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Characterization of Jatropha Oil and its Biodiesel

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Abstract

The ever-increasing demand in consumption of fossil fuel strongly contradicted by its depletion in reserves coupled with the Green House Gas effect associated with the combustion of hydrocarbon has opened a channel for the inevitable desire for an environmentally friendly and a renewable source of energy like bio-fuel. Oil extracted from Jatropha curcas, a non edible plant looks good to be one of the solutions of the problems associated with energy consumption in recent time. Dried Jatropha seeds were shelled and oven-dried and weighed for every 30 minutes until a constant weight was obtained indicating that moisture had been taken care of 300 g of milled Jatropha was soaked in 2000 cm^3 of petroleum ether and covered for 48 hours to avoid vaporization. Whatman No 1 filter paper was used in filtering just as filtrate was concentrated at 60 °C by using water bath. A constant volume of 241 ml was obtained and subsequently characterized. The specific gravity of the oil was calculated to be 0.9, its refractive index stood at 1.47. The specific heat capacity is 2.353 $Jkg^{-1}K^{-1}$ while its viscosity was found to be 28.43 cSt at 32 °C. The fossil diesel engine can operate smoothly with some blend of Jatropha oil even up to 50% with diesel.

Keywords

Viscosity, Jatropha curcas, Oil, Biodiesel, Specific gravity

Introduction

The world's agitation and aggression for more energy is alarmingly on its increase. With the circumstantial availability of fossil fuel and its exhaustiveness, so much effort is fast going into its replacement as a major source of energy with another and also complementation [1]. The rigours and time span that characterize the production of fossil fuel from long buried organisms under intense temperature and pressure are not favourable factors to readily assuage its constant demands. The world at one stage in history had heaved a sigh of relief when it was obvious that this demand could be met by nuclear power plants until the Japanese Fukushima nuclear power plant disaster rewrote the history of energy quest. This singular occurrence has once again brought to the fore the necessity for global warming prevention. Apart from solar power cells, wind generators, geothermal power sources, energy derivable from biomass and biodiesel have become the focal point of green energy for checkmating global warming [2]. Biofuel is perceived to be a reliable energy security, a panacea for greenhouse gas emission and of environmental friendly. Biofuel is derived from the edible or non edible oil from plants and animal fats. The biofuel from edible or non edible oil is known to be renewable because of the source reproduction in seasons [3]. Biofuel could also be obtained from recycled waste vegetable oil and animal fats. The name biodiesel is used to describe environmental friendly and less-polluting fuel for combustion and turbine engines because the carbon (IV) oxide (CO_2) has earlier been absorbed while growth of plant was taking place and therefore CO_2 remains free from variation [4]. Biodiesel, close in combustion properties to fossil diesel is a methyl or ethyl ester of fatty acid. Developed countries in Europe and United States of America and of the world with little or no deposit of fossil oil have devised means of using biodiesel derivable from surplus edible oils such as rapeseed, sunflower and soybean oils as a source of driving pollution-less economy. Africa and other developing nations naturally shy away from the luxury of converting edible oil to biodiesel simply for the purpose of feeding their teeming populace [5]. In addition to that, countries endowed with fossil fuel and gas deposits are not constrained to look for alternative source of energy except when either the issue of green house gas pollution or exhaustion of resource becomes obvious. It is pertinent to note that non-edible oils rather than the edible types have veritable use as biodiesel after appropriately converted for the purpose desired. This accounts for why plants like Jatropha readily comes to mind.

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The plant Jatropha curcas

Two Greek words; *iatrós* which translates to Physician and *trophé* which means processing of food combined together to form Jatropha meaning medicinal application [4]. Different uses are found for different parts of the crop. Snake bite is treated using the root while the latex from it contains properties of anticancer [6].

The genus *Jatropha* is of the tribe Joannesieae of Crotonoideae in the family of Euphorbiaceae comprising about 170 acknowledged species. The family ranges from roots (cassava), rubber (Hevea), fruit (emblic, Otahite gooseberry, tjoopa, rambai, mafia, Chinese laurel etc), nuts (tacay), vegetables (katuk, chaya), hydrocarbon (*Euphorbia* spp.), medicinal (*Croton* spp., *Jatropha* spp.) to oil (castor, tung trees, Chinese tallow tree and physic nut) [4].

The origin of Jatropha is shrouded in controversy; however, Mexico and Central America are strongly accepted to be the centre of its origin [7]. Some sources have submitted that the physic nut appear to have originated from Central Americas just like from Mexico having a natural habitat of coastal regions. After several collection of this nut to ascertain its originality, it was deduced that there is high tendency that Mexico (and Central America) lie the core of the source reason being that it is unavailable in such types of vegetations of Africa and Asia but in planted form [4]. Used as hedge plant by Portuguese traders, its origin is known to be Mexico and was spread to Asia and Africa [5].

Features and climatic condition for cultivation

Jatropha curcas is a plant that resists severe drought, thrives well on the worst fertile soil and most unfriendly climatic condition for plant cultivation. It grows easily and has the tendency to produce seeds for far more than five decades. It is adaptable to arid and semi-arid conditions. The least effort is therefore required for good crop yield. A period of five years is enough to produce reasonable quantity oil if cultivated on good soil and with adequate rainfall condition. 35-40% of the seed mass of Jatropha contains oil [6].

Jatropha cursas is a hardy wood shrub of light gray bark that could attain an average height of 4 m under not too favourable condition and an average of 9 m for good climatic conditions. It thrives best in a well-drained soil e.g. sandy soil. In the absence of rain, plant may be watered once weekly. It can survive a rainfal as low as 250 mm (Cape Verde) with humid condition. It has the capability to thrive under harsh heat as it sheds leaves in the cold. So it does well in warm condition. It resists adverse conditions with age. In tropical regions of the world, Jatropha is grown with 300-1000 mm annual rainfall and occurs majorly at altitudes range of 0-500 metres at an annual mean temperature of well over 20 °C [6].

Jatropha Oil (J. Oil)

About 90 days post flowering period is when the fruit is right for harvesting as the color of the fruits have changed to yellow-brown or black. Fruiting is continuous all year-round in wet climates. In semi-arid regions, harvesting is kept within two months. In view of the staggering nature of ripening, harvesting is done every week and seed removed by crushing fruit shell using two hard surfaces or mechanical decorticator. 50 kg of seed per workday is given by the India's National Oilseeds and Vegetable Oils Development Board (NOVOD). Sun-drying is carried out for the purpose of 6-10% moisture reduction in the case of oil production. If kept under a well aerated condition after well dried, seed may last for one year without loss in seed viability or oil content depletion [6].

High viscosity and low volatility characterize crude oil pressed from seeds and animal fats as a result of compound like free fatty acids (FFA), sterols, phospholipids, water and some other impurities. In view of the foregoing, cannot be smoothly used directly as fuel by having to take it through some chemical processes [8]. By so doing, properties similar to that of fossil diesel may be accomplished. Jatropha oil serves as a good lubricant in view of its high viscosity [6].

Jatropha oil needs to be handled with care due to the presence of toxic phorbol compounds. Adequate measures should be taken to avoid its contact with eye and some mucous membranes like the mouth, nostril and digestive system [9].

Composition of Jatropha oil: Jatropha oil has low free fatty acids (FFA) which are advantageous in storing it. However, oxidation is feasible during storage as a result of high content unsaturated linoleic and oleic acids [10]. Over 75% unsaturated fatty acid is present in Jatropha oil. The fatty acid presence is majorly oleic acid (C18:1) and linoleic acid (C18:2). Submission has been made that Fatty acid is affected at the harvesting time [11]. The oil content of Jatropha seed has between 78-84% unsaturated fatty acids which guarantee the oil fit to be made into biodiesel [12]. At low temperatures, it remains in the liquid state due to the availability of unsaturated fatty acids indicating iodine value that is high. It has high cetane value with sulphur content that is low which predisposes it to low sulphur (IV) oxide emission during exhaustion as combustion takes place. These qualities make it suitable for use as biodiesel [10].

Table 1 outlines the constituent by percentage of J. oil. Curcains and Phorbol esters which do not produce pollution during combustion are mainly responsible for the toxic property of Jatropha. The non presence of sulphur (IV) oxide (SO_2) in diesel engine exhausts that uses Jatropha oil is an indication that harmful environmental impact is non-existent. The blending of Jatropha oil with mineral diesel to a tune 50% is feasible in a compression ignition without significant difficulty in operation. This is as a result of viscosity ratio of Jatropha oil to mineral diesel put at 53 cSt to 8 cSt at 30 °C [14].

Blend of J.Oil and fossil diesel: (B100) also known as pure

Table 1: Jatropha oil's general properties [13].

Constituent	Value (%)
Triglyceride	80-95
FFA	3-19
Moisture	0.5-3
Diglyceride	2-5

diesel and its blend with mineral diesel can find use in any engine of petroleum diesel without necessarily modifying it [15].

The elongated usage of triglyceric esters as biodiesel in modern day diesel engines directly and indirectly is feasible but not satisfactory. This is due to its high viscosity, acid contamination, oxidation to form gum and fatty acid polymerization at storage. Equally, carbon deposition on engines and lubricant thickening are some of the unpleasant outcomes. To surmount these, vegetable oil is processed to attain viscosity and other properties close to fossil fuels [5].

Many experimental findings have revealed that a blend of biodiesel-petroleum diesel and biodiesel make smoke less opaque, decreases particulate matter, lessen non-combusted hydrocarbon and carbon (II) oxide just like carbon (IV) oxide life-cycle emissions. Oxides of nitrogen emitted from biodiesel combustion increase but can be reduced in post combustion. The combustion process of biodiesel is enhanced as biodiesel contains 11% surplus oxygen with lower calorie than diesel [6].

Report by Hardman & co [13] submitted that in 2008, 4 engines of Boeing 747 on a test flight of 3 hours conducted by Boeing and Air New Zealand were successful based on bio-jet fuel obtained from Jatropha oil. Scientific results by Air New Zealand from a test flight that used 48% Jatropha oil and the regular jet fuel depicted between 60 and 65% depletion in Green House Gas (GHG) while for Continental Airlines' test the flight recorded an efficiency of 1.1% above regular jet fuel and also decreased GHG emission's life cycle by between 60-80% emission. In a Boeing trial, Jatropha oil at 20% was blended with traditional jet fuel to obtain jet engine required fuel characteristic.

Mechanical expellers

Extraction of oil from seed by mechanical process may either be carried out using a manual ram press or an engine propelled screw press [7]. 75-80% is extracted with the use of engine operated screw press just as 60-65% oil is obtained from the use of manual ram presses [16]. Efficiencies obtained from more recent studies of engine propelled oil extraction have a range of 70-80%. The various treatments of extraction at the expeller are responsible for the wide range of efficiency. Cooking the seeds as a pretreatment process is capable of enhancing oil production in screw pressing to a tune of 91% post dual pass and 89% post single pass [11]. Below the pressing temperature of 60 °C, phosphorus content in oil reduces. 5-8% oil remains in seedcake after using equipment of screw press. This shortfal can be remedied to a large extent by removing 5% more through solvent extraction for oil yield per unit volume. The cost-effectiveness of 200 tonnes/day processing has been ascertained by the Jatropha Promotion Centre [17].

Oil extraction by the use of Chemicals

Chemical extraction of Jatropha oil presents a better prospect of oil yield than in mechanical expeller. Achten [11] (Table 2) as presented for oil production of various chemical extraction processes carried out on Jatropha and corresponding temperature, pH and time of reactions. The commonest and highest return in oil yield is from the use of n-hexane but also with the longest reaction time. In addition, the use of n-hexane chemical extraction is not encouraging due to the environmental effects arising from its effluents, use of higher precise energy, volatile organic compound higher emission and health effects on humans (operating with inflammable and hazardous chemicals). The adoption for use of aqueous enzymatic oil extractions largely nose-dive these challenges [18] just like the employment of supercritical solvents (majorly supercritical carbon (IV) oxide) or solvents such as isopropyl alcohol and ethanol derived from bio-renewable processes. Although the high efficiency and insignificant environmental impacts of contemporary n-hexane extraction unit outstrips the former units, three phase partitioning has a good return in the shortest possible reaction time [19]. Reaction conditions form the bases of various parameters affecting transesterification reaction. Optimization of parameters will

Table 2: Chemical extractions and various reactions parameters with % oil yields [11].

Method of Extraction and reference	Temp. of reaction	pH of reaction	Reaction time (hours)	Oil yield (%)
n - hexane oil extraction (Soxhelt apparatus) by Gubitz, et al., Forson, et al. [4]	-	-	24	95-99
1st Acetone, 2nd n-hexane by Augustus, et al.	-	-	48	
Aqueous Oil Extraction (AOE) by Winkler, et al.	-	-	2	38
Shah, et al.	50	9	6	38
AOE with 10 mins ultrasonication as pretreatment by Shah, et al.	50	9	6	67
Aqueous Enzymatic Oil Extraction (AEOE) by Winkler, et al. (hemicellulase or cellulose)	60	4.5	2	73
AEOE (alkaline protease) by Winkler, et al.	60	7	2	86
Shah, et al.	50	9	6	64
AEOE (alkaline protease) with 5 mins ultrasonic as pretreatment by Shah, et al.	50	9	6	74
Three phase partitioning [19]	25	9	2	97

determine if the reaction is not complete or insignificant extent of yield. Every parameter is to same extent significant in the accomplishment of high standard biodiesel of regulatory quality [4,11,19].

Chemical extraction enjoys a good economy if adopted in production on a large scale to over 50,000 kg of biodiesel in a day. Paltry 0.3% oil weight is left in seed cake as 99.7% of oil is removed when carbon (IV) oxide or supercritical isopropanol is used in an unbroken mechanical oil extraction process [11].

Transesterification process

Triglyceride + Methanol ⟶ Methyl ester + Glycerine

(Jatropha oil) Sodium Hydroxide (Biodiesel)

The most common process used in converting Jatropha oil to biodiesel is transesterification in which the former is converted to normally methyl esters and glycerine by alcohol (normally methanol) and strong alkaline catalyst (NaOH or KOH) under heat (see equation above). A three stage process involves the conversion of triglycerides to diglycerides; diglycerides to monoglycerides and the latter to glycerine. Between 92-98% biodiesel is produced from original oil through the process of transesterification. This accounts for almost 0.828 tonnes of biodiesel or 32 GJ of energy per hectare. From *Rhizopus oryzae,* obtained lipase enzyme has been put to creative use resulting to a fall in production cost [12]. This process involves some variables temperature of reaction, alcohol to oil ratio, catalyst type (which could be lipase or supercritical alcohol, base, acid). The balance reaction ratio of alcohol to oil is always 3:1 [12].

Laboratory production of biodiesel from jatropha oil

The production in the laboratory involved the use of methanol with maximum molar ratio (6:1) with the catalyst concentration being (1% NaOH) at 65 °C and for 1 hour. For ethanol, maximum molar ratio (8:1) with the catalyst concentration of (1% KOH) at 70 °C for 3½ hours is the condition. Filtered Jatropha oil was measured and heated to a required temperature. Alkoxide solution was introduced into the reacting container and vigorously mixed. After the stipulated time, the mixture was settled overnight after the reaction was stopped. Two layers resulted overnight i.e glycerin at the base and biodiesel at the top. The glycerin could be removed through the bottom of the separating funnel. The pH of the remaining layer being the biodiesel was taken for Phosphoric acid could be added for neutralization by removal of residue arising from catalyst. Purification of the biodiesel was carried out by the removal of methanol, soaps and catalyst residue using warm water; avoiding emulsion through mild shaking. Repetition of the washing process was carried out until the pH of the biodiesel attained 7 and passing the biodiesel through sand filter. The resulting color was brownish yellow. Large scale production could be attained through the process above with filtering involving sand of size (-20 + 60) mesh put over screen size of mesh100 [1].

Emission of oxides of nitrogen rise to an extent with the combustion of biodiesel. Nevertheless, the reduction of NOx emission can be attained by the application of some post-combustion treatments. Biodiesel decomposes naturally and is nontoxic to the extent of the common salt being more toxic than it. Biodiesel is sulphur- and aromatic- free unlike mineral diesel [6].

Materials and Methods

The extraction process used in this research work is the chemical process. Prior to this, the seeds were crushed manually to remove the succulent portion. The sample was dried in the oven for 60 °C to remove moisture. Weight of the seed was taken in 30 minutes interval until a constant value was obtained, an indication that the whole moisture content has been removed. The seed was milled and a 300 g weight of the seed cake was soaked in 2000 cm^3 of petroleum ether and covered with a cork for 48 hrs to avoid vaporisation. The set-up was filtered using Whatman No 1 filter paper. Filtrate obtained from this process was concentrated at 60 °C to obtain a constant volume with the aid of the water bath. A final constant volume of 241 cm^3 or 0.241 litres was obtained. The filtrate being the biodiesel was allowed to cool before subjection to some physical tests.

Determination of the density of the jatropha oil and biodiesel

The density of the biodiesel was carried out using the density bottle of a standard volume at a laboratory temperature of 32 °C using the gravimetric process. The weighing balance used in this process is the sensitive balance, hence density is deduced by equation (1).

Mass of the empty 50 cm^3 density bottle = m_1g

Mass density bottle + biodiesel to the mark = m_2g

$$\text{Denisity of biodisel} = \frac{\left(m_2 - m_1\right)g}{50\ cm^3} \qquad (1)$$

Determination of specific heat capacity of the jatropha oil by electrical method

The mass of copper calorimeter and stirrer was determined as m_1. A quantity of J. oil sufficient enough to cover the heating element was poured into the calorimeter and the new mass of calorimeter and content was reweighed as the mass of the J. oil was deduced as m_2. The initial temperature t_1 of the set-up was read on the inserted thermometer. The terminals of the calorimeter were connected to an external circuit comprising of a d.c. generator, a voltmeter, an ammeter, a rheostat using the plug key and allowed to run for 10 minutes. The circuit was disconnected and the final temperature was read after heating. This experiment was repeated for fossil diesel just as the following readings were taken:

Current, I passed through oil

Voltage, V across calorimeter

Time taken, t for heating

Mass of copper calorimeter and stirrer = m_1g

Mass of J.oil = m_2g

Mass of mineral diesel = m_3g

Theory: Heat supplied by heating element = Heat gained by calorimeter and stirrer + oil.

Determination of refractive index of J. Oil

The determination of the refractive index of J. oil is by vertical displacement of the base of container in which it occupies. The real depth of the container was measured from the base of the container to the level of liquid. With the use of a horizontally fixed optical pin to a retort stand, the new level of the raised base of the beaker known as vertical displacement is located when the liquid is viewed vertically. The apparent depth was deduced from the difference between the real depth and vertical displacement. Hence the refractive index of J. oil is given by equation (2) as:

$$n = \frac{real\ depth}{apparent\ depth} \qquad (2)$$

Determination of viscosity using Ostwald viscometer

Into the clean dry Ostwald viscometer, the oil sample was poured at the bulge end of the equipment, until it was at the upper mark using pipette. The temperature of the liquid was recorded. The pressure was allowed to come in through the atmospheric pressure and the fluid travelled to the lower mark as time for the travel was recorded. This was repeated and the average in time was taken. This was repeated for water and fossil diesel while deduction is made from Equation (3).

$$\text{Theory}: \frac{\eta_1}{\eta_2} = \frac{t_1 d_1}{t_2 d_2} \qquad (3)$$

Where η_1 is viscosity of liquid 1, η_2 is viscosity of water 0.891 centipoises (cP) or centriStroke (cSt) or , t_1 is flow time of liquid 1, t_2 flow time of water, d_1 is density of liquid 1, d_2 is density of water.

Conversion of J.oil to biodiesel

The FFA was determined by titrating 0.1 M KOH against 1 ml oil sample dissolved in 10 ml isopropyl alcohol using phenolphthalein indicator. A titre value of 4.6 ml was obtained. The mass concentration was deduced from the titre and mass concentration expression to be 0.0258 g/ml of the oil.

For 30 ml of oil used, a mass of 0.7743 g KOH is required for the conversion process. 90 ml of methanol was introduced into 0.774 g of KOH which was dissolved using stirring rod. This mixture was kept in a water bath at a pre set temperature of 60 °C for 1 hour. A container of 30 ml oil sample was kept in the water bath to attain the same temperature as the mixture. The contents of two containers were mixed together and constantly stirred for 1 hr at the same temperature of 60 °C before transferring into the separating funnel to stand overnight. The biodiesel and glyerine were separated.

Results and Discussion

The oil yield of 72.18% was obtained after the chemical extraction process with an average of 0.12% accounting for the moisture content (Table 3). This small moisture content was largely due to the condition of the seeds at the time of harvesting. The density of Jatropha oil was measured and calculated as 0.9 gcm^{-3} while fossil diesel has a calculated density of 0.867 gcm^{-3}. The closeness in densities of these two liquids suggests their miscibility in some given ratios for use in engines originally designed to run on fossil diesel only. It is a common knowledge that such blending has succeeded in time past and they are still in use in such engines but with its attendant shortcomings. The specific heat capacity of J.oil was determined to be 2.353 $Jkg^{-1}K^{-1}$ just as that of fossil diesel came up to $2.729 \times 10^{-3} Jkg^{-1}K^{-1}$. Even though their specific heat capacities are close, the implication is that fossil diesel requires less amount of heat than J. oil to raise same unit quantities of each liquid through 1 K. The viscosity of J.oil is 28.43 cSt while that of fossil diesel was found to be 6.08 cSt. Issues arising from the direct use of J.oil for driving diesel engine are tied to its high viscosity. The refractive index of J.oil was obtained as 1.47.

Table 4 is the result of analysis carried out after the J. oil was converted to biodiesel through the transesterification process. The specific gravity stood at 0.799 and the viscosity came down to 3.12 cSt. Remarkable enough is the sharp crash in viscosity of the biodiesel compared to this same property of the J. oil. The value of biodiesel is whiskers away from that of the fossil diesel as deduced initially.

The specific gravity and the kinematic viscosity of biodiesel (Table 4). Its specific gravity is lower than that of the fossil diesel.

Conclusion

Conscious efforts at pursuing the renewable energy programme through the unveiling and popularising the use of biodiesel from J.oil is viable. This undoubtedly will save the world an impending economic embarrassment that may throw it into an avoidable energy crisis in addition to protect-

Table 3: Properties of Jatropha oil extracted by chemical process.

Physical properties	Value
Refractive index	1.47
Specific gravity	0.9
Kinematic Viscosity (cSt) at 32 °C	28.43
Oil yield to gross (%)	72.18
Moisture content (%)	0.12
Specific Heat Capacity (J/Kg/K)	2.353
Free Fatty Acid (%)	2.3
Acid value (mg KOH/g oil)	27.78

Table 4: Properties of biodiesel obtained from Jatropha oil through transesterification process.

Properties	Value
Specific gravity	0.799
Kinematic viscosity (cSt) @ 32 °C	3.12

ing the universe by going green. Results have shown that the proximities that exist between the properties of fossil diesel and biodiesel from J.oil are evidences that both can conveniently blend together and be used in already existing diesel engines; not forgetting the fact that absolute use of biodiesel as fuel in such engines can be employed without necessarily acquiring new systems.

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