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Review Article

Use of Thumba, Jatropha and Ambadi Biodiesel as CI Engine Fuel: A Review

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A B S T R A C T

Biofuels are strongly emerging as partial substitutes for fossil fuel from the economic as well as environmental angle. It is known that most developed and developing countries spend a huge amount of foreign exchange on oil imports. Therefore, these countries would like to introduce the use of biofuels aggressively by cutting down the cost of production and subsidizing the same. It is established now that biofuels have the least adverse effects on the environment when used as a fuel in the CI engines. Biodiesel is basically mono-alkyl esters of long-chain fatty acids and can be used successfully as a fuel in the compression ignition engines Many researchers have concluded that biodiesel holds promise as an alternative fuel for diesel engines, since its properties are very close to diesel fuel; therefore, biodiesel can be used in diesel engines with few or no modifications. Diesel-fuel blends with biodiesel have superior lubricity, which reduces wear and tear on the diesel engine and makes the engine components last longer. Biodiesel can mix well with diesel fuel and stays blended. Biodiesel has a higher cetane number than petroleum diesel fuel, no aromatics, and contains 10-11% oxygen by weight. These characteristics of biodiesel reduce the emissions of Carbon Monoxide (CO), Hydrocarbons (HC) and Particulate Matter (PM) in the exhaust gas compared with diesel fuel. However, NOx emissions of biodiesel increase because of combustion and some fuel characteristics. Hence in this paper, a comprehensive review is presented on the performance, combustion and emission characteristics of three biodiesel fuel Thumba, Jatropha and Ambadi that are easily available in the western part of India. This review will be helpful to the researchers to understand the behaviour of this biodiesel when used as a fuel in CI engines.

Keywords: Transesterification, Thumba (*Citrullus colocynthis*), *Jatropha curcas*, Ambadi (*Hibiscus cannabinus*), Roselle (*Hibiscus sabdariffa* L.)

Introduction

In the development of industrial growth, agricultural sector, domestic needs, transportation, and to meet many other basic human needs the petroleum fuels play a vital role. Every year around 11billion tons of fossil fuel consumed. With this rate of consumption, their sources will soon be exhausted and this may lead to a shortage of fossil fuel. On the other hand, there are the undesirable environmental effects of its production. Emission of smoke, particulate matter (PM), carbon monoxide (CO), carbon dioxide, (CO2), nitrogen oxides (NOx) and unburnt hydrocarbon (UBHC) from petroleum fuel combustion are the main causes of atmospheric pollution and human health. Hence, for sustainable economic growth in human society and harmonious coexistence of human and environment, developing alternative energy is a prime requirement. Biofuel is the most popular choice among renewable energy sources. Improvement in combustion properties and reduction in greenhouse gas emissions are the most notable benefits of Biodiesel. Biodiesel is a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats. Theoretically, any vegetable oil or animal fat which essentially comprises triglycerides of long-chain saturated and unsaturated fatty acid can be developed as a biodiesel fuel.[1]

Biodiesel needs very few or no modifications to be used in diesel engines. Methyl ester of vegetable oils is more acceptable substitutes for diesel fuel as compared to raw vegetable oils. High fuel viscosity is the major problem associated with the use of straight vegetable oil as compared to that of diesel. The most common diesel fuel blends are B10 containing 10% biodiesel and B20 containing 20% biodiesel. Unburnt hydrocarbons, carbon monoxide, and particulate matter reduce with the combustion of Biodiesel, but NOX emission of Biodiesel increases. Brake specific energy consumption was better at lower loads, and it was much closer with diesel at higher engine loads.[2]

Some disadvantages are also associated with biodiesel fuels namely poor storage stability and cold flow properties, inferior spray characteristics and lower heat content. These shortcomings can be overcome by the transesterification process of vegetable oil. NOX emission increases with the use of biodiesel. Soot emission decreases with biodiesel fuels. It is due to the absence of sulphur and aromatics and the presence of fuel-bound oxygen.[3]

In India, there is plenty of forests and trees available as non-edible vegetable oil sources for biodiesel. Despite that plenty of oilseeds remain unutilized or underutilized for biodiesel production. Hence in this paper with the context of India, three biodiesels are considered for review viz. Thumba, Jatropha and Ambadi.

Thumba

Thumba (Citrullus colocynthis), generally known as the colocynth, identified with watermelon, is an individual from the Cucurbitaceous family. Oil of Thumba is non-palatable vegetable oil and it is generally found in western Rajasthan and Gujarat. The seeds of Thumba contain 20-30% oil in it. *Citrullus colocynthis* is known as Bitter apple in English and Indrayan in Hindi. In summer when there is a very high scarcity of regular fodder crops, this plant leaf may be used as fodder. The average yield of Thumba is about 2500–3500 kg of seeds per hectare. Deoiled cake has great importance in the organic fertilizer industry. Presently oil which is extracted is consumed by saponification industries.

It developed wild in the warm, bone-dry and sandy parts all through India. It is almost inexhaustible in north-western fields of India, particularly in the Barmer, Bikaner, Jaisalmer and Jodhpur locale of Rajasthan, and in Gujarat. It can flourish with sandy topsoil, sub desert soils, and along sandy ocean coasts. The precipitation required for its growth is 250–1500 mm annually and temperature requirement is around 14.8–27.8°C. It can grow up to 1500 m. above sea level with the soil of pH between 5 and 7.8. This plant can grow without any special care and it can grow parallel with other crops. The crop cycle for this plant is of 6 months.

Pawar Komal D et al. observed in their work that there was a problem while preparing biodiesel is its by-product-Glycerine.[4] Biodiesel contains about 20% Glycerine. So they reduced this by-product Glycerine and achieved zero effluent discharge biodiesel. They selected Thumba for producing biodiesel with zero effluent discharge.

They concluded that most acceptable reaction pathways to produce biodiesel are Transesterification reactions. Transesterification process can convert any type of feedstock that contains free fatty acids or triglycerides such as vegetable oils, waste oils, animal fats, and waste greases into biodiesel. Thumba vegetable oils can be converted into biodiesel more effectively; efficiently and economically by esterification process. Thumba biodiesel possesses very close properties to mineral diesel. Hence, Thumba biodiesel becomes a strong replacement or substitution of the diesel in compression ignition engines. Thumba biodiesel produced with zero effluent in turns increase the efficiency.

Chavan SB et al. found Thumba oil as a best raw material for biodiesel production. It is a climber and grows in the wild in western part of Rajasthan. They collected the seeds for oil extraction and then proceed for biodiesel production.[5]

They concluded that for transesterification of Thumba oil, KOH can be used as an alkaline catalyst. KOH is easy to remove and its waste stream will be utilized as a fertilizer. The highest yield of TME is achieved at 1:8 molar ratio, 0.75% catalyst (KOH) concentration with 65°C reaction temperature for 90 minutes reaction time. Viscosity, density, cloud point, pour point, etc. like physical properties were slightly higher than fossil fuel. Fuel is safer in transport, storage and in handling as flash point and fire point was too higher. The fuel has a lower calorific value than that of fossil fuel. But all these properties match with properties that mentioned in ASTM 6751 standards. The cloud point of TME is much lower than JME, KME and CME ester. With an increase in blend ratio with fossil fuel density, viscosity, cloud and pour point can be further reduced. Therefore, considering the above conclusions TME can be used directly or with the blends in CI engine.

Mohammed Sabir Usta et al. carried out a transesterification process with an excess of methanol and KOH catalyst in small batches in their study and optimized the biodiesel production from Thumba oil.[6] They analysed and optimized the effect of different parameters like temperature, stirring speed, molar ratio, KOH concentration, time of the transesterification process concerning the percentage of yields through the graphs and charts. From their extensive experimental results, it is found that the maximum yield of thumba methyl ester is obtained at 6:1 molar ratio, 0.75% of KOH at 65°C temperature with 250 rpm and 70 minutes of reaction time.

Abhijeet D Patil et al. applied the Thumba oil (*Citrullus colocynthis*) for biodiesel production using the conventional stirring method and ultrasonic cavitation method.[7] The use of Thumba oil as a feedstock for biodiesel production was explored by an experimental investigation. In the transesterification reaction, the type of catalyst employed and orders concerning individual reactants play a vital role. Their study claims that for the transesterification of Thumba oil with methanol, the acidic ion exchange resin catalyst (Amberlyst 15) can be effectively used. The yield of FAME was higher than 85% after the equilibrium of the reaction. The conversion of triglycerides and yield of biodiesel slightly decreases as the temperature of the reaction mixture increases more than boiling point of methanol. The combination of the optimized parameter for transesterification reaction was found to be 1:6 M ratio of oil to methanol, 1.2% Amberlyst (w/w) catalyst concentration, 65°C reaction temperature. Due to shorter reaction period for 40 min and high yield of biodiesel up to 90% ultrasonic cavitation method was found to be an effective method as compared to the conventional stirring method. The catalyst is surrounded by triglycerides and the reaction occurs at catalyst's surface and the methanol has to reach the surface affecting the concentration of triglycerides. Hence, the nature of the catalyst and individual concentration of reactants decides the rate of transesterification reaction. From physiochemical characterization, biodiesel obtained from thumba oil has very close fuel properties to conventional diesel. As a fuel, the thumba methyl ester was found to be safer to use. The reaction is zero-order concerning triglycerides and second-order concerning methanol and rate constant is 0.1358 lit mol-1 min-1 for conventional stirring method. The mild operating conditions and higher conversions of triglycerides using these effective techniques make them viable for the industrial sector.

Praveen A Harari et al. found in their review that Thumba biodiesel satisfies the important fuel properties as per ASTM specification of biodiesel.[8] Engine works smoothly on thumba methyl ester with performance compared to diesel operation. The thumba biodiesel can be successfully substituted as alternative fuel for CI engine.

YB Mathur et al. explored the possibility and potentiality of low concentration thumba oil diesel blends as substitute fuel for compression ignition engines.[9] In their investigation, it was found that in comparison to other blends of thumba oil diesel blends, the 20% blend of thumba oil in diesel developed highest brake thermal efficiency with lowest brake specific fuel consumption. For this blend the exhaust emission levels of NOX, hydrocarbons, smoke and carbon monoxide found lowest. Therefore, 20% thumba oil in the fuel blend found as optimum blend and may be used in diesel engines without any harmful effect. Blends of 10% and 30% thumba oil in diesel also showed satisfactory performance and emission characteristics, and without any major modifications can also be used in compression ignition engines. For 50% thumba diesel blend some operational problems were observed like carbon deposits on piston, coking of injectors and cylinder walls, valves and piston sticking, etc. After extended engine operation slight gum formation around valves and injectors were also noticed. By modifying the maintenance schedule of engine and regular cleaning of injectors, the problems transpire during engine tests can be reduced to some extent.

Sunilkumar R Kumbhar et al. carried out experiments by using dual biodiesel blends and compared it with diesel fuel characteristics.[10] The performance tests were carried out with diesel, and blends of thumba biodiesel at different compression ratios. Thumba biodiesel blends are found to be a promising alternative fuel for compression ignition engines. At compression ratio 18, brake power of thumba B40 and brake thermal efficiency and brake specific fuel consumption of thumba B10, B20 showed optimum performance. The exhaust emissions such as CO_2, CO and HC of B100 of thumba biodiesel showed less emission percentage/ppm, and for NOX emissions of B10 and B20 of thumba biodiesel showed less emission ppm. The performance of all blends of thumba biodiesel increases with compression ratios and load. All blends of thumba biodiesel showed better performance at CR 18 than other compression ratios. Thumba biodiesel can be substituted for existing diesel in CI engine without any major modifications that are established from engine test results.

Manish Jain et al. made the performance and emissions analysis of the non-edible vegetable oil thumba and its blends with diesel fuel performed on a CI engine.[11] Thumba seeds biodiesel and its blends were tested on a 3.5 kW single-cylinder four-stroke engine and also compared with conventional fossils diesel fuel. The fuel properties of the thumba biodiesel were found similar to the diesel fuel. The thumba biodiesel produced much lesser emissions than that of diesel. With the increase in the percentage of biodiesel, the calorific value of the blends decreases, which affects the performance of high percentage blends. The performance parameter like brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, torque has a similar result at a wide range of power output. Due to complete combustion of the fuel, the smoke emissions of biodiesel blends are much lesser as compare to diesel.

The thumba oil as biodiesel has a great potential to replace conventional diesel fuel at an optimum level. Thumba biodiesel may be the best alternative fuel for the future in India.

S Sreenatha Reddy presented the results of investigations carried out on a single-cylinder, direct injection diesel engine operating on diesel, straight Thumba oil and their blends of 20%, 40% and 100% with diesel.[12] Their investigation concluded that thumba oil can be used as an alternative fuel with higher performance and reduced emissions. They found that the 20% thumba diesel blend produces maximum brake power and reduced BSFC, emissions and smoke density. When compared with diesel and other blends the emissions of straight thumba oil were increasing. For blendsBSFC reduced but slightly increased in case of straight thumba oil. When compared to other blends the straight thumba oil was left unburnt, which increased the emissions like CO, NOx and smoke density. It is due to improper combustion of straight thumba oil than that of blends.

Akash Sase et al. conducted experimental work to obtain the performance and emission characteristics of thumba oil biodiesel on variable compression ratio engine run on various blends of biodiesel, compression ratios and load conditions.[13] Result of work shows that the engine performance is improved with a significant reduction in emissions and without any engine modification.

Brake power obtained is better with biodiesel blends of B50 at all CR. Therefore, B50% can be used as alternate fuel than diesel for better brake power and compression ratio 18 as optimum compression ratio.

At all CR, brake thermal efficiency obtained is better with biodiesel blends of B25%. Hence, B25 is suggested as an alternate fuel to diesel for better brake thermal efficiency and compression ratio 18 as optimum compression ratio.

The biodiesel blends of B70% gave lesser brake specific fuel consumption at all CR. As compared to diesel, the lower calorific value of biodiesel and less power generated for the same fuel consumption are the reasons behind this.

Superior CO emission characteristics are obtained with biodiesel blends of B10% at all CR. This is due to relatively complete combustion takes place at a higher compression ratio.

Lesser HC emission characteristics are obtained with biodiesel blends of B70% at all CR. Lesser CO_2 emission characteristics are obtained with biodiesel blends of B20% at all CR. This is because the vegetable 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.

Lesser O_2 emission characteristics are obtained with biodiesel blends of B50% at all CR. At higher compression ratio due to complete combustion, mainly CO_2 requires the oxygen. At lower compression ratio in addition to CO_2, the formation of CO and NOX also requires oxygen; hence oxygen percentage in the exhaust is decreased.

Lesser NOx emission characteristics are obtained with biodiesel blends of B70% at all CR. This is due to the highest temperature is observed at this compression ratio. But the expected was, highest NOx emission obtained at the highest compression ratio as the higher peak temperature observed with a higher compression ratio.

Bhanu Pratap et al. for analysing the performance and emission characteristics of an engine used full factorial design using Design Expert.[14] The VCR engine is fuelled with diesel in the first stage at different engine load and compression ratio. In the next stage, different fuel blends of thumba oil are used with engine load at 18 CR (optimum set from the first stage). In the third stage, B20 blend at different engine load and the compression ratio was analysed. Therefore, using full factorial design three-stage optimization was carried out. To check the significance of the predicted model for BTE and BSFC in the first stage and BTE and BSFC along with HC, NOx, and CO emissions in the second and third stage, ANOVA analysis was performed. To check the validity of optimum results, an optimum set of engine load and the compression ratio was identified, and confirmation tests were carried out. The fitted values were found very near to the experimental values for all models. For all performance and emission parameters, the average error was found within the acceptable limits. The analysis shows that at the load 10 kg the optimum values of BTE, BSFC, HC, CO and NOx was 19.725%, 0.456 kg/kWh, 38.432 ppm, 0.026% and 348.744 ppm respectively, CR of 18, and blend percentage of 20. Results obtained from the optimization are consistent hence full factorial design with the help of Design Expert can be used to find the optimal set of engine input parameters and can optimize the performance characteristics & emissions of the engine.

Narayan Lal Jain et al. used thumba oil which is non-edible vegetable oil, having high viscosity and low volatility as a fuel in CI engine.[15] They used waste heat of engine's exhaust gases for preheating the Thumba oil to reduce the viscosity along with blending with diesel fuel. To obtain performance and emission characteristics with a various blend ratio of heated and unheated thumba oil with diesel the experiment was conducted with a single-cylinder diesel engine.

It was observed that heating of thumba oil up to 80–100°C is sufficient to bring the viscosity nearer to diesel. Among all the preheated thumba blends the highest thermal efficiency and lowest brake specific fuel consumption were found for preheated B20 thumba blend. Among all the preheated thumba blends least emissions were found for preheated B20 thumba blend. Preheated thumba B20 blend was found an optimized blend as it gave better results than other blends. Thermal efficiency is 1.27% (25.93%) higher and brakes specific fuel consumption is 0.02 kg/kWh (0.33 kg/kWh) lesser for the preheated thumba B20 blend than the unheated same blend. Emission characteristics for preheated thumba B20 blend were also better as it emits 2.6% less smoke, 0.02% less smoke, 5PPM less HC, 0.08% higher CO2 and 11 PPM higher NOX as compared to unheated same blend. Preheated thumba B20 blend gives very close thermal efficiency, 0.067% lesser to diesel fuel (26.6%) but emits 5.6% lesser smoke, 0.01% lesser CO, 9 ppm lesser HC, 0.22% lesser CO_2, and 16 ppm lesser NOx. Performance and emission characteristics are poorer if thumba oil used directly as straight vegetable oil with preheating. Good results were obtained by a combination of blending and preheating of thumba oil. Hence, combined preheating and blending is the best technique for using vegetable thumba oil as fuel for CI engine in the rural area for agriculture, irrigation, power generation. Cost of per litre thumba oil production is lower than the current price of mineral diesel in India and the net cost of B10 and B20 thumba blends are also lesser per litre present diesel price.

Shashi Kumar et al. in their work used preheated Thumba oil for blending with diesel to run a single cylinder CI engine.[16] Viscosity decreases by preheating of oil which results in better atomization and combustion of fuel. By blending the fuel, the performance is further improved and emissions are also found lesser as compared to pure diesel.

The brake thermal efficiency of B20 was more than diesel and other concentration blends but brake specific fuel consumption of preheated thumba oil was more than diesel. For B20 blend exhaust gas temperature and smoke opacity were also much less. Experimental results revealed that 20% concentration of thumba oil in diesel is more suitable fuel. Along with the increase in the efficiency of the engine, it also reduces the emissions.

Rajesh Govindan et al. made a CFD analysis of biodiesel fuel combustion using ANSYS FLUENT R14.5 software to study the effect of blending ratio on the combustion characteristics in compression ignition (CI) engine.[17] Along with these parameters such as in-cylinder pressure, temperature, and heat release rate etc. were also determined. They took pure diesel, 10%, 20% and 30% blending of thumba oil with pure diesel as fuel for this study.

Similar combustion stages for both diesel and thumba biodiesel blends were found on the basis of the analysis of in-cylinder pressure-crank angle history and heat release analysis. Also, no objectionable combustion feature such as knocking was observed. As compared to diesel during premixed combustion phase thumba biodiesel blends had lower heat release rate. The peak of heat release rate for diesel during premixed stage is about 35.03 % and during mixing stage is about 1.09% higher compared to B20. As compared to pure diesel the heat release for thumba biodiesel always starts nearly 2º to 3º crank angle earlier. Higher in-cylinder pressure and temperature for the thumba biodiesel blends is predicted during combustion as compared to pure diesel. The peak in cylinder pressure for D100, B10, B20 and B30 is 61.94 bar, 63.46 bar, 63.61 bar and 64.13 bar respectively. The peak in-cylinder pressure increases with the increase in blending ratio. The peak pressure for B30 is nearly 1.05% higher than B10. For both diesel and thumba biodiesel blends stable and smoother engine operation was observed.

Jatropha

Jatropha curcas is a large shrub or tree native to the American tropics. It is commonly found and utilized throughout most of the tropical and subtropical regions of the world. This plant grows in the tropical and subtropical region and also in sandy and saline soils. The seeds of Jatropha contain oil from 30–50% by weight, and the kernel contents range from 45–60%. The seed production under cultivation is about 1.5–2.5 tonne per hectare, which corresponds to oil yields of 500–720 litre per hectare. Indian government started biodiesel from Jatropha as it is rich in oil content (approx. 66.4%) and it grows in non-agricultural lands. Due to the presence of the toxic phorbol esters, it is non-edible. It is a drought and pest resistant perennial tree, cultivated in Central and South America, South-east Asia, India and Africa. It has some desirable properties namely low acidity, good stability than soybean oil, low viscosity as compared to castor oil and better cold properties as compared to palm oil. As compared to diesel, the density, flash and fire points of Jatropha oil are higher. JOME has been accepted and recommended by National Biodiesel board of India as an alternate fuel for blending with commercial diesel.

K. Pramanik in his investigation decreased the high viscosity of the *Jatropha curcas* oil by blending with diesel[18]. The various blends of *Jatropha curcas* oil and diesel were prepared, analyzed and compared with diesel fuel. His study also includes the effect of temperature on the viscosity of biodiesel jatropha oil. Engine performance was significantly improved as compared to vegetable oil alone. Due to the decrease in viscosity of the vegetable oil the specific fuel consumption and the exhaust gas temperature were reduced. With blends containing up to 50% volume of jatropha oil acceptable thermal efficiencies of the engine were obtained. It is observed from the results that 40–50% of jatropha oil can be substituted for diesel without any engine modification and preheating of the blends.

The viscosity of 30% blend of jatropha oil has values close to that of diesel fuel. The viscosity of 40%blend of vegetable oil has a slightly higher than that of diesel. By heating the blends, the viscosity was further reduced. For the blends containing up to 50%, jatropha oil acceptable brake thermal efficiencies and SFCs were achieved. Slightly higher exhaust gas temperatures were recorded for the blends with a lower percentage of vegetable oils compared to diesel but they were much lower than the jatropha oil in all cases. Hence, up to 50% of jatropha oil can be used in place of diesel for use in a C.I. engine without any engine modification. With pre-treatment of the oil, the properties of the blends are further improved so that a higher percentage of jatropha oil in the blend can be used in the CI engines.

G. H. Kawade et al. investigates the properties of jatropha biodiesel fuel with their different percentage of blending with diesel fuel and is compared with diesel fuel.[19] Single-cylinder four-stroke compression ignition engine was used for experimenting. JBD10%, JBD20%, JBD30%, JBD40% and JBD50% blends were used for testing and loads applied for testing were 0%, 10%, 20%, 30%, 40%, 60%, 80% and 100%.

By mixing vegetable oil with diesel in varying proportions considerable reduction in viscosity was achieved. The brake power obtained remains throughout the same for all blending and diesel fuel. Thermal efficiency for 20% blending of jatropha biodiesel found superior as compared to another blending of fuel. BSFC decreases with the increase in blending concerning load and its same about for diesel fuel. The exhaust temperature of the gases increased with the increase in the percentage of blending. For the blends containing up to 40%, jatropha oil acceptable brake thermal efficiencies and SFCs were achieved. With pre-treatment of the oil, the properties of the blends are further improved so that a higher percentage of jatropha oil in the blend can be used in the CI engines.

In the work by M. Senthil Kumar et al. various methods of using vegetable oil (Jatropha oil) and methanol such as blending, transesterification and dual-fuel operation were studied experimentally.[20] Experiments were conducted on single-cylinder direct injection diesel engine running at constant 1500 rpm and varying power outputs. Methanol to jatropha oil ratio in dual-fuel operation was maintained at 3:7 on the volume basis. This ratio is very near to the fraction of methanol used to prepare the ester with jatropha oil. The brake thermal efficiency was found better in dual-fuel operation (28.7%) and with the methyl esters (29%) as compared to neat jatropha (27.4%). The smoke was lesser with all methods when compared to neat vegetable oil. The values of smoke emission are 4.4 Bosch Smoke Units (BSU) with neat jatropha oil, 4:1 BSU with the blend, 4 BSU with methyl ester of jatropha oil and 3:5 BSU in the dual-fuel operation.

As compared to diesel, the Nitric Oxide (NO) level was lower with jatropha oil. With the dual-fuel operation and the blend with methanol, it reduced further. Hydrocarbon (HC) and carbon monoxide (CO) emissions in Dual-fuel operation remained higher than the ester and the blend.

Ignition delay observed higher with neat jatropha oil which increased further with the blend and in dual-fuel operation but reduced with the ester. Peak pressure and rate of pressure rise were recorded higher in all the methods compared to neat jatropha oil operation. As compared to diesel, jatropha oil and methyl ester showed higher diffusion combustion. Dual fuel operation resulted in higher premixed combustion.

The overall conclusion of their experiment is that jatropha oil can be used as fuel in diesel engines directly and by blending it with methanol. Better performance and reduced smoke emissions can be achieved by using methyl ester of jatropha oil and dual fuel operation with methanol induction. The dual-fuel operation showed the lowest smoke and NO levels but there is an increase in HC and CO emissions.

In the research by Deepak Agarwal et al., experiments were designed to study the effect of reducing jatropha oil's viscosity by increasing the fuel temperature using waste heat of the exhaust gases.[21] Blends of jatropha oil with mineral diesel were also tested to study the effect of reduced blend viscosity on emissions and performance of diesel engine. Diesel and jatropha oil were characterized for their various physical, chemical and thermal properties. To bring down the viscosity in close range to diesel it was observed that heating the Jatropha oil between 90°C and 100°C is sufficient. Jatropha blends 30% possess viscosity near to diesel. For diesel and preheated jatropha oil, optimum fuel injection pressure was found to be 200 bar.

At different loads and constant speed of 1500 rpm, the performance and emissions tests were conducted with diesel, preheated Jatropha oil, unheated jatropha oil and blends of jatropha oil. Jatropha oil is found to be a promising alternative fuel for compression ignition engines from the experimental results obtained. Jatropha oil can be directly used as straight vegetable oil as a replacement of diesel fuel and it does not require any major alteration in the engine. As compared to diesel and heated jatropha oil, BSFC and exhaust gas temperatures for unheated Jatropha oil were found to be higher whereas thermal efficiency was found lower for unheated Jatropha oil as compared to heated jatropha oil and diesel. With comparison to that of diesel CO_2, CO, HC, and smoke opacity were found higher for Jatropha oil whereas these emissions were found to be close to diesel for preheated Jatropha oil.

BSFC and exhaust gas temperature were found higher for Jatropha oil blends compared to diesel whereas thermal efficiency was found to be closer to diesel. Smoke opacity, CO_2, CO, and HC were found to have increased with an increasing proportion of Jatropha oil in the blends compared to diesel.

Polu Vidya Sagar et al. found that Biodiesel is alternative diesel fuel and is widely used in CI engines to reduce exhaust gas emissions which in turn helps in the reduction of environmental degradation.[22] When compared to diesel engines Biodiesel usage results in higher NOx emissions. By using Exhaust Gas Recirculation (EGR) they reduce the NOx emissions. For different Biodiesel blends and neat Diesel various engine performance parameters are carried out and analyzed. With the help of EGR, they observed a reduction in NOx emissions with little reduction in power output.

It was observed that NOx emissions were reduced by 30% at 10% EGR compared to that of neat diesel. It is due to lower flame temperatures and reduced oxygen availability. Using EGR brake thermal efficiency increased at lower loads due to re-burning of recirculated gases but it decreases, at higher loads. For better brake thermal efficiency values, it was found that 10% EGR is optimum. By using EGR, HC and CO emissions were found reduced while smoke capacity emissions were increased. Specific fuel consumption was higher with biodiesel regardless of EGR because the calorific value of biodiesel is lower and viscosity is higher.

Ekanath R. Deore et al. conducted research to blend Jatropha and Karanja biodiesel and testing these fuels for a diesel engine.[23] They varied the percentage of Karanja in Jatropha fuel. Their research shows deteriorated energy performance but emission performance was improved.

A single-cylinder diesel engine was used for testing with compression ratio 16 and injection timing maintained to be constant at 23° BTDC. For pure biodiesel and its blend ignition delay was observed to be low compared with diesel fuel. Hence the heat release rate was higher for diesel fuel compared with other fuels. Peak pressure for biodiesel blend was observed at 11-13 ATDC. Due to loss of heating value of the biofuel and its high viscosity reduction in power output was observed. Reduction in power loss for K20J80 fuel was 2% less compared with other blends. BSFC was higher for K20J80 fuel compared with Jatropha biodiesel by about 6–10% for the entire range of load. For K50J50 fuel BSFC was observed to be decreased by 10–15%. The main cause of a decrease in brake thermal efficiency was higher BSFC for pure biodiesel. K20J80 fuel can be said to be an optimum blend since power loss was only 2% and BTE was higher than diesel by 5-10% and higher than Karanja by 6–12%.

HC and NOx emission shows a great reduction. Compared with pure biodiesel and petro-diesel the HC emission was ZERO for the blends of two kinds of biodiesel.

Pankaj Dubey et al. investigates the behaviour of the combination of Jatropha biodiesel and turpentine oil in a diesel engine.[24] Jatropha biodiesel and turpentine oil form a high and low viscosity fuel combination. Calorific values of these fuels are comparable to that of diesel hence this combination may suit the diesel engine. To examine combustion performance and emission characteristics using Jatropha methyl ester with turpentine oil blends (dual fuel blends) and conventional diesel experimental work is carried out on a Kirloskar make, the single-cylinder, naturally aspired diesel engine. From performance and emissions point of view, dual fuel blends are found to be the best substitute for conventional diesel fuel. At full load condition, BT 50 resulted in a reduction of 2.9%, 4.72%, 4.56%, 42.5% and 29.16% in the brake thermal efficiency, NOx, HC, CO and smoke respectively. CO2 emissions increase by 10.7%.

A. Rehman et al. checked the possibility of using biodiesel in IS/60 Rovers gas turbine. A dynamometer was used for loading the turbine and emission was recorded by AVL gas analyser.[25] Their study observed Jatropha oil having characteristics properties very close to diesel oil but viscosity is higher which they reduced by degumming/esterification of Jatropha oil. They observed that the esterified Jatropha oil is miscible with diesel fuel in any proportion and can be used as biodiesel blended fuel for gas turbine application. Specific gravity was also reduced from 0.917–0.881 at 15°C. Jatropha oil is found to be inferior in calorific value in the range by 7–9%. It may be due to the difference in chemical composition and the difference of carbon-hydrogen content. Initially, the fuel consumption of various blends was found higher at lower loads due to low volatility, higher specific gravity and high viscosity but it gradually improves as the combustion proceed due to decrease in viscosity. Carbon monoxide and Hydrocarbon emissions reduced as compared to diesel. This may be because biodiesel blends are rich in oxygen which causes to better combustion. NOx emissions are higher than diesel due to better combustion resulting in higher cycle temperature and NOx emissions are temperature dependant. These results suggest that jatropha can be one of the alternate fuels for gas turbine.

S. Imtenan et al. conducted an investigation for the improvement of jatropha biodiesel–diesel blend by adding oxygenated cold starting additive i.e. 5–10% n-butanol and diethyl ether by volume.[26] They utilised a 4-cylinder turbocharged indirect injection diesel engine running at speed from 1000–3000 rpm maintained at constant torque of 80 Nm. For the modified blends, performance and emission characteristics were compared with Jatropha-diesel blend. At different operating conditions, cylinder pressure diagram and heat release analysis were conducted. This helps in exploring the features of combustion mechanism and correlate them with the performance and emission characteristics.

The viscosity of the diesel–biodiesel blend reduced with the addition of n-butanol and DEE. A marginal reduction in calorific value of modified blends was seen with the addition of n-butanol and DEE.

Due to higher cetane number, in-cylinder pressure developed with J20 was higher than diesel but the addition of n-butanol and DEE reduced the pressure. It is due to retarded SOC and higher latent heat of evaporation of the additives. 10% of additive blends produced better effects than 5% additive blends. For the additives, HRR during the premixed part of the combustion was decreased but, in the diffusion-controlled zone, HRR was better for the modified blends compared to J20.

Due to lower calorific value and inferior atomization quality, J20 showed higher BSFC than diesel. But the addition of 10% n-butanol blend showed decreased BSFC than J20. It was because of higher combustion efficiency due to higher oxygen content, lower density and viscosity of n-butanol. 10% DEE blend showed further decrement of BSFC than J20. DEE performed better than n-butanol.

NO emission for J20 was higher than diesel. Due to higher oxygen content, 5% n-butanol and DEE blends showed slightly higher NO emission than J20. But 10% blend of both of them reduced NO emission due to comparatively lower temperature environment during combustion. CO emission reduced further by adding n-butanol and DEE as compared to J20. Results are better with n-butanol than DEE. 10% n-butanol and DEE blends reduced the smoke opacity considerably than J20. Sufficient oxygen remains always available for the oxidation of soot in the n-butanol and DEE blends. HC emission increased for the modified blends due to slip of fuel out of the combustion chamber for the evaporative nature of n-butanol and DEE.

Therefore, regarding performance and emission characteristics, 10% blends of n-butanol and DEE showed a higher improvement than 5% blends.

Felix Sebastian Hirner et al. investigates the influence of waste-cooking-oil (WCO), jatropha-oil, and Karanja-oil derived biodiesels on combustion and emission characteristics in a single-cylinder diesel engine.[27] The testing parameters were speed of 1200 rpm, an indicated mean effective pressure of 0.5 MPa and the fuel injection pressures (FIPs) of 40, 80, and 120 MPa. The fuel injection timing was varied from -15 crank angle degrees after a top dead centre to -3 CAD a TDC.

FIP and the cetane number governed the ignition delay. The cetane number is always in the same order as the heat release and in-cylinder pressure curves. For higher FIPs, the difference in heat release and in-cylinder pressure curves becomes prominent. As compared to diesel and WCO biodiesel, at 120 MPa FIP, Jatropha and Karanja biodiesels showed an approx. 0.6 CAD earlier start of combustion.

A clear split up in trend between the lower viscosity fuels with lower cetane number (diesel and WCO biodiesel) were seen at higher FIPs (80 and 120 MPa). Similarly, for higher viscosity fuels with and higher cetane number (Jatropha and Karanja biodiesels) split up in trend was observed at higher FIPs.

In general NOx emissions were lesser for biodiesels especially for advanced injection timings and low FIPs situations. It is due to the lower in-cylinder temperature and a higher degree of incomplete combustion as shown in HC, CO and smoke emission trend.

Smoke emissions marginally decreased with increasing FIP and it did not depend on the injection timings for diesel. With all types of biodiesels, smoke emissions were higher and it decreased as the fuel injection timings were retarded.

Ambadi

A rain fed wasteland evergreen edible oil and vegetable plant, ***Hibiscus Cannabinus*** *L.* is commonly known as 'kenaf' or 'Phundi' in kannada or **'Ambadi'** in hindi. Ambadi belong to *Malvaceae* family. The origin of ambadi is from Africa, and it is found that the diversified forms of the ambadi and its related species in the Hibiscus species, including ***Roselle (Hibiscus Sabdariffa L.)*** are found growing widely in many countries of eastern Africa and now in India. Ambadi is extensively used in fibre making and nowadays the seed oil also used in biodiesel production.

The seeds are tetrahedral in shape. Hibiscus Cannabinus seeds are greyish or dull green in appearance and Hibiscus Sabdariffa plant seeds are brown or pink. The seeds of two plants contain a capsule with 20–25 seeds. The seeds have good storage stability and with strongly adherent seed coat difficult to separate from kernel. The seed is flaked, cooked by steam and the oil is obtained by the process of expression. Hibiscus Cannabinus and Hibiscus Sabdariffa seeds yield a vegetable oil that is edible with no toxins.

Plants are grown well in poor soil and can be grown on waste land as these plants do not require any nutritional requirement. Within 3–4 months, about 300–400 kg of seeds is produced per acre if sown whole land. Seed yield mainly depend on the soil and climatic condition of the area. It is estimated that with about 400 grown up Hibiscus Cannabinus and Hibiscus Sabdariffa plant on a hectare of waste land with an average yield of 15 kg seeds per plant, the yield can go up to 6000–7000 kg seeds every year.

K. Surendra Babu et al. found the interest in using Hibiscus species (Hibiscus cannabinus and Hibiscus sabdariffa) as feedstocks for the production of biodiesel.[28] They blend the Hibiscus cannabinus and Hibiscus sabdariffa biodiesel with diesel in different percentages. While operating a single cylinder diesel engine following conclusion were made.

With Hibiscus oil used as fuel, same brake thermal efficiency for maximum load was obtained. Similarly, specific fuel consumption for maximum loads same for other loads. CO and CO_2 emission were found relatively lower than diesel but smoke opacity was found higher than diesel. NO_x emission was found lower than diesel.

Rashmi Gadwal et al. shows that Hibiscus cannabinus and Hibiscus sabdariffa species plants can be used for biodiesel production.[29] Their seeds contain 21–25% oil and their physical and chemical properties are very close to fossil diesel. They converted the crude hemp and roselle seed oil into biodiesel by alkali catalyzed transesterification with methanol in the presence of a catalyst (NaOH) and used it into a single cylinder four stroke water-cooled compression ignition engine. Different percentage of Hibiscus cannabinus and Hibiscus sabdariffa biodiesel blended with diesel were evaluated at variable loads at constant speed and results were finally compared with the diesel.

The study revealed better results and which were confirming ASTM standard and all the variables in this study clearly influenced the alkali-catalyzed transesterification in a positive manner.

In order to preserve the biodiversity, oil crops which are available locally need to be identified and evaluated for its biodiesel potential. Jindal S et al. explored Hibiscus cannabinus (Ambadi) as alternative fuel in diesel engines.[30] The properties of its methyl ester (biodiesel) were found well within the range prescribed by ASTM. When compared to diesel on volume basis this biodiesel found to possess 8% lesser heat content. Its thermal efficiency and specific fuel consumption improved when used with 20% blend (B20). With the biodiesel blends combustion regimes were also seen improved. By using lower blends of this biodiesel, the emission advantage can also be harnessed. The unburnt hydrocarbons and smoke reduce to a great extent with the use of 20% AME in diesel,

Abhishek Sahu et al. investigates the reliability of using easily available edible vegetable seed oil roselle oil to produce biodiesel.[31] By the base catalyst transesterification process the oil was converted to biodiesel. The physical and chemical properties of roselle oil and biodiesel were found very close to diesel. For enhancing the combustion quality oxygenate additive Methanol and Ethanol were used.

Roselle oil showed good conversion rate to biodiesels with about 30–35% of ‘oil value’. From one litre of Roselle seed-based vegetable oil approximately 700 ml of bio fuels can be obtained apart from glycerine. When mixed 5% of Methanol or Ethanol with Diesel, the performance of a diesel engine could be increased, especially in the high load conditions.

When diesel fuel compared with its various blends, blend consisting 5% Methanol, 5% Roselle biodiesel and 90% Diesel showed better performance than other blends. This blend has the least Brake Specific Fuel Consumption, Brake Specific Energy Consumption and highest Brake Power, Brake Thermal Efficiency among all.

Similarly, among ethanol blends, blend consisting 5% Ethanol, 30% Roselle biodiesel and 65% Diesel has least Brake Specific Energy Consumption, highest Brake Power and highest Brake Thermal Efficiency when load was increases but pure Diesel shows better Brake Specific Fuel Consumption than other blends.

Ravindra Kumar Yadav et al. in their investigation, used mixture of four types of biodiesels produced from *Jatropha curcus*, *Pongamia pinnata*, *Hibiscus subdariffa* (lal ambari) and waste cooking oil.[32] These oils were mixed in equal proportions and then this mixture is blended with diesel in different proportions i.e. 10%, 20%, 30%, 40%, 50%, 75%, 100% of biodiesel.

20% blend of mixture of biodiesels in conventional diesel was found to be best performer. For all the blends of biodiesel tested on the engine up to 70–80% of full load, emissions of carbon monoxide and un-burnt hydrocarbon reduced as load increases and beyond that these emissions increases. As the engine load increases on the engine up to 80% of full load, nitrogen oxide emission increases. It is due to the presence of oxygen available in biodiesel.

From this investigation it was found that the blended fuel sample AJKWB10-30 can be used in diesel engine without any modification in engine hardware. It clearly shows that diesel engine can be operated with any kind of biodiesel, it is not necessary to depend on some particular type of biodiesel only.

Conclusion

Biodiesel is a renewable, biodegradable, non-toxic and environmentally friendly fuel. The results obtained from the above reviews confirm the potential of thumba, jatropa, and ambadi biodiesels and their blends have in reducing the overburdening imports of diesel fuel. Biodiesel acts like petroleum diesel, but produces less air pollution, comes from renewable sources, is biodegradable and is safer for the environment. Producing biodiesel fuels can help create local economic revitalization and local environmental benefits. The government may consider providing support to safe to handle, store and transport. Biodiesel derived from vegetable oils can be used in diesel engines with little or no modifications. Biodiesel emits lower CO, HC and PM than the diesel fuel. Though the biodiesel produces higher CO_2, it is considered as carbon-neutral to balance the CO_2.

Biodiesel has some drawbacks when compared to mineral diesel fuel such as undesirable properties at low temperatures, higher viscosity, higher brake specific fuel consumption, higher NOx emissions and slightly lower brake thermal efficiency. The higher specific fuel consumption and lower brake thermal efficiency are generally due to lower heating value and higher density the activities related to the collection of seeds, production of oil from non-edible sources, production of bio-fuels and its utilization for a cleaner environment.

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