Jatropha Curcas Oil Based Fuels for C.I. Engines: A Comprehensive Review

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ABSTRACT

The rapidly depleting fossil fuels and environmental degradation due to burning these fuels has increased attention in alternative fuels. Further, the use of alternative fuels can significantly save foreign exchange. Since the edible oils are not available in excess, the researchers are concentrating on use of non-edible oils as engine fuels. One of such promising renewable alternative fuel is non-edible jatropha curcas oil. The plant of jatropha curcas is easy to harvest and once planted can produce seed for upto 50 years. Further, the properties of jatropha curcas oil are quite comparable with those of diesel except kinematic viscosity. The problem of high viscosity can be tackled in several ways such as blending, preheating of oil and transesterification. The performance and emission characteristics of C.I. engine using jatropha curcas oil based fuels has been found to be in tune with the diesel fuelled engine. A comprehensive overview on all aspects of jatropha curcas oil based fuels has been presented in this paper.

Keywords: Jatropha curcas oil, biodiesel, alternative fuel, fuel inlet temperature, blending.

INTRODUCTION

The depletion of non-renewable fossil fuel reserves, environmental pollution due to burning of these fuel and growing energy demand have jointly necessitated for exploration of alternative fuels. The energy used in various power sectors is essentially based on diesel and it is, therefore, imperative that some alternative to diesel be developed. Alternative fuels like alcohols, vegetable oils and natural gas are identified as potential fuels for C.I. Engines. Vegetable oils are bio-origin based fuels, which are non-toxic and eco-friendly. They are bio-degradable, their sources are renewable and can be obtained easily. Vegetable oils operate in a conventional engine design just like petro-diesel. Therefore, no major engine modification is required while using vegetable oils as engine fuel [1-5]

In the view of these advantages, large number of researchers worldwide has carried out investigation in the area of vegetable oils based fuels. The researches have shown that vegetable oils have fuel properties and provide engine performance much close to diesel. Kalam et al. [6] evaluated emission and deposit characteristics of diesel engine when operated on preheated crude palm oil and its emulsion with water. Hwang et al. [7] conducted test on diesel engine using waste cooking Oil based biodiesel to evaluate emission of the soot particles. Patel [8] evaluated performance characteristics of diesel engine using various blends of waste cooking oil and diesel. Yadav et al. [9] experimented on methyl esters of Oleander, Kusum and Bitter Groundnut oil. Delalibera et al. [10] investigated the potential of four vegetable oils (linseed, crambe, rapeseed and jatropha) with preheating and engine work temperature. Srithar et al. [11] investigated the effect of blending two biodiesels (pongamiapinnata oil based biodiesel and mustard oil based biodiesel) on performance and emissions characteristics of C.I. engine. Khan et al. [12] experimentally evaluated Kirloskar diesel engine performance and emissions using 10/90 blend of sesame oil and diesel.

Panneerselvam et al. [13] experimentally studied performance, emissions and combustion characteristics of C.I. engine fuel running on watermelon (Citrullus vulgaris) methyl esters. Ramakrishnan investigated [14] performance and emission characteristics of jojoba oil fueled direct injection C.I. engine.

Idea of using vegetable as diesel engine is not new. Dr. Rudolph Diesel first developed the diesel engine in 1895 with the intention of running it on a variety of fuels including vegetable oil. Dr. Diesel used peanut oil to fuel one of his engines at the Paris Exposition of 1900 [15]. In 1912, R. Diesel said "The use of vegetable oils for engine fuel may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time" [16]. His visionary prediction is becoming true today as more and more biodiesel is being used globally.

Vegetable oil based fuels causes various engine problems such as carbonization of injector, piston head and surfaces of cylinder, gum development, wear of vital parts, ring-sticking and thickening of the lubricating oil etc. This is due to high viscosity of vegetable oils [17-19]. This problem can tackled using various techniques such as blending with other fuels like diesel [3,4,8,14,18-20], preheating the fuel i.e. heating the fuel before injecting into engine cylinder [2,4,6,10,17,21-23] and transesterification [1,5,7,9-11,24-25].

The conversion reaction of fatty acids (vegetable oil or animal fat) with methanol or ethanol to form esters and glycerin is called as transesterification. Methyl or ethyl ester of fatty acids formed is called biodiesel. The stoichiometry of transesterification process requires atleast three moles of alcohol per mole of vegetable oil to yield three moles of fatty acid ester and one mole of glycerol. A catalyst is used to improve the reaction rate and yield. The process can occur at moderate temperature ranging from 60 to 80°C. The conversion of triglycerides into methyl or ethyl ester brings about a drastic change in their properties. It reduces the molecular mass to one-third hence a significant reduction in viscosity and density is achieved. [1, 26-27]

Use of edible oils as fuel for C.I. engines has limited applications due to higher domestic requirement and their expensiveness. In the view of this, use of non-edible oils compared to edible oils is more significant as an alternative fuel. Non-edible oil can be obtained from jatropha curcas, pongamia pinnata, nag champa, rubber seed, neem etc. With an abundant supply, jatropha curcas oil has great potential as an alternate for diesel [28-32]. In this paper, a detailed review of available researches on the use of non-edible jatropha curcas oil based fuels in C.I. engines has been presented.

JATROPHA CURCAS OIL

Jatropha curcas oil is obtained from the dried ripe seeds of the Jatropha curcas plant. It is in-edible oil [17]. Jatropha curcas is a large shrub or tree native to the American tropics but commonly found and utilized throughout most of the tropical and subtropical regions of the world [18, 33]. It belongs to the Euphorbiaceae family [34-35] and commonly known as Physic nut, Ratanjot, Jamalghota, Jangaliarandi or Kala-aranda [36]. It is a drought-resistant, perennial plant and has capability to grow on marginal/poor soils. It requires very little irrigation [37]. It can grow in arid, semi-arid and waste land [38]. The jatropha curcas plants start to yield from the second year of plantation but in limited quantity. If managed properly, it starts giving 4-5 kg per tree seed production form 5th year onwards and seed yield can be obtained upto 50 years from the day of plantation [36]. The oil content of Jatropha seed is 30 to 40% by weight [38]. In the winter, jatropha plants lose its leaves and do not produce any fruits. Fruit production takes place from mid-summer to late fall with variations in production peaks [39].

India has nearly 63 million ha of wasteland, of which 33 million ha have been allotted for tree plantation. Jatropha can grow conveniently on wasteland. The extensive training should be provided to the farmers and rural entrepreneurs so that they could learn the latest technology and agro-practice related to Jatropha cultivation [40]. Jatropha curcas plants have been planted in the University Polytechnic campus of Aligarh Muslim University. Photograph of the plants grown in the University Polytechnic campus is shown in Figure 1.

Figure 1. Jatropha Curcas Plantation

Jatropha curcas is a small plant with smooth gray bark. The bark discharges whitish, watery latex when cut [41]. Usually, jatropha curcas plant reaches a height of 3 to 5 m but can reach up to 8 to 10 m when grown under favorable conditions [42]. The plant has large green to pale-green leaves, broadly ovate, cordate, shallowly three lobed, petioles. Fruit of jatropha is yellowish green in color [43]. The fruits are bi-lobed capsules, ovoid green, and in cluster of 7-10, which on ripening turn dark colored [44]. Photograph of fruits and dried seeds of jatropha curcas plant are shown in Figure 2 and 3 respectively.

Figure 2. Fruits of Jatropha Curcas Plant

Figure 3. Seeds of Jatropha Curcas Plant

The oil obtained from jatropha seed can be easily combusted as fuel without being refined [45]. It burns with clear flame producing no free. Jatropha curcas oil is used a fuel for lighting and cooking and in C.I. engine based vehicles, electricity generating sets, pump sets, heavy farm machinery [46]. The advantages of jatropha curcas oil are that they are renewable and its plant control erosion of soil. A part from being used as fuel, jatropha curcas oil is also used for in cosmetics industry and for manufacture of candles and soap [47]. De-oiled cake of jatropha contains nitrogen, phosphorus and potassium, so it can be used as organic manure. Jatropha seed press cake and jatropha oil have insecticidal properties. In spite of several advantages jatropha also suffers from certain disadvantages, which should be given due consideration while dealing with this species. Jatropha seeds are hard and toxic. Thus, the de-oiled cake cannot be used as fodder for animal. After extraction of oil from seed, the detoxification of the de-oiled cake is required so that the seed cake can be used as fodder [4]. Haas et al. [48] found that de-acidification and bleaching could reduce the content of toxic phorbol ester to 55%.

FUEL CHARACTERIZATION

The fatty acid composition of jatropha curcas oil consists of myristic, palmitic, stearic, arachidic, oleic and linoleic acids [18, 49]. Table 1 shows, fatty acid composition of jatropha curcas oil.

Table 1. Fatty acid profile of jatopha curcas oil [33]

Fatty Acid	Formula	Structure	Wt%
Myristic Acid	$C_{12}H_{28}O_2$	14:0	0.5-1.4
Palmitic Acid	$C_{16}H_{32}O_2$	16:0	12–7.0
Stearic Acid	$C_{18}H_{36}O_2$	18:0	5.0–9.7
Oleic Acid	$C_{18}H_{34}O_2$	18:1	37-63
Linoleic Acid	$C_{18}H_{32}O_2$	18:2	19-41

The important chemical and physical properties of jatropha curcas oil are compared with diesel in Table 2. It can be seen from the table that the flash point of jatropha curcas oil is much higher than that of diesel. The higher flash point means that jatropha curcas oil is safer under heated conditions. Hence, it can be said that jatropha curcas oil is safer in handling, transportation and storage [39]. However, high flash point attributes to its lower volatility characteristics [50-51]. The calorific value of jatropha curcas oil is observed to be lower than that of diesel. The presence of chemically bound oxygen in vegetable oils lowers their calorific value [1-2, 4].

Table 2. Fuel characterization [2, 17-18]

Property/Fuel	Jatropha curcas oil	Diesel
Flash Point (°C)	219	76
Calorific Value (MJ/kg)	39.73	42.01
Density (g/cm^3, at 30°C)	0.915	0.858
Cetane Number	38	50
Kinematic Viscosity (cSt, at 38˚C)	40.97	2.96
Iodine number (cg I/g oil)	96.2	38.3

The density of jatropha curcas oil is slightly higher than that of the diesel. The higher density means that, fuel consumption rate for jatropha curcas oil operation will be higher than diesel [17]. The cetane number of jatropha curcas oil is 38 as compared 50 for diesel. Thus, the tendency of diesel knock is higher in case of jatropha curcas oil operation. For liquid fuels, viscosity is determined at a specific temperature. This is due to the fact that viscosity is dependent upon temperature. At standard temperature, kinematic viscosity of jatropha curcas oil is much higher than that of diesel. This is due to their large molecular mass and chemical structure of vegetable oil [18]. Viscosity is an important property of any fuel as it is an indication of the ability of fuel to fuel. In case of C.I. engine, it is essential to have fuel that flows well and a lower viscosity is desirable. Iodine value is a measure of the degree of unsaturation of the fuel. Unsaturation can result in formation of deposits and storage stability problem. Iodine value of the jatropha curcas oil is high as compared to diesel. Thus, deposits formation tendency with non-edible jatropha oil operation is expected to be higher [17].

JATROPHA CURCAS OIL BASED FUELS FOR C.I. ENGINE

Extensive research has been carried out to evaluate the feasibility of jatropha curcas oil based fuel as a replacement of diesel in C.I. engines. A summary of such studies is presented here.

Forson et al. [52] tested performance of DI diesel engine using different blends of jatropha oil and diesel. The test results showed that CO_2 emissions were similar for all fuels. Also, increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for jatropha oil and its blends with diesel were observed. The best performance was obtained with blending containing 97.4% diesel and 2.6% jatropha oil.

Mirunalini et al. [53] experimentally assessed performance and emission characteristics of DI engine running on jatropha curcas oil-diesel blends as fuels. The results showed that at full load condition, 200 bar fuel injection pressure, the specific energy consumption of 10% for jatropha oil-diesel oil blend was very close to that of diesel fuel use. The brake thermal efficiency of 10% jatropha oil-diesel blend at 200 bar fuel injection pressure was found to be very close to that of diesel. The exhaust gas temperature is minimum for 10% blend at 200 bar and increases with increase the blend. The lowest CO emission was observed with 10%

blend of Jatropha oil-diesel at full load condition with 200-bar fuel injection pressure. A reduction of 32.53 % was observed in NO_x emission with 40% blend of jatropha oil in diesel fuel and 250-bar fuel injection pressure. At full load condition, lowest smoke intensity was observed with 10% blend of jatropha oil in diesel fuel at 200-bar injection pressure.

Khan et al. [17] studied effects of fuel inlet temperature on the performance of a C.I. engine running on pure jatropha curcas oil. For this purpose, a heating arrangement was designed, fabricated and fitted to existing engine setup. With an increase in fuel in temperature, engine performance was found to improve. Acceptable brake specific fuel consumption and brake thermal efficiency values were obtained with jatropha curcas oil preheated to 80ºC. However, a slight increase in peak cylinder pressure values was noticed at elevated fuel inlet temperature.

Pramanik [18] experimentally investigated effect of blending on performance of C.I. engine fueled with blends of jatropha curcas oil and diesel. Significant reduction in viscosity was achieved by blending jatropha curcas oil with diesel in different proportions. The test result should that brake specific fuel consumption and exhaust gas temperature decreases with increase in diesel in fuel blend. With blends containing upto 50% jatropha curcas oil, an acceptable performance was observed.

Chauhan et al. [54] achieved reduction in viscosity of jatropha oil by heating it from exhaust gases and evaluated performance and emission characteristics of diesel engine running of pre-heated fuel. They observed that lower brake thermal efficiency and higher brake specific energy consumption were obtained when engine was operated on jatropha oil as compared to diesel. Increase in fuel inlet temperature resulted in increase of brake thermal efficiency and reduction in brake specific energy consumption. Emissions of NO_x using jatropha were lower than diesel and it increases with increase in fuel inlet temperature. Emissions of CO, HC and CO_2 emissions for jatropha oil operation were found higher than diesel. However, with increase in fuel inlet temperature, these emissions reduced. Optimum fuel inlet temperature was found to be 80ºC.

Hossain et al. [55] evaluated performance, combustion and emission characteristics of IDI Diesel engine fueled with jatropha oil and karanja oil. Reduction in viscosity of vegetable oil was achieved by utilizing heat from the engine water jackets. It was found that brake specific fuel consumption was higher for vegetable oils than diesel. At higher load, brake thermal efficiency of the preheated vegetable oils was almost equal to that of diesel. At low load, higher CO_2 and NO_x emissions were observed while CO emissions were similar to diesel operation. However, at higher loads the vegetable oils gave slightly higher CO emissions. Since the combustion temperature of the vegetable oil is higher, NO_x emissions for the vegetable oils are higher than diesel.

Pradhan et al. [56] carried out experimentation to evaluate combustion characteristics of DI diesel engine using preheated jatropha oil. They achieved reduction in viscosity of crude jatropha oil by heating it using the heat from exhaust gas. The results showed that jatropha oil operation exhibited slightly higher cylinder pressure, rate of pressure rise and heat release rate as compared to high speed diesel operation during the initial stages of combustion for all engine loadings. Ignition delay was observed to be shorter for preheated jatropha oil. It was also observed that brake specific fuel consumption and exhaust gas temperature increased while brake thermal efficiency reduced when preheated vegetable oil was used. The reduction in emissions of CO_2, HC and NO_x emissions were observed for preheated jatropha operation while CO emission was found to increase.

Rao et al. [57] conducted experiments to evaluated performance and emissions of different blends of pongamia, jatropha and neem methyl esters. The experiment results showed that blend containing 20% vegetable oil produced an engine performance close to that of pure diesel. Smoke, HC and CO emissions at various loads were found to be higher for diesel as compared to biodiesel blends. Pongamia methyl ester gives better performance compared to jatropha and neem methyl esters.

Sahoo et al. [58] obtained methyl esters of jatropha curcas, karanja and polanga oils and conducted experiments on three cylinder tractor engine during various blends of these biodiesels with diesel. Test data were obtained under full/part throttle position for different engine speeds. Change in exhaust emissions (Smoke, CO, HC, NO_x, and PM) were also studied for determining the optimum test fuel at various operating conditions. The maximum increase in power was observed for 50% jatropha curcas based biodiesel-diesel blend at rated speed. Brake specific fuel consumptions for all the biodiesel blends with diesel increases with blends and decreased with speed. There was a reduction in smoke emissions for all the biodiesel and their blends as compared to pure diesel operation. Smoke emissions were observed to reduce with blending.

Khan et al. [59] investigated effects of using blends and jatropha curcas oil as fuel in C.I. engine. In this investigation reduction in viscosity of jatropha curcas oil was achieved by addition of diesel in different proportions (50%, 80% and 90%). The brake specific fuel consumption and brake thermal efficiency values obtained with 20% jatropha curcas oil were found to be close to those obtained with pure diesel. Exhaust gas temperature was found to be maximum when engine was operated on 50% jatropha oil blend. They concluded that the blend containing 20% jatropha curcas oil showed an engine performance comparable to diesel and can be added to diesel for short-term operation without any engine change.

Jindal [60] evaluated effects of engine operating parameters on emissions of NO_x using jatropha methyl ester as fuel when engine was operated at standard parameters, the emissions of NO_x produced with biodiesel as fuel were found to be lower in comparison to diesel. It is observed that increase in compression ratio results in increase of emissions of NO_x whereas increase in injection pressure results in reduction in NO_x emissions. When jatropha based biodiesel was used as fuel, high compression ratio associated with high injection pressure, results in lower NO_x emissions. While at lower engine speeds, NO_x emissions increase peaking at 1440 rpm. It was also observed that emissions of NO_x tend to decrease when injection timing is retarded.

Rahman et al. [61] investigated the prospect of making of biodiesel from Jatropha curcas oil and used it in C.I. engine for performance evaluation. They observed that brake power and brake thermal efficiency of engine using biodiesel and blend of 50% biodiesel-50% diesel was greater than that obtained with diesel. Exhaust gas analysis showed that percentage of CO_2 in biodiesel and blend of 50% biodiesel- 50% diesel was found to be lower than the diesel. The percentage of O_2 in biodiesel was found to be higher than the diesel.

Elango et al. [62] evaluated performance and emission characteristics of a diesel engine fuelled with blends of Jatropha curcas oil and diesel. The test results showed that the brake thermal efficiency for diesel operation was higher at all loads. Among various blends, highest brake thermal efficiency and lowest specific fuel consumption was observed with fuel blend containing 20% Jatropha curcas oil. CO_2 emissions for blend containing 20% jatropha oil were observed to be lesser than diesel.

Khan et al. [2] investigated performance of a diesel engine running on pure jatropha curcas oil at two different inlet temperatures- 35ºC and 65ºC. The investigation showed that jatropha curcas oil preheated to 65ºC can be directly used in C.I. engine instead of diesel without any operational difficulty and modification in engine design. Unheated oil showed moderate rate of price rise and lower peak cylinder pressure. Heated oil showed a comparative reduction in delay period and shorter combustion duration.

Loganathan et al. [63] experimentally evaluated performance and emission characteristics of DI diesel engine running on various blends of jatropha based biodiesel and dimethyl ether under five engine loads at the maximum torque. The di-methyl ether was used as an dope to enhance combustion characteristics. The test results showed that the engine performance improved and emissions reduced on addition of di-methyl ether. As compared to pure jatropha oil, blend containing 10% additive showed 10% increase in brake thermal efficiency. Further, emissions of CO, HC and NO_x emission were observed to reduce for all blends.

Patil et al. [64] used jatropha oil based biodiesel in M&M Turbo-charged diesel engine in pure and blended form. The power, torque, and brake thermal efficiency using biodiesel were observed to be higher at various load conditions compared to pure diesel while specific fuel consumption was found slightly higher. The blend containing 20% biodiesel showed better performance than the diesel and other blends.

Mamilla et al. [65] conducted experiments to analyze performance and emission characteristics of DI diesel engine using jatropha oil methyl esters. The fuels used were neat Jatropha methyl ester, diesel and various blends of jatropha oil methyl ester with diesel. The experimental result showed that blend containing 20% jatropha oil methyl ester gave best performance with reduced emissions. It was also noticed that smoke density increased with increasing load for all the blends of biodiesel and decreased at higher blends of Jatropha methyl esters.

Kumar et al. [66] investigated the effect of compression ratio (CR) on the performance and emission characteristics of a DI diesel engine using Jatropha based biodiesel (50%) blended-diesel fuel. Experiments were conducted using three CRs (14, 16 and 18:1) at 1500 rpm with varying load from 0 to 100%. The results showed that increasing compression ratio improves the combustion characteristics of biodiesel. At higher compression ratio, increase in brake specific fuel consumption and decrease in brake thermal efficiency was observed. However, slight increase in brake power was found especially at higher load. Significant reduction in smoke opacity), CO, O_2 and HC emissions and increase in CO_2 were observed.

Abedin et al. [67] experimentally investigated performance, emissions and heat losses of diesel engine using palm and jatropha biodiesel blends. They observed decrease in brake power and increase in BSFC when engine operated on 10% and 20% blends of palm and jatropha biodiesel. Further, reduction in emissions of CO and HC were observed when biodiesel blends were used. While NO_x emission decreased by 3.3% while operating on palm biodiesel blends, whereas it is increased by 3.0% while operating on jatropha biodiesel blends.

Bhaskar [68] carried out experiments at a constant speed with different injection pressures (210, 220, 230 and 240 bar) on diesel engine using blends of jatropha curcas methyl ester. The effect of injection pressure on CO and smoke opacity of single cylinder, four stroke, water cooled DI diesel engine was observed. The experimental investigation showed that jatropha biodiesel blends produced lower CO emission and smoke opacity at 220 bar injection pressure as compared to remaining injection pressures.

CONCLUSIONS

In this paper, information related to the feasibility of jatropha curcas oil as C.I. engine fuel was collected and arranged in a systematic manner so that it can provide an insight into the research being conducted utilizing this fuel. Jatropha curcas oil is obtained from the dried ripe seeds of the Jatropha curcas plant. It is a promising renewable alternative fuel for C.I. engine offering number of advantages. Jatropha plant is a drought-resistant and perennial plant, which can grow on all types of soils. It can grow in arid, semi-arid and waste land.

The review conducted shows that the non-edible jatropha curcas oil can be used as a fuel in C.I. engine without any major engine alterations. It was observed that the fuel properties of jatropha curcas oil were in good agreement with those of diesel except kinematic viscosity. Reduction in kinematic viscosity can be successfully achieved by blending (with diesel), preheating (before injecting into engine cylinder) and transesterification (conversion to methyl or ethyl ester). The collected information shows that a better engine performance and lesser emissions were obtained when jatropha curcas oil based biodiesel was used as a fuel.

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