen, the drop represents the volatile content. With the air medium, weight fraction left after the temperature reaches 900 $^{o}$C represents the ash fraction. The weight of the sample drops faster in the case of air as the sample tends to burn and react with air, while in Nitrogen; it does not react with this inert gas.

### 3.2 Diesel engine tests

A performance testing of diesel engine that used the jojoba methyl ester is shown in Fig. 4. The engine used is Ricardo E6 research engine with variable compression ratio. A reference test with a gasoil fuel has been also carried out. As may be seen in the figure that the jojoba methyl ester fuel used (JME) gives similar power curve to the diesel fuel case. This gives indication of the acceptable fuel ignition quality with similar heating value that gives similar torque output

### 3.3 Solid jojoba waste combustion

During this test, the solid jojoba waste has been brunet in the furnace shown in Fig.5. The furnace uses LPG gas flame – coming from the bottom of the furnace to heat the jojoba solid flakes at the beginning, then the gaseous fuel is turned off and the solid fuel combustion could sustain the flame, where it leaves up inside a cooling jacket. The use of the cooling jacket is to measure the amount of heat transferred from the flame and combustion gases. The temperatures of the solid flame bed, the exhaust gases and the cooling water exist have been measured. The heat transferred to water is calculated from the heat balance to cooling water. The continuous fuel flow rate for this test was at a rate of 60 g/min while the air flow rate of 50 kg/hr (Air/Fuel=13.89).

Fig. 6 presents the results for this test. The combustion of the solid fuel in the flame bed produced a temperature of 750 $^{o}$C for the flame bed and 250 $^{o}$C for the exhaust. This leads to heat transferred to the water jacket; an average value of 13.2 kW in this test. The overall heat release from the fuel is about 16.2 kW in this test. This indicates a more complete combustion in this test.

## 4. Conclusions

From the experimental work carried out in the current study, the following conclusions may be drawn:

10% of biodiesel has been extracted from the solid waste of the jojoba fruits.

The properties of the oil extracted are almost similar to those for diesel fuel and they are acceptable for biofuel.

The solid waste produced has considerable amount of energy and can be used as a source of alternative energy in furnaces.

The diesel engine used the jojoba methyl ester produced similar power-speed curve to diesel fuel case.

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Table 1: Elemental analysis of solid Jojoba remains (before extraction)

| Element | (wt%) |
|---|---|
| C | 49.63 |
| H | 8.41 |
| N | 3.24 |
| O | 19.6 |
| Volatile material | 76% |
| Moisture content | 4% |
| Ash | negligible |

Table 2 Physical and chemical properties of raw jojoba oil extracted from solid remains

| Property | Test method | 100 % raw jojoba oil |
|---|---|---|
| Flash point ($^oC$) | ASTM D-93 | 292 |
| Pour point ($^oC$) | ASTM D-97 | 6 |
| Ash content (% by weight) | ASTM D-482 | 0.014 |
| Kinematic viscosity at 40 $^oC$ (cSt) | MODIFIED ASTM D-445 | 25.484 |
| Kinematic viscosity at 100 $^oC$ (cSt) | MODIFIED ASTM D-445 | 6.459 |
| Density at 23 $^oC$ ($g/cm^3$) | PAAR | 0.8631 |
| Specific density at 15 $^oC$ | | 0.864 |
| Carbon content *% by mass) | Heraeus device | 81.8 |
| Hydrogen content (% by mass) | Heraeus device | 5.2 |
| Calorific value (MJ/kg) | | 42.761 |

Table 3 Physical and chemical properties of jojoba biodiesel

| Property | Gas oil | jojoba methyl ester |
|---|---|---|
| Flash point ($^oC$) | Min. 55 | 61 |
| Pour point ($^oC$) | 4.5 – 10 | 4.4 |
| Ash content (% by mass) | Max. 0.01 | 0.002 |
| Kinematic viscosity at 40 $^oC$ (cSt) | 1.6 – 7 | 19.2 |
| Density at 23 $^oC$ ($g/cm^3$) | 0.81-0.86 | 0.86 |
| Carbon content % by mass) | 87.45 | 86.98 |
| Hydrogen content (% by mass) | 11.3 | 12.99 |
| Rest of composition (% by mass) | 1.25 | 0.03 |
| Inorganic acids | Nil | Nil |
| Sulfur content % by mass | Max. 1.2 | Nil |
| Water content % by volume | Max. 0.15 | 0.5 |
| Carbon % by mass of 10% residual | Max. 0.1 | 0.5 |
| Calorific value (MJ/kg) | Min. 44.3 | 47.38 |
| Cetane No. | Min. 55 | 63.5 |
| Diesel index | Min. 48 | 47.12 |
| Color (by Saybolt chronometer) | Max. 4 | 1 |
| Corrosion of copper strip at 100 $^oC$ for 3 h | Max. 1 | 1 |

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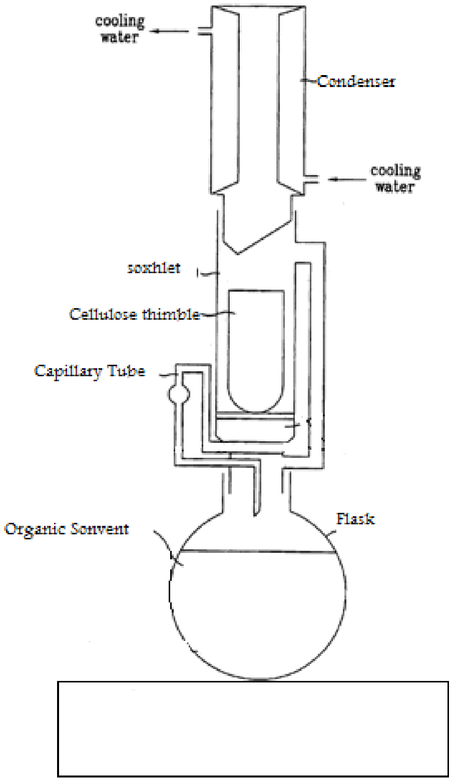
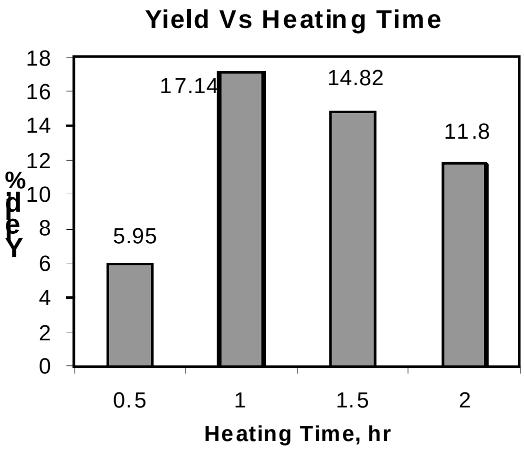
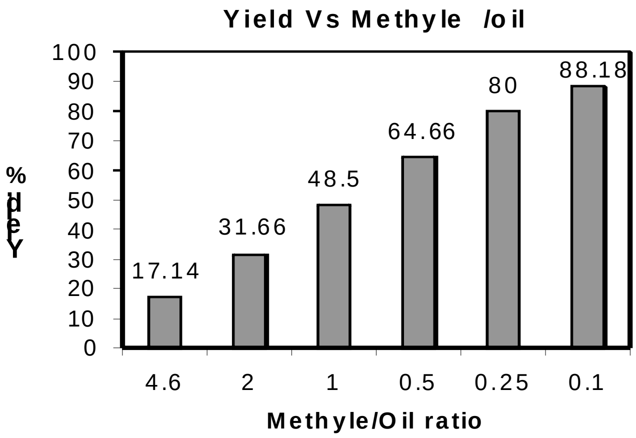



Figure 1 The schematic representation of the extraction using the soxhlet apparatus




(a)




(b)

Figure 2 Effect of heating time and methanol fraction on the yield of jojoba methyl ester

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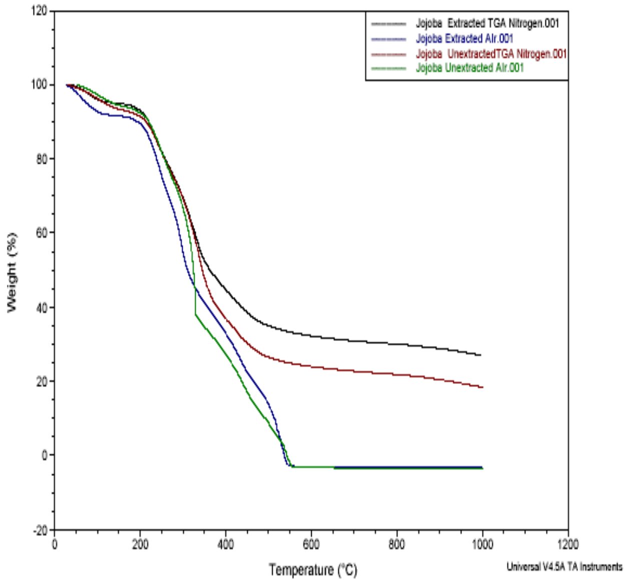


Figure 3 TGA analysis of solid jojoba flakes before oil extraction and after – in Air and Nitrogen

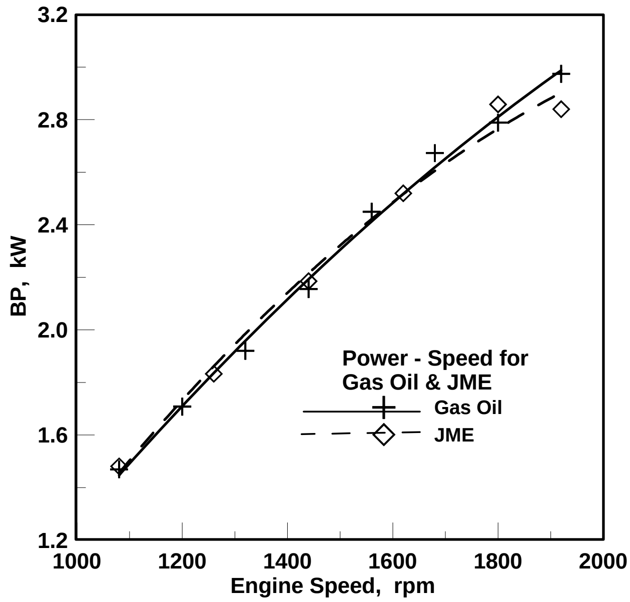


Fig. 4 Power curve for pure JME and pure diesel

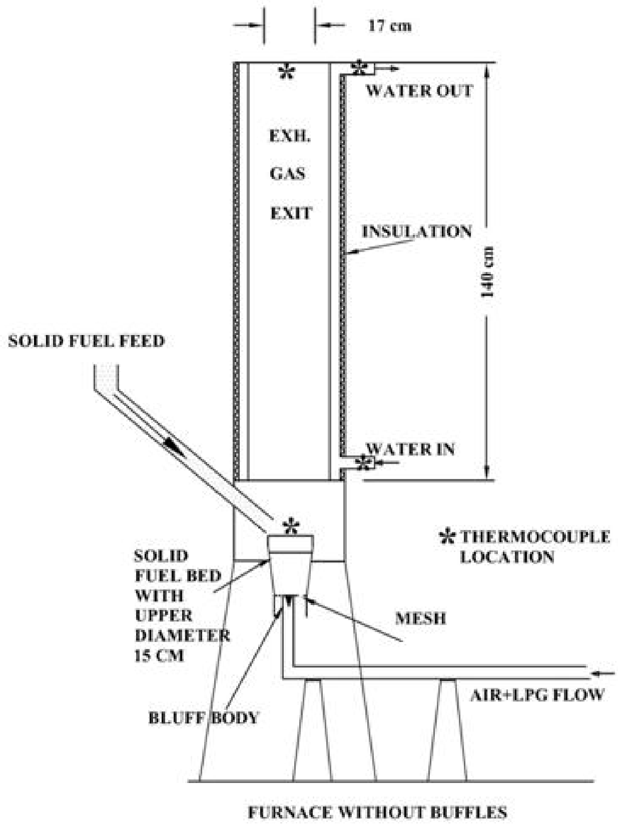


Figure 5 Solid fuel combustion furnace

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Continuous fuel feed at a rate of 120g/2-min and air flow rate of 50kg/hr

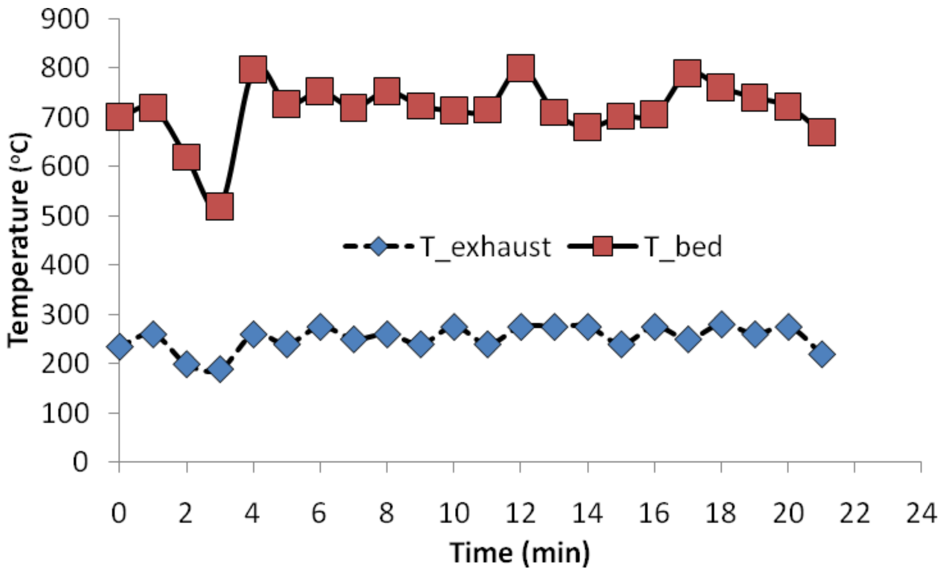


Fig. 6a: Temperature measurements in the solid combustion furnace

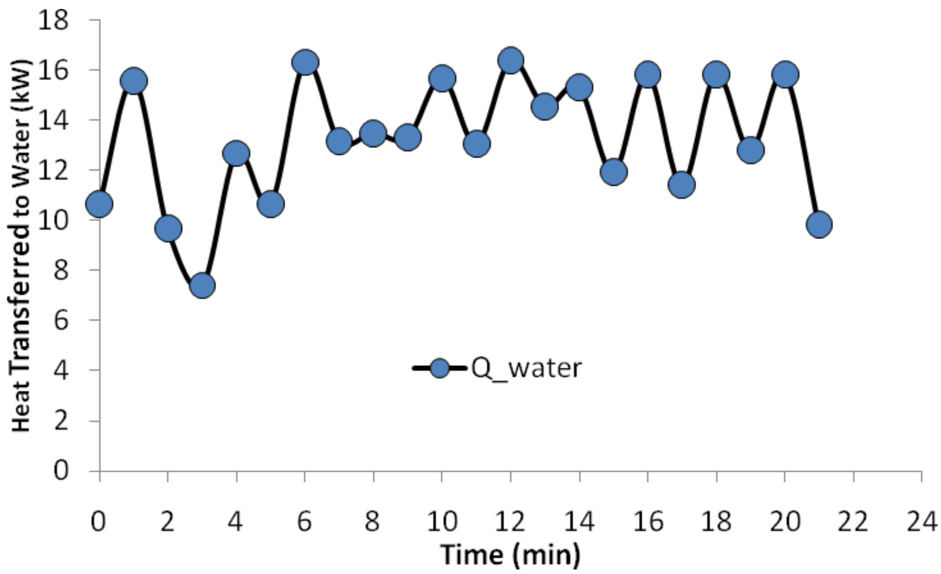


Fig.6b: Rate of heat transfer to water jacket in the solid combustion furnace

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