Calophyllum Inophyllum biodiesel as a future transportation fuel in Compression Ignition Engine: A Review

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ABSTRACT

This paper reviews the biodiesel production method from Calophyllum Inophyllum oil and its fuel characterization. In addition to that it also studies the performance and exhaust emission characteristics of Calophyllum Inophyllum methyl ester with diesel fuel. The increasing industrialization, modernization and motorization of the world have led to a steep rise for the demand of petroleum products, these fuels are obtained from limited reserve. These limited sources are highly concentrated in certain regions of the world. So, there are many countries not having these resources and facing a foreign exchange crisis, due to import of crude oil, Now it important to look forward for alternative source of fuel which can be produced from available materials within the country. Biodiesel it is also called as a natural fuel may be a good source or substitute for fossil fuel in future. It can be made from non-edible oil like Jatropha curcus, Madhuca indica, Gossypium arborreum etc. There is a better source as a raw material for biodiesel production is Calophyllum Inophyllum oil also known as hone oil. As it is an evergreen tree and grows along the coastal area. This paper is focused on the study related to collection of seeds, oil extraction then produced for biodiesel production which is used with blends with diesel as an alternative fuel in CI engine. The physic-chemical parameters showed that Calophyllum Inophyllum may works as a sustainable feedstock for biodiesel production that is equivalent to fissile fuel as per AS6751.

Keyword –*Calophyllum Inophyllum oil, Trans-esterification, fuel properties, Engine characteristics*

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1. INTRODUCTION

The fast depletion of world‘s crude oil reserves and increasing environmental concerns has created a great demand for environmentally benign renewable energy resources. Biodiesel emerged as a sustainable alternative fuel to petroleum origin diesel and its usages have been encouraged most of the countries. The concepts using vegetable oil as fuels are firstly develop by Dr. Rudolf Diesel in 1895 when the first diesel engine to run on vegetable oil. Rudolf Diesel Stated: "The use of vegetable oil for engine fuels may have been seen insignificant today. But such oil may become in source of time as important as petroleum and the coal tar products of the present time". Biodiesel is a natural and biodegradable fuel defined as a mixture of fatty acid methyl or ethyl esters extracted from vegetable oil or animal fats and it is used in diesel engines and heating systems. Thus biodiesel be considered as mineral diesel having an advantage of reduction of greenhouse gases and it is renewable resource [1]. Vegetable oils are quite favorable alternative fuels for diesel engines. Biodisel fuels are mono alkyl esters and generally derived from fatty ester of vegetable oil or animal fat [2]. Mostly biodiesel is prepared from oils like sunflower, palm oil, rapseed, soyabean etc. throughout the world. Depending on the weather and soil conditions, different nations looking into various vegetable oils for diesel fuel substitute; sunflower and palm oil in Malaysia, rapseed oil in Europe and soyabean oil in USA are being considered as a substitutes for diesel fuel seed oil .As the derived oil from vegetable oil could not be used directly in diesel because of its higher viscosity. High viscosity of pure vegetable oil would reduce the fuel atomization and increase the fuel spray penetration, which would be responsible for high engine deposits and thickening of lubricating oil. The use of chemically altered vegetable oil that is biodiesel does not require modification in engine or injection system or fuel lines and is directly used in any diesel engine. Biodiesel can be made from vegetable oils or animal fats via trans-esterification. The trans-esterification is the reaction between oil and fat, with a short chain alcohol (methanol, ethanol, and propanol) in the presence of suitable catalysts, as they give high production yield [3].

Most of researchers have worked feedstock having higher FFA levels using alternative processes like pyrolysis, micro emulsion, supercritical one. But there are certain exceptional cases where in direct trans-esterification cannot be performed. Such cases appear in raw vegetables oils or in non-edible oils like castor, karanja, Jatropha, simaroubae, mahua and nagchampa i.e. calophyllum inophyllum. As these non-edible oils having high free fatty acids (FFA). For determining whether the raw vegetable oils can be Trans-esterifies directly, the acidity is the most important parameter that must be known. After FFA determination, we can convert the oil into ester that is biodiesel with two step chemical process that are esterification and trans-esterification. In the first step, the oil is treated by an acid dissolved in methanol to reduce FFA content, whereas in the second step the preheated esterified oil is trans-esterified with methanol in the presence of base catalyst to form ester and glycerol [4].

2. CALOPHYLLUM INOPHYLLUM LINN OIL

C. megalocarpus is a member of the Euphorbiaceae family. The tree can be found in natural forests, forest margins or as a canopy tree. C. megalocarpus is indigenous to East Africa (Burundi, Democratic Republic of Congo, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda). It grows under the conditions of altitudes between 1300 and 2200 m with an annual rainfall between 800 and 1600 mm and average annual temperature varying between 11 and 268°C. The fruit of C. megalocarpus contains 3 ellipsoid-ovoid or oblong-ellipsoid seeds. The tree produces up to 50 kg of seeds and a hectare produces 5–10 t of seeds per year. The seeds have an average oil content of 40–45%. [5,6] C. inophyllum is a member of the Clusiaceae family (commonly known as mangosteen family). The tree is also known as Polanga or Nagchampa in India, Nyamplung in Indonesia, or honne in the Philippines. It is a medium-sized, evergreen, submaritime tree that grows best in deep soil or on exposed sea sands. The annual rainfall requirement of the tree ranges between 750 and 5000 mm. The tree can be found growing in East Africa, India, Southeast Asia, Australia, and the South Pacific. The seed has very high oil content (65–75%). C. inophyllum oil is nonedible and dark green. [6] The C. nucifera tree is native to Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. However, it has an exotic distribution in many countries such as Argentina, Cameroon, China, Fiji, Madagascar, the United States, and Zanzibar. The trees have a smooth, columnar, light-grey/brown trunk, with a mean diameter of 30–40 cm at breast height, and they are topped with a terminal crown of leaves. The biophysical limits of the tree are as follows: altitude: 520–900 m, mean annual temperature: 20–288°C, and mean annual rainfall: 1000–1500 mm. The fruits are green, at first, and turn brownish as they mature; yellow varieties go from yellow to brown.[7] each cycle i.e. seven levels for desorption cycle (day cycle) and seven levels for adsorption cycle (night cycle).

2.1 Botanical Description of Calophyllum Inophyllum Plant:

Plant Size: Calophyllum inophyllum L. is a large tree of shorelines and coastal forests. It usually grows 12–20 m (40–65 ft) in height, but open-grown trees can become wider than they are tall, often leaning, with broad, spreading crowns. Trees growing along the shoreline may reach out with trunks almost parallel to the ground. The tree can often be recognized at a distance by its large, spreading horizontal branches [8].

Flowers: It bears clusters of 4–15 fragrant white flowers about 2.5 cm (1 in) across and 8–14 mm (0.3–0.6 in) long on long, sturdy stalks in leaf axils. There are 4–8 oblong petals. Trees may flower all year, but flowering is heaviest in late spring/early summer and late fall in the northern hemisphere [8].

Leaves: The opposite leaves are dark green, shiny, and hairless with broadly elliptical blades 10–20 cm (4–8 in) long and 6–9 cm (2.4–3.6 in) wide. Both the tip and base of the leaves are rounded. Leaf veins run parallel to each other and perpendicular to the midrib. The scientific name Calophyllum comes from the Greek words for “beautiful leaf” [8].

Fig- 1: Calophyllum Inophyllum L. tree flowers and fruits [8] & [9]

Fruit: The ball-shaped, light green fruits grow in clusters. Fruits are 2–5 cm (0.8–2 in) in diameter. The skin, which turns yellow and then brown and wrinkled when the fruit is ripe, covers the thin pulp, the shell, a corky inner layer, and a single seed kernel. Fruits are usually borne twice a year [8].

Seeds: One large brown seed 2–4 cm (0.8–1.6 in) in diameter is found in each fruit. Seeds are prepared by cleaning off the skin and husk from the shell of the seed; there are 100–200 seeds/kg with shells intact but husks removed [8].

Uses: The total Calophyllum Inophyllum linn tree has got excellent medicinal properties.

Wood: The beautiful wood has a fine lustrous texture that shows a distinctive interlocked grain. It is white and red when cut and ages to a reddish brown. Because of this interlocked grain, swan surfaces tend to be woolly. The wood is moderately dense, specific gravity 0.6-0.8 and is somewhat difficult to work due to interlocked grain. The wood is particularly useful for food platters and calabashes, as it imparts no taste to the food. It is also prized for handicrafts because of its beauty. It is traditionally used in boat making. Elsewhere it is also used for general furniture, construction. It has however, been variously, described as vulnerable or resistant to termite attack [10]. The bark acts as an antiseptic and disinfectant. Rubbed with water lime juice, it makes a useful application on armpits, groins and feet in bromidrosis. The bark taken internally acts as an expectorant and is useful in chronic bronchitis. The resin is mixed with strips of bark and leaves steeped in water and the oil which rises to the surface is a household application for sore eyes.

Oil: The greenish yellow oil obtained from the Calophyllum seeds was used as an alternative to candlenut oil in lamps. It may be used for hair oil. It was also used to furnish wooden bowls [11] and for cosmetic and topical applications for healing of burns and skin diseases. As Calophyllum oil is a significant topical healing agent with skin healing, anti-inflametory [12], and antimicrobial properties [13]. The oil can also use for soap making. Oil contains benzoic and oxi-benzoic acids. Small amount of vitamin F and phosphor-aminolipids come along with glycerides and saturated fatty acids. The plant contains free fatty acids, glycerides and steroids (canophyllal, canophyllol. Canoophyllic acids). Filtered Calophyllum oil is applied to wounds possesses the capacity to promote the formation of new tissue, thereby accelerating healing and growth of healthy skin. This process of forming new tissue is known as 'ciatrisation'[13] The oil is a widely used as a traditional topical aid. In coastal area some peoples uses Calophyllum oil for applying to cuts, scrapes, soriasis, diabetic sores, anal fissures, sunburn, dry or scaly skin, blisters and to relieves sore throat when it is applied topically to the neck. The oil also demonstrates pain relieving properties and has been used traditionally to relieve neuralgin, rheumatism and sciatica. The calophyllum oil also demonstrates anti-inflamatory activity which has 4-phenyicoumarin calophylloidea[14] and a group of xanthones including dehydrocycloguanandin, calophyllin-B, jacareubin, mesuaxanthone-A, mesuaxanthone-B and euxanthone. These all xanthones explaines reductions of rashes, sores, swelling and abrasions with topical applications of the oil [15].

Xanthones and coumarins in calophyllum oil demonstrate anti- oxidant properties, specifically inhibiting lipid perixidation. The antioxidant property of oil helps to protect skin cells from damage by reactive oxygen species.

De oiled Cake: It constitutes flavonoids, uranoflavonoids, and furan derivatives and is used in treating skin diseases and in bio pesticide. The meal cake can be used as fertilizer, pesticide and used for organic farming. Seed shells can be used as combustibles.

Gum: The gum extracted from the plant (from wounded bark) is emetic and purgative but also has use for the treatment of wounds and ulcers.

2.2 Advantages of Calophyllum Inophyllum Tree [16].

i. Does not compete with food crops (it is non-edible oil).
ii. High survival potency in nature, still productive until 50 years.
iii. Lot of seedlings and easy Silviculture.
iv. As windbreaker, soil and seashore conservation.
v. Multipurpose in use of its seed, wood, gum, processing by products.
vi. Calophyllum Inophyllum is used in pharmacuticals drugs.

3. OIL EXTRACTION TECHNIQUES

Preliminarily processes need to be done to extract the oil from the seeds. First, the seed needs to be separated from the fruits. Then the drying process is done in the oven or under the sun to expected moisture contents. To extract oil, it is very important to grate the kernel to get a higher percentage of oil. The main techniques available to extract oil can be classified by (a) mechanical extraction (b) chemical extraction (c) enzymatic extraction. Besides some other techniques has also been used including accelerated solvent extraction, supercritical fluid extraction, microwave-assisted extraction. Among all the oil extraction techniques, mechanical and chemical extraction techniques are the popular method.

4. PRODUCTION OF CALOPHYLLUM OIL

According to the literature, Calophyllum oil cannot be used directly in diesel engines because of its higher viscosity which causes a problem such as poorer atomization of the fuel spray and less accurate operation of the fuel injectors in the engine [17,18]. Table 2 shows the problem that causes in the engine due to the use of Calophyllum oil. However, some process could be used to produce biodiesel as well as reduce the viscosity of Calophyllum. The available techniques are pyrolysis, micro-emulsification, dilution and trans-esterification [19–23]. Pyrolysis is the process in which one substance is converted into another substance by heat in the present of catalyst [24]. This process is simpler than another process. Dilution is the process in which Calophyllum oil are mixed with the diesel fuel to reduce the viscosity as well as to be used in the engine. Micro emulsification is the formation of micro-emulsions which is

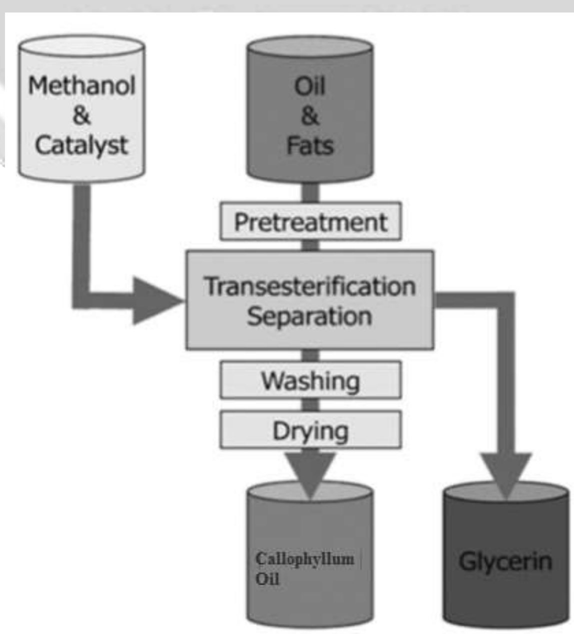

Fig- 2: Conventional process of Calophyllum oil production from crude Calophyllum oils [16].

The potential solution to solve higher viscosity issue of Calophyllum [25]. Trans-esterification which is also termed as alcoholises is some consecutive reversible reaction (as shown in Figure) between Calophyllum oil and alcohol in the presence of a catalyst. In the trans-esterification process, triglycerides are converted into monoglyceride [26–30]. Trans-esterification process can be categorized as acid catalyst trans-esterification, alkali catalyst trans-esterification, and lipase catalyst trans-esterification. Fig. 2 shows the conventional process of Calophyllum oil production from crude Calophyllum oils. Among the all conversion technic, trans-esterification process is the economical and efficient process which is widely used for Calophyllum oil production [18, 32-34]. Table 3 shows the comparison of Calophyllumoil production techniques.

Triglyceride (TG) + ROH ↔ Diglycerides (DG) + RCOOR1 (1)

Diglycerides (DG) + ROH ↔ Mono glyceride (MG) + RCOOR2 (2)

Monoglyceride (MG) + ROH ↔ Glycerol + RCOOR3 (3)

Table -1: Problems of using crude oils in engine [35]

Problems in the Engine	Reason
Carbon deposits on automotive components	Higher viscosity
Filter plugging, injector coking, nozzle blocking	Polymerization products, free glycerine
Failure of engine lubricating oil	Polyunsaturated fatty acid of vegetable oil
Cold weather starting	Higher viscosity
Heavy gum and wax formation, deposition on piston, piston rings, injectors and cylinder wall	High viscosity, oxidation
Corrosion of high pressure injecting pump, injectors, injector nozzles, supply or feed pumps, high pressure pipe	Free water, free FAME, corrosive acids, high viscosity at low temperature, iodine value, total acid number
Fuel delivery problems, poor nozzle spray atomization	Higher viscosity
Elastomer like nitrile rubber softening, swelling, hardening, crackin	Free methanol, free water in the mixture

Table -2: Comparison of Calophyllum production techniques [36]

Technologies	Dilution or micro-emulsion	Pyrolysis	Trans-esterification	Supercritical methanol
Advantages	Simple process	Simple process	Fuel properties are closer to diesel	No catalyst
		No-pollutions	High conversion efficiency	Short reaction time
			Low cost	High conversion
			It is suitable for industrialized production	
			Low free fatty acid and water content are required (for base catalyst)	

Disadvantages	High viscosity	High temperature is required	Products must be neutralized and washed	Apparatus cost is high
	Bad volatility	Apparatus is expensive	Accompanied by side reactions	Apparatus cost is high
	Bad stability	Low purity	Difficult reaction products separation	High energy consumption

4.1 Calophyllum Production Techniques

The trans-esterification reaction proceeds with catalyst or without any catalyst by using primary or secondary monohydric aliphatic alcohols having 1–8 carbon atoms. Generally, alcohol and triglycerides (vegetable oil and animal fat) are not miscible to form a single phase of mixture. Hence, the poor surface contact between these two reactants causes trans-esterification reaction to proceed relatively slow. Introduction of catalysts improves the surface contact and consequently reaction rates and biodiesel yield as it is able to solve the problems of two-phase nature between triglycerides and alcohol. However, without the presence of catalysts, the reaction rate is too slow for it to produce considerable yield of biodiesel. Hence, researchers around the world have been developing numerous alternative technologies which can solve the problems facing catalytic reaction by using non-catalytic processes [37].

4.1.1 Catalytic Calophyllum Oil Production

Calophyllum oils can be trans-esterified by heating them with an alcohol and a catalyst. Catalysts used in biodiesel production are divided in two general categories, homogenous and heterogeneous types. If the catalyst remains in the same (liquid) phase to that of the reactants during trans-esterification, it is homogeneous catalytic trans-esterification. On the other hand, if the catalyst remains in different phase (i.e., solid, immiscible liquid or gaseous) to that of the reactants, the process is called heterogeneous catalytic trans-esterification. In catalytic methods, the suitable selection of the catalyst is an important parameter to lower the biodiesel production cost. So, commercial biodiesel is currently produced by trans-esterification using a homogenous catalyst solution. Another factor affecting the selection of catalyst type is the amount of free fatty acid (FFA) present in the oil. For oils having lower amount of FFAs, base catalyzed reaction gives a better conversion in a relatively short time while for higher FFAs containing oils, acid-catalyzed esterification followed by trans-esterification is suitable. It has been reported that enzymatic reactions are in sensitive to FFA and water content in oil. Hence, enzymatic reactions can be used in trans-esterification of used cooking oil. Various studies have been carried out using different oils as raw material, different alcohols (methanol, ethanol, butanol), as well as different catalysts, including homogeneous ones such as sodium hydroxide, potassium hydroxide, and sulphuric acid, and heterogeneous ones such as lipases, CaO and MgO. These methods are classified as follow [37]:

i. Homogeneous catalytic trans-esterification.
   a. Homogeneous base catalytic trans-esterification.
   b. Homogeneous acid catalytic trans-esterification.

ii. Heterogeneous catalytic trans-esterification
   a. Heterogeneous solid-base catalytic trans-esterification.
   b. Heterogeneous solid-acid catalytic trans-esterification.

iii. Bio catalytic trans-esterification

4.1.2 Non-Catalytic Biodiesel Production

In a catalytic reaction to produce biodiesel through trans-esterification, several processes, such as purification of the esters, separation and recovery of unreacted reactants and catalysts, are involved. These process render-production of biodiesel through a conventional trans-esterification system complicated, thus giving a reason to investigate the production of biodiesel from triglycerides via non-catalytic reactions. Beside catalytic methods, there are two non-catalytic trans-esterification processes. These are the super critical alcohol process and BIOX process. These methods are classified as follow [37]:

i. Super critical alcohol trans-esterification.

ii. BIOX co-solvent trans-esterification.

4.2 Advantages and Disadvantages of Biodiesel (Calophyllum Oil [48])

The biodiesel has numerous benefits as well as some shortcoming [38-47], which have been listed below. The major benefits of using biodiesel as a fuel is:

i. Biodiesel has less emission such as CO2, CO, SO2, PM and HC compared to diesel.

ii. Biodiesel increases the engine life and reduces the need for maintenance.

iii. Biodiesel improve the vehicle perform better as it having higher cetane number.

iv. Production of biodiesel is easier than diesel and is less time consuming.

v. It can be used without adding additional lubricant, unlike diesel engine.

vi. Biodiesel having a great potential for stimulating sustainable rural development and a solution for energy security issue.

vii. Biodiesel is less costly than diesel because it is produced locally.

viii. Biodiesel does not need to be drilled, transported, or refined like diesel.

ix. Biodiesel is better than diesel fuel regarding sulfur content, flash point, aromatic content, and biodegradability.

x. It is safer to handle, being less toxic, more biodegradable, and having a higher flash point.

xi. Non-flammable and non-toxic, reduces tailpipe emissions, visible smoke and noxious fumes and odors.

xii. Higher combustion efficiency, portability, availability, and renewability of biodiesel.

xiii. No required engine modification up to B20.

4.3 Biodiesel Also Has Some Disadvantages That Are Given As Follows:

i. It emits more NO_x emission than diesel.

ii. Higher pour and cloud point fuel freezing in cold weather causing a cold weather starting.

iii. Biodiesel has a corrosive nature against copper and brass.

iv. The higher viscosity due to the large molecular mass and chemical structure of vegetable oils leads to a problem in pumping, combustion, and atomization in the injector system of a diesel engine.

v. Biodiesel lower engine speed and power. The biodiesels on the average decrease power by 5% compared to that of diesel at rated load

vi. Coking of injectors on the piston and head of the engine.

vii. Biodiesel degradation under storage for prolonged periods.

viii. The high viscosity, in long-term operation, introduces the formation of injector deposits, plugging of filters, lines and injectors, ring sticking and incompatibility with conventional

ix. Lubricating oils. Carbon deposits on piston and head of the engine.

x. Biodiesel causes excessive engine wear.

5. CHARACTERISTICS OF CALOPHYLLUM OIL

5.1 Oil Percentage: The available oil percentage in Calophyllum seeds is 55-75%.

5.2 Physico-Chemical Properties: The fresh extracted crude oil is greenish yellow and it get darkened during the storage. The oil having disagreeable odor and bitter taste. All properties are given in table-3.

Table -3: Physico-chemical Properties of Calophyllum Inophyllum oil [1]

Property	Unit	Value
Color	--	Greenish yellow
Odor	--	Disagreeable
Density at 15oC	gm/cc	910
Kinematic Viscosity at 40°C	Cst	38.17
Free Fatty Acid	mgKOH/g	28.16
Moisture	%	12%
Saponification Value	--	203
Calorific Value	MJ/KG	32.50
Specific Gravit	--	0.908
Flash Point	°C	224
Fire Point	°C	253

The compressibility effect of the vegetable oil causes an earlier injection of fuel into the engine cylinder as compared to diesel fuel [49]. This earlier injection does not play an important role, as the injection advance difference is at maximum 1°C even for the neat vegetable oil [50].

The major difference occurs in atomization process, i.e. the mean droplet size of vegetable oil is much higher than diesel fuel [51]. This is because high viscosity (38.17Cst) and low volatility of vegetable oils lead to difficulty in atomizing the fuel and in mixing it with air.

5.3 Free Fatty Acid Present In Calophyllum Oil[51,52]: Extracted oil consisted of pure triglyceride and rests were free fatty acids and lipid associates, which is the measure of Unsaponifiable matter.

5.3.1 Yield: Alkaline trans-esterification converts triglycerides in the oil to their respective methyl ester. Parameters that are to be optimized for alkaline trans-esterification are molar ratio and amount of catalyst. The rate of stirring, temperature and time was kept constant that are 650rpm, 65°C and 90min. Out of the different molar ratios tried, 8:1 molar ratio gives high yield of biodiesel from Calophyllum oil with 1.2% catalyst concentration. The used catalyst, potassium hydroxide which was separated easily from the mixture owing to soft nature of potassium soaps. The KOH amount was varied as 0.5wt%, 1.0wt% and 1.2wt%. The amount of KOH was needed

As a catalyst was 1.2wt% for Calophyllum oil). Potassium hydroxide, as a catalyst has an advantage over sodium hydroxide as the former is easily soluble in methanol. It is also suggested that waste stream occurring from the biodiesel purification (brine solution) while using KOH as catalyst may act as a fertilizer for soil due to potassium content.[52] Temperature of 65 ±0.50°C was optimum for the best conversion of biodiesel. 650 rpm was found to be sufficient for mixing of methanol and oil phase resulting in better conversion. 90 minutes reaction time resulted in completion reaction with high conversion of fatty acid methyl esters of Calophyllum oil.

Table -4: The Fatty acid composition of Calophyllum oil

Fatty acid name	Carbon number	Composition (%)
Lauric Acid	C12:0	0.75
Myristic Acid	C14:0	0.75
Palmitic Acid	C16:0	14.400
Heptadeconic Acid	C17:0	0.110
Stearic acid	C18:0	15.570
Palmitoleic Acid	C16:1	0.246
Cis-10 Heptadecanoic Acid	C17:1	0.038
Oleic acid	C18:1n9c	34.410
Cis- 11 Ecosenoic Acid	C20:1	0.794
Linoleic Acid	C18:2n6c	28.343
Alpha- Linolenic Acid	C18:3n3	0.150
Gamma- Linoleic Aci	C18:3n6	0.238
Cis-11, 14, 17- Eicosatrienoic Acid	C20:3n3	0.249
Cis- 5,8,11,14,17- Eicosapentaenoic Acid	C20:5n3	0.066
Cis- 13,16- Docosadienoic Acid	C22:2	0.422

5.3.2 Properties of Calophyllum Methyl Ester: As per ASTM standards. Among the general parameters for biodiesel, the viscosity controls the characteristics of the injection from the diesel injector. The viscosity of vegetable oil derived biodiesel can go to very high levels and hence it is important to control it within acceptable level to avoid negative impact on fuel injector system performance. Therefore viscosity specifications proposed are nearly same as that of the diesel fuel. It is further reduced with increase in petroleum diesel amount in the blend.

Table -5: Properties of Calophyllum Methyl Ester as Per ASTM 6751 Standard

Parameter	Calophyllum Oil Methyl Ester (COME)
Density (gm/cc),15°C	0.892
Kinematic viscosity (cSt), 300°C	3.87
Flash Point (°C)	176
Fire Point (°C)	182
Acid value	0.702
Moisture (%)	0.01
Gross Calorific value (MJ/KG)	37.18

The density of biodiesel from Calophyllum oils meets the requirements of ASTM biodiesel is 0.892 gm/cc. Although the density of COME is slightly higher, but still included in the ASTM standard biodiesel making biodiesel produced viable. Differences related to the density of fatty acid composition and degree of purity of the biodiesel [52].

Flash point of a fuel is the temperature at which it ignites when exposed to a flame or spark. The flash point of biodiesel is higher than the petro diesel, which is safe for transport purpose.

The above listed fuel properties indicate that the Calophyllum oil methyl ester (COME) is the best suited as per American Standards for Testing & Material (ASTM) norms for using as biodiesel in pure as well as in blending form.

6. PERFORMANCE AND EMISSION CHARACTERISTICS OF CALOPHYLLUM OIL[1,53-59].

6.1 Performance Characteristics

6.1.1 Brake Thermal Efficiency Brake: Thermal Efficiency is defined as break power of a heat engine as a function of the thermal input from the fuel. BTE constantly increases based on the load condition. This was due to a reduction in heat loss and increase in power with increase in percent load. The brake thermal efficiency is quite higher than that of diesel Variation of Carbon Monoxide (CO) with Compression Ratio

6.1.2 Specific Fuel Consumption: Specific fuel consumption, abbreviated SFC, compares the ratio of the fuel used by an engine to a certain force such as the amount of power the engine produces. Higher proportions of calophyllum oil in the blends increases the viscosity which in turn increases the specific fuel consumption due to poor atomization of fuel.

6.1.3 Mechanical Efficiency: Diesel fuel has lag in the mechanical efficiency compared with that Biodiesel blends. This shows that the biodiesel lubricity have reduces the friction losses

6.2 Emission Characteristics

6.2.1 Smoke Emission: Smoke Density increases with increase in Load and produces more smoke at all Load condition and this may be due to lesser calorific value and high density.

6.2.2 CO emission: The percentage of CO emission for low compression ratio increases due to the rising temperature in the combustion chamber. The CO emission of the biodiesel and its blends are lower for high compression ratio. The CO emissions are higher at lower compression ratio, however, decreased at higher compression ratio. This is due to relatively complete combustion takes place at higher compression ratio. The CO emissions for biodiesel and its blends are higher, compared to diesel over the entire range of fuel blends, due to poor volatility of biodiesel resulting in poor mixing, rich pockets formed in combustion chamber, and consequently, poor combustion, which leads to higher CO emission.
The percentage of CO emission for low compression ratio increases due to the rising temperature in the combustion chamber. The CO emission of the biodiesel and its blends are found to be lower for high compression ratio.

6.2.3 Variation of Carbon Dioxide (CO2) Emissions
The biodiesel and its blends emits lower percentage of CO2 as compared to diesel at higher compression ratio, this is because of the calophyllum oil contains oxygen contents in it, so the carbon content is relatively lower in the same volume of fuel consumed at the same compression ratio, due to this CO2 emissions would have been decreased compared to diesel. At lower compression ratio, incomplete combustion of high carbon content diesel fuel causes less CO2 emissions as compared to biodiesel and its blends.

6.2.4 Variation of Hydrocarbon (HC) with Compression Ratio
The HC emission decreases with increase in compression ratio for the entire range of fuels, this is due to the complete combustion of fuel at a higher compression ratio, hence less amount of HC will emits. The HC emissions is higher at lower compression ratio, this is due to relatively less compression which retard the reactions of

combustion, because of poor volatility, the poor spray characteristics, poor mixing, rich pockets formed in combustion chamber,

6.2.5 Oxides of Nitrogen: it is observed that the NOx emission for entire range of fuel is higher at the high compression ratio, this is due to highest temperature is observed at this compression ratio.

6.2.6 Oxygen Emission: Oxygen emissions tend to decrease with the increase in the load and this may be due to more consumption of oxygen in the combustion chamber.

6.2.7 Exhaust Gas Temperature: The exhaust gas temperature increase with increase in the brake power. The exhaust gas temperature reflects on the status of combustion inside the combustion chamber. All blends gives low exhaust gas temperature when compared to that of diesel. The diesel gives higher exhaust gas temperature because of its higher heat content.

7. CONCLUSION

The Calophyllum oil possesses good oil characteristics for a CI engine which can be used as a blend with diesel. Due to its physic-chemical properties it could be used as a biodiesel feedstock and for Industrial application. The way of reducing the biodiesel production costs is to use less expensive feedstock containing free fatty acids, such as non-edible oils. With no competing food uses, this characteristic turns attention to calophyllum inophyllum linn which grows in coastal area of in our country. The production of biodiesel from this oil may provide a valuable local, regional and national benefit. Calophyllum tree can be planted as an ornamental tree like Pongamia pinnata in the gardens, on road sides, railway track. To develop biodiesel into an economically important option in India, it is required to work on biological innovations to increase the yield & minimize the gestation period of Calophyllum inophyllum linn tree.

8. REFERENCES

[1] Chavan S. B. Kumbhar and Deshmukh R.B; Calophyllum Inophyllum linn(“Honne”)Oil, A source for Biodisel Production;Research Journal of hemical Science, 2013, vol.3(11), 24-31.
[2] Puhan S., Vedraman N., Rambrahaman B.V. and Nagrajan G., Mahua (Madhuca indica) seed oil: A source of renewable energy in India, J. Sci.Ind. Res., 64, 890-896 (2004)
[3] Mishra S.R., Mohanty M.K., Das S.P. and Pattanaik A.K., Production of biodiesel (Methyl Ester) from Simarouba Gauca oil, Res. J. Chem. Sci., 2(5), 66-71 (2012)
[4] Venkanna B.K., Venkataramana Reddy, Biodiesel production and optimization from Calophyllum (hanne oil)- A three stage method., Biosource Tech., 100, 5122-5125 (2009)
[5] A. E. Atabani, A. S. Silitonga, H. C. Ong, T. M. I. Mahlia, H. H. Mas- juki, I. A. Badruddin, H. Fayaz, Renewable Sustainable Energy Rev. 2013, 18, 211–245. [6]
[6] World Agroforestry Centre. Croton megalocarpus. 2013 [cited 2013 21st April]; Available from: http://www.worldagroforestry.org/ treedb2/AFTPDFS/Croton_megalocarpus.pdf.
[7] A. E. Atabani, T. M. I. Mahlia, I. A. Badruddin, H. H. Masjuki, W. T. Chong, K. T. Lee, Renewable Sustainable Energy Rev. 2013, 21, 749–755.
[8] Friday JB, Okano D, Species profiles for Pacific Island Agroforestry: Calophyllum inophyllum (kamani). Hawaii, USA: Permanent Agriculture Resources (PAR); 2006 [
[9] A.S. Silitonga, A.E. Atabani, T.M.I. Mahlia, H.H.Masjuki, I.A.Badruddin, A compartive analysis of physical and chemical properties of Jatropha curcas.L, Calophyllum Inophyllum. L and Sterculia Feotida .L oil. IGEC-6 – 2011 – 102.
[10] Mueller-Dombois D., Fosberg F.R, Vegetation of the Tropical Pacific Island, Springer-Verlag, New York (1998)
[11] Little E.L. Jr. and Skolmen R.G, Common forest trees of Hawaii (Native and Introduced) Agricultureal Handbook No 679. USDA Forest service, (1989)
[12] Uphof J.C., Directory of economic Plants, Verlag von, J. Cramer, Lehre, Gremany (1968).
[13] Sundaram B.M., Gopalkrishnan C, and Subramanian S., Antibacterial acitivity of xanthones from calophyllum inophyllum linn., Arogya journal of health science, 12,48- 49, (1986).
[14] Petard P., Tahiti-Palynesian medicinal plants and Tahitian remedies, Noumea, New Caledonia, South Pacific Commission, (1972)

[15] Bhalla T.N., Saxena R.C., Nigam S.K., Kisra G. and Bhargava K.P., Calophylloide, a new nonsteriodal anti- inflametory agent, Indian J. Med. Res., 72, 762-5 (1980).
[16] Mofijur M, Rasul MG, Hyde J, et al. Role of biofuel and their binary (diesel– biodiesel) and ternary (ethanol–biodiesel–diesel) blends on internal combustion engines emission reduction. Renew Sustain Energy Rev 2016;53:265–78.
[17] Bhuiya MMK, Rasul MG, Khan MMK et al. Prospects of 2nd generation biodiesel as a sustainable fuel—Part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. Renew Sustain Energy Rev 2016; 55: 1109-28.
[18] Jayed MH, Masjuki HH, Saidur R, et al. Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia. Renew Sustain Energy Rev 2009;13:2452–62.
[19] Demirbas A. Biodiesel production from vegetable oils via catalytic and non- catalytic supercritical methanol transesterification methods. Prog Energy Combust Sci 2005;31:466–87.
[20] Demirbas A. Progress and recent trends in biodiesel fuels. Energy Convers Manag 2009;50:14–34.
[21] Canakci M. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel. Bioresour Technol 2007;98:1167–75.
[22] Agarwal AK, Rajamanoharan K. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Prog Energy Combust Sci 2007;33:233–71.
[23] Balat M. Potential alternatives to edible oils for biodiesel production - A review of current work. Energy Convers Manag 2011;52:1479–92.
[24] Atabani AE, Silitonga AS, Ong HC, Et al. "Non-edible vegetable oil: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characterics, engine performance and emission production. Renew Sustain Energy Rev 2013; 18: 211-45.
[25] Abbaszaadeh A, Ghobadian B, Omidkhah MR, Najafi G. Current biodiesel production technologies: a comparative review. Energy Convers Manag 2012;63:138–48.
[26] Gerpen JV. Biodiesel processing and production. Fuel Process Technol 2005;86:1097–107.
[27] Sanjid A, Masjuki HH, Kalam MA, et al. Production of palm and jatropha based biodiesel and investigation of palm-jatropha combined blend properties, perfor- mance, exhaust emission and noise in an unmodified diesel engine. J Clean Prod 2014;65:295–303.
[28] Shahid EM, Jamal Y. Production of biodiesel: a technical review. Renew Sustain Energy Rev 2011;15:4732–45.
[29] Silitonga AS, Ong HC, Mahlia TMI, et al. Biodiesel conversion from high FFA Crude Jatropha Curcas, Calophyllum Inophyllum and Ceiba Pentandra oil. Energy Proc 2014;61:480–3.
[30] Singh SP, Singh D. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renew Sustain Energy Rev 2010;14:200–16.
[31] Sharma YC, Singh B. Development of biodiesel:current scenario. Renew Sustain Energy Rev 2014;29:517-27.
[32] Atabani AE, Mahlia TMI, MH H, et al. A comparative evaluation of physical and chemical properties of biodiesel synthesized from edible and non-edible oils and study on the effect of biodiesel blending. Energy 2013;58:296–304.
[33] Parawira W. Biodiesel production from Jatropha curcas: A review; 2010. 5: 1796- 808. 808. [55] Jain S, Sharma MP. Biodiesel production from Jatropha curcas oil. Renew Sustain Energy Rev 2010;14:3140–7.
[34] Jain S, Sharma MP. Biodiesel production from Jatropha curcas oil. Renew Sustain Energy Rev 2010;14:3140–7.
[35] H.. ahmudul, F.Y Hagos, R amat, A.Abdul Adam, W.F.W. Ishak, R. Alenezi; "Production, characterization and performance of biodiesel as an alternative fuel in diesel engines- A Review" Renewable and Sustainable Energy Reviews; 2017: 72;497-509.
[36] Advanced Biofuels Study Strategic Directions for Australia. L.E.K.; 2011.
[37] Abbaszaadeh A, Ghobadian B, Omidkhah MR, Najafi G. Current biodiesel production technologies: a comparative review. Energy Convers Manag 2012;63(0):138–48. http://dx.doi.org/10.1016/j.enconman. 2012.02.027.
[38] Atadashi IM, Aroua MK, Aziz AA. High quality biodiesel and its diesel engine application: a review. Renew Sustain Energy Rev 2010;14:1999–2008.
[39] Demirbas A. Biodiesel: a realistic fuel alternative for diesel engines. London: Springer; 2008.
[40] Yusuf NNAN, Kamarudin SK, Yaakub Z. Overview on the current trends in biodiesel production. Energy Convers Manag 2010;52:2741–51.

[41] Westbrook SR. Significance of tests for petroleum products, 7th ed.. West Conshohocken, PA: ASTM International; 2003. p. 63–81, S.J.
[42] Ali OM, Mamat R, Abdullah NR, Abdullah AA. Analysis of blended fuel properties and engine performance with palm biodiesel–diesel blended fuel. Renew Energy 2016;86:59–67.
[43] Pali HS, Kumar N, Alhassan Y. Performance and emission characteristics of an agricultural diesel engine fueled with blends of Sal methyl esters and diesel. Energy Convers Manag 2015;90:146–53.
[44] Öztürk E. Performance, emissions, combustion and injection characteristics of a diesel engine fuelled with canola oil–hazelnut soapstock biodiesel mixture. Fuel Process Technol 2015;129:183–91.
[45] Özçelik AE, Aydoğan H, Acaroğlu M. Determining the performance, emission and combustion properties of camelina biodiesel blends. Energy Convers Manag 2015;96:47–57.
[46] Mofijur M, Masjuki HH, Kalam MA, et al. Energy scenario and biofuel policies and targets in ASEAN countries. Renew Sustain Energy Rev 2015;46:51–61.
[47] Yang L, Takase M, Zhang M, et al. Potential non-edible oil feedstock for biodiesel production in Africa: a survey. Renew Sustain Energy Rev 2014;38:461–77.
[48] Tapasvi D., Wisenborn D., Gustafson C., Process model for biodiesel production from various feedstocks, Trans, ASAE, 48 (6), 2215-2221, (2005).
[49] Varde K.S., Bulk modulus of vegetable oil-diesel fuel blends, 63,713-5, (1984).
[50] Rakopoulos C.D., Antonopoulos K.A., Rakopoulos D. C., Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesel of various origins, Energy Conversion and Management, 47, 3272-3287, (2006).
[51] Kamimoto T, Matsuoka S., Prediction of spray evaporation in receiprocating engine, SAE, (1977)
[52] Trembly A.Y., Cao P., Dube M.A., 'Biodiesel production using ultra low catalyst concentrations, Energy and Fuels (22) 2748-2755 (2008)
[53] G. Deepankumar, "Experimental Investigation Of Performance And Emission Characteristics Of Tamanu Oil As Alternative Fuel In Ci Engine" Experimental Investigation Of Performance And Emission Characteristics Of Tamanu Oil As Alternative Fuel In Ci Engine; Volume 4 Issue 6 June 2015, Page No. 12471-12475.
[54] A. Sanjid, H.H. masjuki, .A. Kalam, S.. Ashrafur Rahman, .J Abedin, S. palash."Impact of palm, mustered, waste cooking oil and calophyllum inophyllum biofuels on performance and emission of CI engine" Renewable and Sustainable Energy Reviews;2103, vol.27,664-682.
[55] Ashish G.Bandewa, Raahul Krishna, SV Chanapattana: "Experimental Investigation of Emission Characteristics of VCR Engine using Calophyllum Inophyllum Bio-Diesel Blends as a Fuel" ; International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE) ISSN: 2349-7947 Volume: 2 Issue: 2.
[56] A. E. Atabani et al. Fuel Properties of Croton megalocarpus, Calophyllum inophyllum, and Cocos nucifera (coconut) Methyl Esters and their Performance in a Multicylinder Diesel Engine; Energy Technol. 2013, 1, 685–694.
[57] Varathan R, Karuppasamy K; "Performance Emission and Combustion Characteristics of Honne Oil Biodiesel Blends in Diesel Engine"; International Journal of Mechanical Engineering and Research, ISSN 0973-4562 Vol. 5 No.1 (2015).
[58] B. K. Venkanna & C. Venkataraman Reddy; "Performance, Emission, and Combustion Characteristics of a Diesel Engine Running on Blends of Honne Oil and Diesel Fuel" ISSN: 1543-5075 (Print) 1543-5083. http://www.tandfonline.com/loi/ljge20.
[59] Rahul Krishnaji Bawane, Nilima Baliram Gadge, Swapnil Ambhore, Aquib Shaikh: Experimental Investigation of Emission Characteristics of Calophyllum Inophyllum Linn (Honne) Oil as Alternative Fuel in CI Engine; International Journal of Scientific & Engineering Research, ISSN 2229-5518 Volume 5, Issue 6, June-2014.