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Exploration Of Mahua Oil (Madhucaindica Seed Oil) Biodiesel As A Fuel In Compression Ignition Engine: A Review

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Abstract

The aim of this paper is to study the literature on Mahua oil (MadhucaIndica seed oil) biodiesel fuel synthesis, performance, combustion, and emissions.This exploration is characterized by various researches carried out on Mahua oil biodiesel as substitute for diesel to operate the diesel engine. The world's need for oil and gas has increased rapidly of increased industrialization and modernization. This growth in the economy has led to a significant increase in energy consumption, with fossil fuels including coal, crude oil, and natural gas providing the majority of that energy. However, due to the short supply of fossil fuels, many researchers are looking for possible substitute fuels that may be made from sustainable sources.Biodiesel has gained popularity as a result of its environmental advantages and the fact that it is biodegradable.

In this article, an attempt has been made to review the research works on mahua oil biodiesel production, performance, and combustion and emission characteristics and additivesand modified operating parameterseffecting characteristics of the engine.

Keywords- Biodiesel, Mahua, Nano additives, Transesterification.

Nomenclature

ASTM	American society for testing and materials	NaOH	Sodium hydroxide
IC	Internal combustion	Al_2O_3	Aluminium oxide
DI	Direct injection	CeO_2	Cerium oxide
bTDC	Before Top Dead Centre	Fe_2O_3	Ferric oxide
CR	Compression ratio	SiO_2	Silicon dioxide
IT	Injection timing	BTE	Brake thermal efficiency
IP	Injection pressure	BSFC	Brake specific fuel consumption
HSD	High speed diesel	EGT	Exhaust gas temperature
MOME	Mahua oil methyl ester	HRR	Heat release rate

FFA	Free fatty acids	CO	Carbon monoxide
DEE	Di-ethyl ether	HC	Hydrocarbon
H_2SO_4	Sulphuric acid	NO_x	Nitric oxide
KOH	Potassium hydroxide	CO_2	Carbon dioxide

1. Introduction

In major parts of the world, fossil fuels including coal, crude oil and natural gas provide nearly all of the energy. Unfortunately, such nonrenewable resources will be depleted in coming years. As a result, the investigation of alternate clean and sustainable energy sources has received recognition, with the capacity to address many present social concerns, namely the hike in crude oil rates and ecological imbalance, including atmospheric adulteration and global warming due to fossil fuels combustion.

Over the last several years, population rise has resulted in a massive upsurge in energy consumption. Fortunately, projections of fossil fuel depletion continue to grow, due to advancements in drilling technology and the development of enormous volumes of shale gas (natural gas) deposits. As a result, despite the advancement of contemporary and sustainable resourcesin particular nuclear, solar, and wind energy, combustion technologies will remains to serve a significant role in the area of energy conversions [1]

Biodiesel fuels are getting popularand have been highly suggested as a feasible alternative to petroleum diesel. The National Soy Diesel Development Board, which initiated the commercialization of biodiesel in the USA, came up with the term "biodiesel" in 1992 in the USA. Biodiesel can be incorporated with petro diesel since its properties are analogous and it emits fewer harmful pollutants.One of the better alternatives is biodiesel. It's produced from sunflower, palm, cottonseed, rapeseed, soybean, and peanut oils, among other oilseed crops [2-3]. Due to food supply disruptions in certain places, such as India, it might be difficult to implement edible as a biofuel. Non-edible oils have increased in popularity as a result of their ineffective on the food chain, as well as the fact that they can be farmed even in drought-prone locations. Mahua oil,Calophyllum Inophyllum oil, Jatropha oil,Castor oil, Neem oil, and other non-edible oils may be made [4].

This article analyzes the production of biodiesel using non-edible Madhuca Indica seed oil as potential feedstock, as well as performance, combustion and emission characteristics with addition of nano additives, alcohols and modified operation conditions.

2. Biodiesel as an alternate fuel

Biodiesel has the possibility to be among the most effective substitutes. It is derived from the oils of a variety of oilseed plants, including sunflower, palm, cottonseed, rapeseed, soybean, and peanut.

Biodiesel has been used practically as long as the diesel engine altogether. Rudolf Diesel registered his engine in 1892, making it the first diesel engine which works on vegetable oil. He successfully operated the engine with peanut oil over many hours in 1900. In 1912, he anticipated that vegetable oil will one day be employed as a substitute, comparable to diesel [2].

2.1 Classification of biodiesel feedstock

Bio-diesel is one of the few types of alternative fuels available. Biodiesel is typically classed into three generations [5,6] shown in the Table.1.First generation biodiesels are made out of edible biofuels, namely rapeseed, soybean, coconut, corn, palm, mustard, olive, rice, and so on. At the beginning of the biodiesel phase, edible oils were extensively employed in the synthesis of biodiesel. Commodity supplies and the relatively simple conversion technique are the primary advantages of first generation fuel sources.Edible oils are derived from oilseed grains and plant fruits, and they have nutritional value and are consumed by humans. However, using these oils in IC engines can have a negative impact on the food chain, and they are expensive [7]. Second generation biodiesels are made out of vegetable oil or animal feed stocks,which are used to make non-edible oils.The concentration of toxic chemicals in the oilsextracted from such sources makes them unfit for human intake. These plants can be effectively grown in places unfavorable for agricultural crops even at a much cheaper cost than edible oil crops, and their development reduces atmospheric carbon dioxide levels. Moreover, the utilization of low-cost non-edible oils may help to enhance the economics of biodiesel preparation and commercial manufacturing on a large scale. However this requires more energy and much higher quantity of materials [8]. With a quick growth rate, ability to fix greenhouse gases and high lipid production capacity, microalgae are now being promoted as an attractive third generation biofuel feedstock (fat). They may also be cultivated on non-arable area and in salty water, and they do not conflict with food or feed crops. Microalgae areemployed to produce a variety of sustainable biofuels. Methane, biodiesel, and bio-hydrogen are examples of these. There are several benefits to manufacturing biofuel from algae, since it can generate 15-300 times more biodiesel per acre than typical crops. Furthermore, high-quality farm production is not needed for the production of microalgae biomass [9].

Generation of biodiesel	Biodiesel feedstock	Advantages	Disadvantages
First generation biodiesels	rapeseed, soybean, coconut, corn, palm, mustard, olive, rice etc.	• Availability of crops • Relatively simple conversion technique	• limitation in food supply • relatively high price

Second generation biodiesels	Mahua, Jatropha, Calophylluminophyllum, Castor, Neem etc.	• No impact on the food chain • Grow even in drought-prone regions	• Additional alcohol required • Relatively low yield • Requires more energy and materials
Third generation biodiesels	Micro algae, Waste cooking oil, Tallow oil, Poultry oil etc.	• reduced greenhouse impact • increased growth rate • high percentage of oil	• High initial investment; • Requires sunshine; • Issues with larger-scale production; • Challenges with oil extraction

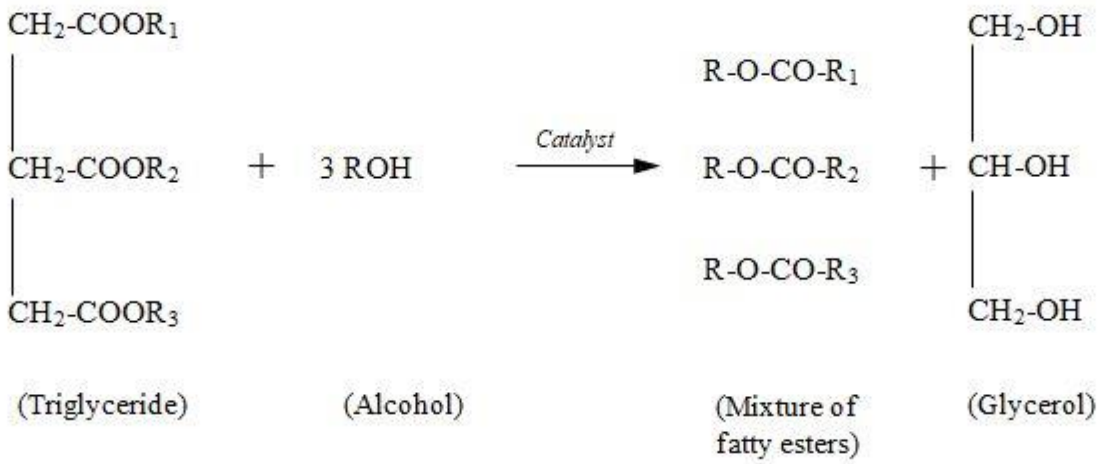
Table 1 Classification of generations of biodiesel [6-9]

2.2 Fuel transforming techniques

For the preparation of biodiesel fuel, a variety of well-established processes are available. It is beneficial to modify crude oils to minimize its viscosities so that the resulting product has adequate qualities for application as fuel oil. There are several procedures available for this transformation in order to create higher grade biodiesel [6,10].

- Dilution
- Micro-emulsions
- Pyrolysis
- Transesterification

Transesterification is the most common technique employed to convert the free fatty acids in the raw oil into ester which having similar properties as diesel fuel [6]. The chemical process that includes triglycerides and alcohol with a catalyst to create esters and glycerine is known as transesterification (alcoholysis). This transesterification employs three successive reversible reactions: triglyceride to diglyceride conversion, diglyceride to monoglyceride conversion, and diglyceride to monoglyceride conversion. Following that, glycerides are transformed into glycerine, yielding an ester within every phase. A catalyst is often utilized to increase and accelerate the reaction kinetics, allowing it to be finished in a little amount of duration. Due to the reversibility of this transesterification, extra alcohol is employed to increase the stability of the product. When a transesterification process is successful, it yields ester and glycerine. Despite the fact thatesters are the intended outcomes of transesterification processes, glycerine retrieval is equally significant owing to its wide range of uses in everyday items. Alkalis, acids, and enzymes may all catalyze the transesterification process [6,10].Equation depicts a simplified model of its chemical reaction.



(1)

Where R1, R2, and R3 are fatty acid chains and which are long-chain hydrocarbons.Vegetable and animal oils typically contain palmitic, stearic, oleic, linoleic, and linolenic acids. Triglyceride is turned into glycerol at each time 1 mole of fatty ester is released.

3. Mahua seeds as a potential feedstock

Numerous crops are produced not just for food and manure, but also for an incredible range of unique industrial goods. The lookout for new oil plant products with higher oil or fat extraction rates for nutritional, medicinal, and other purposes is essential. The life cycle of mahua biodiesel have been shown in Fig. 1.Mahua oil (Madhucaindica) is extracted from the seeds of the Madhucaindica tree, which is native to much of India. Mahua seed has around 35–40% oil, whereas the kernel contains approximately 70% oil. Every year, every tree yields 20–40kg of seed.The color of unprocessed yet processed raw mahua oil has a greenish yellow tint. A tree requires 8–15 years for a tree to completely grow, and an adult tree may provide fruit for up to 60 years. It is semi-evergreen herbage indigenous to IndiaMahua oil has around 20% FFAs and has a yield of 181,000 metric tons per year in India. [10-12]

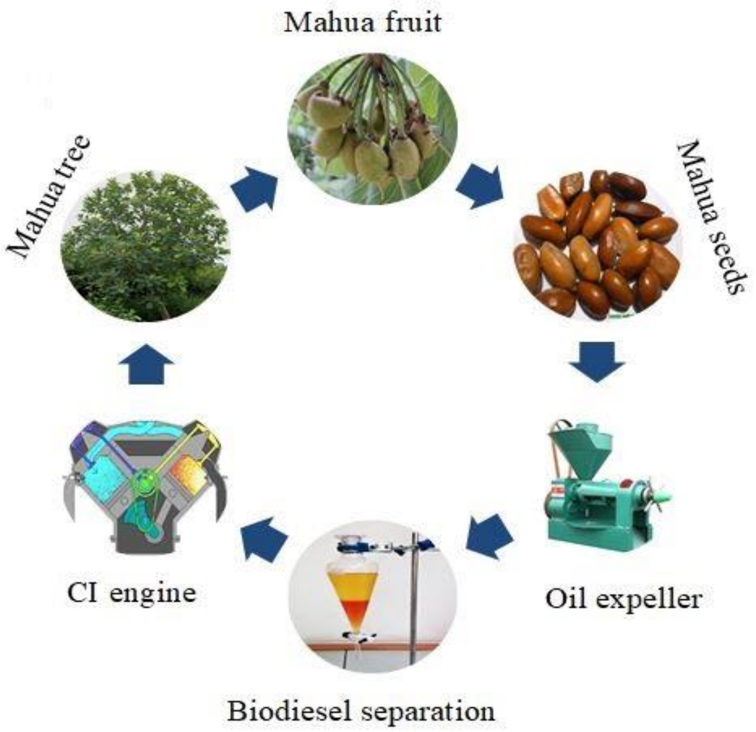


Fig. 1.Life cycle analysis of mahua oil biodiesel

The unprocessed yet filtered rawmahua oil is greenish yellow in color. The fatty acid profile determines the quality and effectiveness of fats and oils. According to the fatty acid profile of mahua oil, the main fatty acids are palmitic acid, stearic acid, oleic acid, and linoleic acid. Table 2 indicated mahua oil contains a high concentration of saturated along with mono-unsaturated fatty acids.

Oils and fats can be processed into bio-diesel in at least four ways transesterification, dilution, micro-emulsions, and pyrolysis. The standard method is transesterification. It is a chemical process that forms fatty acid alkyl esters and glycerine, which is catalyzed by oil or fat and an alcohol [13]. In Fig.2, steps associated in synthesis of biodiesel and simple transesterification process was indicated.

Fatty acid	Formula	Composition (wt%) range
Palmitic Acid	$C_{16}H_{32}O_2$	16-28.4
Stearic Acid	$C_{18}H_{36}O_2$	17.5 -25.1
Oleic Acid	$C_{20}H_{40}O_2$	41.0-51.0
Linoleic Acid	$C_{18}H_{34}O_2$	10.00-15.00
Arachidic Acid	$C_{18}H_{32}O_2$	0-3.31

Table 2 Fatty acid Composition of Mahua oil [13,14,18]

The oil derived from mahua seeds and transesterified mahua biodiesel are evaluated for essential fuel properties namely density, calorific value, pour point viscosity, flash and fire point. The biodiesel from mahua oil showed characteristics near to diesel. Table 3 summarizes the parameters of raw mahua oil and biodiesel.

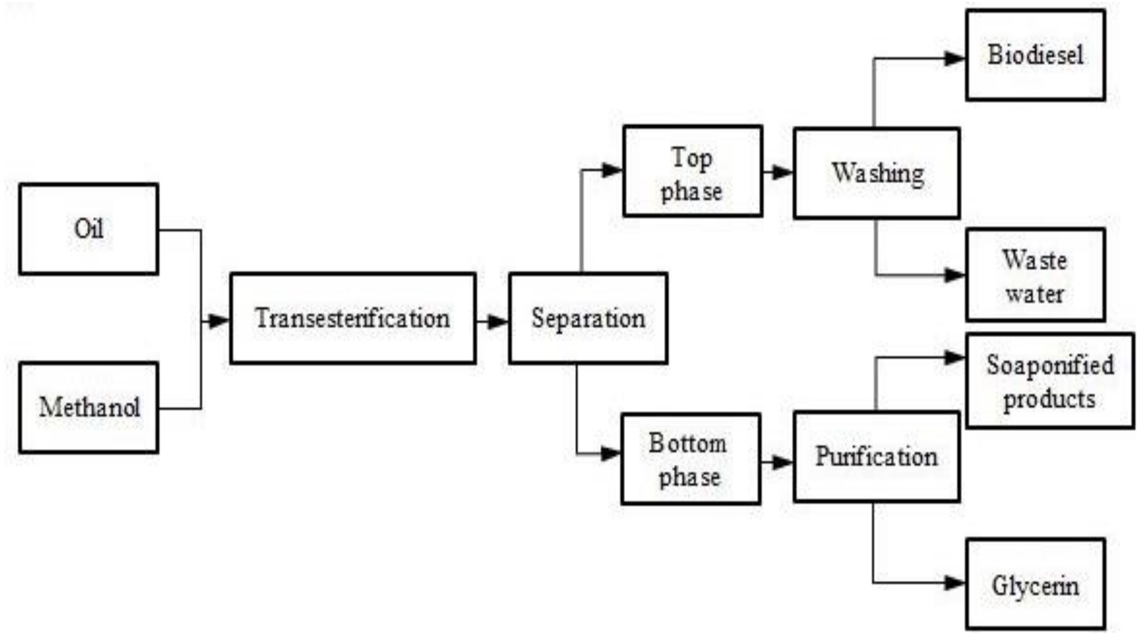


Fig. 2 Basic transesterification process [14-20]

Property	Unit	Mahua oil	Mahua biodiesel
Density at 15°C	Kg/m^3	900-960	860-910
Viscosity at 40°C	mm^2/s	24-40	2-6
Flash point	°C	220-240	120-210
Fire point	°C	230-260	130-200
Pour point	°C	10-16	2-6
Calorific value	Mj/kg	35-40	36-41

Table 3 Physiochemical properties of Mahua oil and Mahua biodiesel [12,13,14,16,19]

3.1 Production of biodiesel from mahua oil

Many researchers have investigated Mahua biodiesel as a substitute fuel in diesel engine. Researchers used various techniques to convert crude mahua oil into a useful biodiesel. Bahadur et al. [14] produced mahua oil by two step transesterification. 100 mL of raw mahua oil and 35 mL of methanol were combined. 1.5% v/v conc.$H_2SO_4$was added to this mixture. Using a magnetic stirrer, the produced sample was heated to 45°C for an hour. The pre-treated mahua oil was combined with alcohol in a 1:5 ratio, as well as 0.75% v/v KOH catalyst. A magnetic stirrer was used to heat the mixture to 45°C at 500 rpm. ChandrasekaranMuthukumaran et al. [15] optimized the biodiesel production process.The quantity of methanol used and the temperature has a major impact on the output of mahua biodiesel. The highest biodiesel yield of 88.71 % was produced using 1.5 % KOH as the catalyst, 0.32 % v/v methanol, a temperature of 60 C, and duration of 90 min. The ASTM criteria were satisfied by the prepared mahua biodiesel.SukumarPuhan et al. [16] synthesized Mahua oil biodiesel from crude oil by transesterification process. Mahua oil was heated to 60°C and added methanol and NaOH to it with magnetic stirrer for 2 hr. The Biodiesel and glycerine separated and top layer collected and washed. SukumarPuhan et al. [17] Mahua oil was combined with methanol and ethanol in a 20:1 molar ratio, as well as 5% v/v H_2SO_4, and the solution was heated for 5 hr. The produced upper phase was collected, cleaned, and dried in an over at 110°C. H. Raheman et al. [18] and Deepesh Sonar et al. [19]produced Mahua biodiesel from raw mahua oil in two step transesterification process. A two-step 'acid–base' method was employed to synthesize biodiesel from raw mahua oil in a lab size unit, using methanol as a reagent and H_2SO_4 as well as KOH as catalysts for the acid and base reactions respectively.Suresh M. Senthilet al. [20] studied the process of calcination or catalytic cracking alters the physiochemical components of a material can be used as a catalyst. Catalytic cracking was conducted in a catalytic apparatus at 300 °C for 2 h. 200 ml of methanol was mixed with 1000 ml of Mahua oil for the biodiesel production, and the transesterification process was conducted in a reaction chamber at 60 °C for 30 min. KOH and cracked red mud were employed as catalysts at proportions of 15 g in1 liter of Mahua oil, respectively. As a final product, about 0.8 L biodiesel was obtained for 1 L of Mahua oil.

Mahua oil is economical and the manufacturing of biodiesel from it can be ratcheted up to an industrial scale. Mahua biodiesel is an excellent substitute to fossil fuel since it has comparable properties to petro diesel fuel and is less expensive.

3.2 Works on mahua biodiesel as an alternate fuel

Mahua plants can be found in various states in India, including Orissa, Chattishgarh, Jharkhand, Bihar, Madhya Pradesh, and Tamil Nadu, where they have successfully developed. It makes use of waste and dry area that is unsuitable for any other kind of growth. Its plant does not need any particular or specific care since it is highly adaptive to any weather condition, results in a maximum height of 20 m. In terms of fuel properties, Mahua is equivalent to diesel and is accessible in large amounts that are unused. On a volume basis, it has a calorific value of 96.30 %. Concerning power output, BSFC, and BTE, blending mahua oil with diesel by 20% has no significant effect [10,11]

Many researchers investigated on blending mahua oil biodiesel with diesel, adding higher alcohol and diethyl ether, including different nanoparticles into the fuel blend, and changing engine specifications like IP, IT, and CR.

3.2.1 Mahua oil biodiesel blended with diesel

Several researchers investigated the characteristics of the engine with mahua oil biodiesel as fuel. There are many researches focusing on the composition of biodiesel in the Diesel/Biodiesel blend.SukumarPuhan et al. [16] studied engine performance that Mahua oil methyl ester (MOME) as a fuel is not significantly different from diesel. MOME noticed a little power reduction and an upsurge in fuel intake. This might be owing to the ester's reduced heating value. CO and HC emissions are too low for MOME. NO_x were quite lower in ester than in diesel.SukumarPuhan et al. [17] compared the mahua oil biodiesel prepared from methanol and ethanol. When esters are compared to diesel on performance and emissions, the findings are favorable. In compared to diesel, esters burned more effectively. Based on the results of this research, it is determined that methyl and ethyl esters can be employed as alternative fuel in diesel engines. In terms of performance and emissions, methyl ester gave better results over ethyl ester and diesel fuel.

H. Raheman et al. [18] investigated mahua biodiesel blends as fuel and compared with diesel. The proportion of biodiesel in the fuelmixture raised theBSFC and reduced the BTE. With increasing the load, the CR and IT test showed a reverse trend. The smoke opacity and CO in flue gases decreased with raise inproportion of mahua biodiesel in the blends, while NO_x increased. However, when engine load increased, the amount of emissions raised for all test samples. The B20 blend gave enhancedperformance and also reduced emissions over diesel and other blends.

Deepesh Sonar et al. [19] investigated the mahua oil and mahua biodiesel blends. It indicated at higher blends, BSFC raised and BTE reduced. CO and HC in flue gases decreased, while NO_xslightly increasedas the proportion of biodiesel in the fuel blend increased. It was found that may be effectively mixed into diesel fuel up to 20%, making it a good substitute fuel for diesel. The performance and emission characteristics of the engine using mahua biodiesel mixes can be greatly enhanced by altering the IOP. At 226 bar,mahua oil and diesel fuel mixturehaving up to 30% mahua oil can be employed as a fuel.

M. Senthilet al. [20] investigated mahua biodiesel obtained from red mud catalyst blended with diesel at different ratios. In this investigation, red mud biodiesel as B50 was shown to be the optimum blending alternative regarding to physio-chemical qualities namelyrelative density, heating value, pour point, and consumption of fuel was lower than KOH biodiesel. For a 25% blend, the red mud biodiesel had reduced fuel efficiency. The engine performance was equally optimal, in contrast to diesel, suggesting red mud biodiesel using Mahua oil can become a viable substitute fuel.

N.Kapilan et al. [21] investigated mahua oil biodiesel and its blends as B5, B20 and B100 compared to diesel. When compared to the B100, B5 and B20 blends have greater thermal efficiency but increased emissions. The B5 blend is more efficient than the B20 blend. According to the investigation, it is derived that mahua oil biodiesel as well as its blends could be employed as a alternate fuel in agricultural diesel engines.

NabnitPanigrahi et al. [22] studiedthe engine characteristicswith the mahua biodiesel blends as fuel. The mahua biodiesel added to diesel at a proportion of B20, B30 and B40 and compared to diesel. BSFC is raised at maximum load for B20. Diesel has a better BTE than biodiesel, although for larger loads, the B20 is comparable to diesel. B20 has the highest brake thermal efficiency at increasing loads. Blended oils showed a little increase in NO_x emissions. However, CO_2 and HC emissions are minimized. The CO emissions of the fuels grow when they are at full load. At higher loads, the emissions of B20 are comparable to that of diesel.

S. Savariraj et al. [23] investigated mahua oil biodiesel blended into diesel at the proportions of 25%, 50%, 75% and 100%. The upsurge in the composition of biodiesel reduced the BTE and raised the BSFC. Emissions of CO, HC, smoke, NO_x increased with mahua oil. Sunil Kumar et al. [24] examined the influence of biodiesel and diesel blending on the engine characteristics. Mahua oil biodiesel blends as B10, B20 and B30 were used as a fuel and compared with diesel. The performance of biodiesel blends was noticed to be similar to diesel. Almost at every load, CO, HC, and NO_xwere noticed to be the lower for mahua biodiesel than diesel. B10 and B20 fuels have lower emission characteristics than diesel as well as B30 fuels and can replace diesel.

S. Ramasubramanian et al. [25] the biodiesel obtained from mahua oil through transesterification was blended with diesel into M10, M20 and M30 and these fuel samples were tested and compared to diesel. BTE increased as the proportion of biodiesel increased. M30 indicated greater BTE and a lower BSFC compared to diesel and other blends. M30 exhibited lower CO, HC, and smoke emissions, as well as a slight lower NO_xthan diesel.

Biodiesel has been discovered to be an adaptable and potential substitute fuel with qualities comparable to diesel. Without any changes, biodiesel could be employed in diesel engines. The primary issues with biodiesel include excessive density viscosity, poor energy density and efficiency, volatility, and greater NO_x emission, with NO_x emission and viscosity being key concerns. Various alcohols including methanol, ethanol, butanol, pentanol,hexanol are used as an oxygenated additive to mitigate the disadvantages with neat biodiesel.

3.2.2 Mahua oil biodiesel with Alcohol and other additives

M. Vinayagam et al. [26] investigated exhaust emissions by incorporating mahua biodiesel blended with Hexanol as B90H10 and B80H20 and compared the results with pure biodieseland diesel. HC, CO and NO_x were reduced at all loads. SenthilkumarMasimalai et al. [27] investigated the mahua oil blended with methanol at from 5%-20% of four compositions. It indicated that the BTE was improved upto 15% of methanol and methanol induction in dual fuel engine indicated superior BTE compared to mahua/methanol blend. Methanol induction indicated lower $NO_x$and smoke emissions besides raise in HC and CO emissions compared to normal mahua/methanol blend. Swarup Kumar Nayak et al. [28] prepared fuel blends with mahua oil and Diethyl carbonate of 5%-15% with biodiesel as B85, B90, B95 and B100. These samples were tested on the diesel engine. Increased proportion of additive indicated improved BTE and reduced BSFC. EGT is reduced with increased additive composition. CO, HC, smoke and NO_x were decreased appreciably with raise in additive composition in biodiesel. N.Vadivel et al. [29] investigated the fuel samples prepared from the mahua/mustard biodiesel and diesel with 5% of diethyl ether (DEE). DEE enhances the physiochemical qualities of biodiesel-diesel by adding it to the fuel. The BTE and BSFC have improved with the inclusion of DEE to the biodiesel-diesel mixture. When compared to plain diesel, the fuel sample with 25% of biodiesel and 5% DEE blend has reduced smoke opacity and lower CO at peak load. When compared to plain diesel, the HC and NOx emissions reduced. Adding DEE to biodiesel-diesel blends can be a potential strategy for increasing the efficiency of diesel engines without modifying the engine.Roshan Raman et al. [30] evaluated the characteristics of the engine with the test samples B5, B10, B15, B20 and 10% and 20% DEE with B20. BTE increased and BSFC reduced with B20-20DEE compared to other test samples. CO and HC emissions were significantly decreased with the inclusion of DEE. Smoke opacity andNO_xwere lower than diesel. HRR of the B20-20DEE blend was found to be greater than all other fuels tested, which might be attributable to the blend's superior physicochemical features, optimal fuel-air mixing, and better atomization characteristics, as well as an increase in-cylinder pressure.

3.2.3 Mahua oil biodiesel with Nano additives

Metal oxide-based additives help improve engine performance and reduce toxic emissions. Metal oxide additives are added to enhance the qualities of biodiesel and diesel fuels, allowing for full combustion and reduced pollution levels in diesel engines. The catalytic effects of metal-based additives on hydrocarbon combustion are the most common.These additives are often applied to diesel engines as a metal organic complex, with the metal formed as nanoparticles. Particle trapping devices are a good way to cut down on residue emissions. Fuel additives made from nanometal-based oxides are helping to enhance the performance, combustion and emissions of direct injection diesel engines.

Megavath Vijay Kumar et al. [31] investigated mahua biodiesel diesel blend B20 and added CeO_2 nanoparticles of concentration 50, 100 and 150ppm Due to better combustion produced by CeO_2 nanoparticle in mahua biodiesel blend fuel, the BTE of the engine increases while the BSFC decreases with the inclusion of CeO_2 nanoparticles. The enhanced combustion generated by CeO_2 nanoparticles in the MOME mix fuel reduces CO and HC emissions. The application of the nanoparticle reduces smoke opacity and NO_x.C. Syed Aalam et al. [32] studied the engine characteristics with mahua biodiesel blend, nanoparticles of Al_2O_3 and Fe_2O_3were added at composition of 40, 80 and 120ppm. At optimum working conditions, nanoparticles blended B20 showed a significant increase in BTE. In comparison to F80, A80 proved particularly effective in enhancing BTE. When nanoparticles were added to B20 fuel, the toxic contaminants in the exhaust gases were dropped considerably compared to B20. HC and smoke emissions were better reduced with A40 over F40. YuvarajanDevarajan et al. [33] investigated mahua oil biodiesel B100 added with CuO nanoparticles of 100ppm of particle size 10 nm and 20 nm. Diesel had a higher BTE than other test samples. BTE is raised with B100 with CuO nanoparticles with an average diameter of 20 nm. With the inclusion of CuOnanoparticles, the BSFC value decreased. The inclusion of CuO reduces its magnitude even further. At all loads, CO, HC, and smoke emissions from BD100C20 were relatively lesser than diesel. NOx emissions reduced as the particle size of nanoparticles increased.VijayakumarChandrasekaran et al. [34] investigated mahua oil biodiesel on diesel engine in two phases. In first stage, the mahua biodiesel was blended with diesel at different proportions. The results of test samples indicated that B20 showed optimum characteristics. The nanoparticles of CuO were added to B20 at 50ppm of dosage. It indicated that BTE was slightly enhanced and BSFC was decreased. CO, HC and smoke emissions were mitigated and NO_x was found to be slightly raised with addition of CuO nanoparticles. Prabhu Kishore Nutakki et al. [35] synthesized the mahua oil biodiesel by transesterification process and nanoparticles of SiO_2 were dispersed in a solvent to form nanofluid. This nanofluid of SiO_2 at dosage of 40, 80 and 120ppm mixed with mahua biodiesel and diesel blend B20 to form nanofuel blend. At B20S120 BSFC was reduced and BTE enhanced compared to B20. With increase in dosage of SiO_2in fuel blend HRR and In-cylinder pressure increased. Diminished emissions were observed with the addition of SiO_2 nanofluid, but NO_x emissions were raised.

3.2.4 Mahua oil biodiesel with modified engine operating conditions

Several studies suggested that modified engine operating conditions have significant effect on enginecharacteristics. Numerousinvestigations were carried out using various combinations of mahua biodiesel and its blends as a fuel in CI engines with varied operating conditions especially Compression ratio (CR), Injection timing (IT), and Injection pressure (IP).

Sivaganesan S et al. [36] investigated mahua biodiesel blend B20 by modifying operation condition of diesel engine. Here the compression ratio of the engine changes as CR 15.5, 16.5 and 17.5. Performance characteristics such as BTE increased and BSFC reduced with increased compression ratio at peak load. CO and HC emissions were reduced at higher compression ratio and smoke opacity is lower than diesel at all compression ratios. HRR and In-cylinder pressure were increased at higher compression ratio. ChandrakasanSolaimuthu et al. [37] examined the impact of injection timing of fuel on the characteristics of the engine with mahua biodiesel blend B25, B50, B75 and B100. Injection timing of 22^{o}, 23^{o} and 24^{o}bTDC were considered. At injection timing of 22^{o}bTDC showed better results for all test samples compared to other injection timings. B25 at 22^{o}bTDC of injection indicated higher BTE, higher HRR and lower exhaust emissions. H. Raheman et al. [38] investigated six test samples of mahua biodiesel blends of 0-100% by varying the injection timing from 35^{o} to 45^{o}bTDC and compression ratio of 18, 19 and 20. The engine's performance decreased when the proportion of biodiesel in the mixture was increased under the same operating parameters. However, once the CR and IT were increased, engine performance with biodiesel blends became similar the high speed diesel.Biodiesel can be combined with HSD up to 20% at any CR and ITassessed to get nearly comparable performance as diesel. A. P. Venkatesh et al. [39] investigated diesel engine characteristics with diesel and Mahua oil methyl ester to see how changing injection pressures of 180, 200 and 220 affected engine performance and emissions at various loads.With changing injection pressure, performance characteristics such as BTE and BSFC showed no change. At lower injection pressures, smoke and HC emissions were minimal. At different load conditions, Mahua methyl ester of M200 and M220 has been shown to emit less nitrogen oxide than diesel.Balaji Mohan et al. [40] studied the characteristics of the engine with mahua biodiesel B20 by varying IP and IT. At variable injection pressure injection timing kept constant as 23^{o}bTDC and vice versa at 225 bar. BTE and BSFC were improved at higher injection pressure and at 21^{o}bTDC injection timing B20 indicated reduced emissions with compromising on performance characteristics.

4. Other benefits of mahua oil

Madhuca Longifolia is a huge, shaded, deciduous tree that grows wild and is farmed over most of the central Indian Territory. The flowers, fruits, seeds, and wood of the tree are all valuable. They are used to boost breast milk production. The refined juice of the blossoms is said to be a tonic that is both nutritious and cooling. The liquid produced from the bloomsthat can be used to manufacture vinegar, has made the tree famous. The leaves are used as a bandage to treat dermatitis. In Indian ayurvedic therapy, the leaf char is combined with ghee to treat a wound and burn treatment. Mahua medicines are useful to treat intestinal worms, lung infections, and frailty and malnourishment. The constringent bark extract is used to treat dental issues, inflammations, and diabetes [41].

5. Conclusion

The challenge of decreasing crude oil reserves, as well as growing attention to environmental degradation caused by petroleum-based fuel emissions, has prompted an exploration for sustainable substitute fuels to replace petroleum-based fuel. Biodiesel, which is environmentally friendly and made from renewable resources, has rapidly gained popularity.

Non-edible oils like Mahua oil, Jatropha oil, Calophyllum Inophyllum, Castor oil, Neem oil etc. have gained much attention as an alternative fuel due its adaptability. Mahua oil has been the subject of numerous studies as an alternative fuel.

- Studies on Mahua oil biodiesel blended with diesel indicated Performance near to near to diesel and significantly reduced emissions. Many authors suggested that 20% of biodiesel/diesel blend could be utilised as a fuel in diesel engine without modifications of engine. B20 gives lower exhaust greenhouse gases with compromising on engine's performance.
- Viscosity of biodiesels are higher than diesel, to overcome this drawback researchers used alcohol as an additive to the biodiesel and its blends in order to reduce the viscosity and eventually decreasing harmful exhaust emissions.
- Combustion characteristics with mahua oil biodiesel was studied by numerous researchers which indicated improved combustion with the inclusion of nanoparticles into the fuel blend results in more surface-to-volume ratio and better atomisation and stability leads shorter ignition delay in the combustion chamber.
- Many researchers have worked on engine modifications such as modifying compression ratio, injection timingand injection pressure. Change in engine parameters results in slight enhancement in performance, effective combustion and significant reduction in emissions were noticed.

From this review it can determined that mahua oil biodiesel can be used in diesel engine with no substantial modifications. The criteria of acceptable efficiency, fuel economy and reduction of hazardous emissions of the engine are feasible. However additional studies under correct operating parameters with better design are necessary to explore maximum potential of biodiesel engine.

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