A Review of Biodiesel Production, Engine Performance and Emission Characterisation with Nano Additives

Dayananda Murthy T[1], Dr. Yogish H[2], S Puneeth[3], N S Kumaraswamy[4]
[1,3]*Department of Mechanical Engineering, JSSSTU, Mysuru*
[2,4]*Department of Mechanical Engineering, Sri Jayachamarajendra College of Engineering, JSSSTU, Mysuru*

Abstract **To power diesel engines, fuels like biodiesel and diesel are mixed together in variable amounts. Because of this, the amount of hazardous pollutants that are emitted into the environment has been lowered as a result of the increased use of biodiesel blends. This literature review gathers findings on how the usage of various biodiesel mixes affects the performance, efficiency, and emissions of diesel engines under a variety of conditions. The objective of this study was to investigate the efficiency of biodiesel when used in diesel engines. According to the data, diesel that has been combined with biodiesel is slightly more efficient than diesel that has not been mixed with biodiesel. It also has a shorter ignition delay. Biodiesel is a practical alternative fuel source that may be used in diesel cars. Antioxidants, cetane number improvers, cold flow characteristic enhancers, and many other types of additives were only some of the things that a big number of researchers and scientists looked into and investigated. Another type of additives that has been the subject of research is known as enhancers of cold flow characteristics. The current research examines and compares the properties of a number of additives, focusing on how these additions impact the overall quality of the biodiesel mix, as well as diesel engine performance and emissions.**

Keywords: Biodiesel, Biodiesel blend, Conventional diesel, Diesel engine, Emission gases

1. INTRODUCTION

As transportation energy consumption climbs 1.1% every year, improving the transportation infrastructure boosts any country's GDP. Industrialization has raised energy demand. The 1970 crude oil crisis began when crude oil was used to fulfil energy demand. Academics and scientists worldwide studied alternative fuels to address this challenge. Population expansion has increased car use and released harmful pollutants into the environment. Biodiesel combustion lowers carbon monoxide, sulphur dioxide, unburned hydrocarbons, and nitrogen oxides [1]. Biodiesel and diesel are chemically and physically identical, according to several studies [2–6]. Ogunkunle et al. [7] reviewed global biodiesel production and vehicle engine fuel use. Since biodiesel works in diesel cars, more people are using it. Datta et al. found that biodiesel's environmental advantages offset engine performance losses. [8]. Humans may safely consume vegetable or animal fat biodiesel. Biodiesel's low sulphur and high cetane rating are benefits. Replicating diesel is difficult. Due to its high kinematic viscosity and density, biodiesel may improve engine efficiency and reduce burning at low temperatures [9-18]. B20 (20% biodiesel, 80% diesel) improves density, viscosity, calorific value, flash point, and engine efficiency. [9]–[11]. Bio-based additions affect biodiesel. Lawan et al. investigated. [19]. The feedstock's phenolic content and freezing point affect bio-based additives' antioxidant and cold flow suppressing effects. Arjanggi et al. examined the benefits of employing waste plastics as biodiesel additives, polymer breakdown processes, fuel properties, and composition. [20]. Mohd Noor et al. [21] researched biodiesel for marine diesel engines. Fuel stability, increased production and feedstock costs, material incompatibility, cold flow characteristics, and maritime applications without marine-grade criteria will necessitate new strategies and technologies.

Gad et al. evaluated diesel engine performance and emissions using cotton ethyl ester blends with HHO gas and kerosene [22]. Kerosene improved cooling. HHO enhanced combustion. Adu-Mensah et al. studied hydrogenated biodiesel modifications for oxidation stability and cold flow [23]. Catalysts reduce trans-FAME and partial hydrogenation, they say. Oxidized biodiesel containing aldehydes, ketones, and short-chain acids did not degrade FDM for CRDE, according to Chandran's biodiesel-FDM compatibility literature review [24]. (common rail diesel engine).

Jiaqiang et al. researched biodiesel engines [25]. Low Temperature Combustion (LTC) mode reduces NOx and PM emissions better than biodiesel additives, exhaust gas recirculation (EGR), water injection (WI), emulsion technology (ET), a modification in injection strategy, concurrent technologies (ST), and combustion chamber design. Wang et al. [26] found that fatty acid chain length, unsaturation, and oxygen content impact PM emission in biodiesel-powered diesel engines.

Akhabue et al. [27] inserted chicken droppings into sulfonated calcined corncobs to create a bifunctional biocatalyst (BBFC). Neem seed oil (NSO) has 4.426% free fatty acids after biocatalysis. Ramalingam et al. [28] examined diesel engine parameters using a moringa oleifera biodiesel mix using cutting-edge injection technologies. Fuel injection pressure (300–600 bar) and timing affect engine emissions (15–25 degrees of crank angle before top dead centre). Moringa oleifera biodiesel reduces CO and CO2 more than NOx. Suresh et al. [29] found that raising VCR engine compression pressure enhances performance and reduces emissions.

Singh et al. [30] studied biodiesel chemical compositions, properties, and standards. They found that FAME content affects biodiesel fuel chemical and physical qualities. Chain branching, unsaturation, and length affected FAME properties, both positively and negatively. FAME's compositional features boost fuel stability, but low-temperature performance may suffer. Fatty acid composition is difficult to determine since it affects biodiesel characteristics in the opposite manner. Cold flow, lubricity, viscosity, cetane number, and oxidative stability show FAME's biodiesel feedstock potential. Oxidation stability and cold flow, which vary by feedstock, are crucial. High-quality FAME has less polyunsaturated fatty acid, reducing oxidative instability.

Gasoline, hydrogen, natural gas, biogas, and alcohol biodiesel blends were all put to the test by Mirhashemi et al. [31] in an effort to lower NOX emissions. Blends of biodiesel fuel with conventional gasoline or diesel may help establish the best injection pressure and fuel mixture for minimising NOX emissions. Engine performance, combustion, and emissions were analysed for all three fuel types by Erdiwansyah et al. [32]. There are benefits and drawbacks to using alcohol and biodiesel in vehicles. Diesel fuel, biodiesel, and 1-heptanol (C7 alcohol), a next-generation higher alcohol blend, were investigated by Yesilyurt [33] for their effects on performance, combustion, and exhaust emissions in a diesel engine. They discovered that by mixing oxygenated 1-heptanol into diesel fuel and biodiesel/diesel fuel blends, they could decrease emissions of CO and unburned HC while simultaneously increasing emissions of CO2, O2, and NOX.

Blends of diesel, biodiesel, and ethanol/bioethanol were evaluated in diesel engines by Shahir et al. [34]. Lower concentrations of ethanol (below 5%) were more effective. It's difficult to instal additional catalytic converters to lower NOx emissions. diesel engine performance and emissions utilising biodiesel-alcohol mixes was studied by Zaharin et al. [35]. Blends containing alcohol reduce emissions of CO, HC, and PM while increasing NOx. Combustion efficiency, combustion temperature, and NOx emission all improve with an increase in oxygen content. Diesel-biodiesel blends with oxygenated alcohols and nanoparticle fuel additives were investigated by Mujtaba et al. [36] in compression ignition diesel engines. Emissions of carbon monoxide and hydrocarbons were lowered by alcohols and B30, while emissions of nitrogen oxides were decreased by CNT nanoparticles and B30. In order to better understand how biodiesel mixes influence IC engine durability, performance, and emissions, Hasan et al. [37] looked at the environmental and economic consequences of biodiesel production. Biodiesel blends with a low percentage of other fuels may be used in most existing vehicles without any adjustments to the engines. Long-term usage with plenty of biodiesel means you can put off buying a new engine.

Life cycle assessment of biodiesel was studied by Hosseinzadeh Bandbafha et al. [38]. The dangers to society from using biodiesel fuel were discussed by Godri Pollitt et al. [39]. Using animal models, scientists analysed the effects of biodiesel engine exhaust on the cardiovascular system, lungs, and overall health while using soy, rapeseed, maize, and sewage fuels. Biodiesel feedstock quality, standardised test methodologies, and gas pollutant assessment were proposed as policy targets for improved public health.

According to Soudagar et al. [40], biodiesel increases nitrogen oxide emissions, is incompatible with cold temperatures, and clogs engine components including fuel filters, tanks, and lines, requiring regular repairs.

They think nanoparticle fuel additives might boost biodiesel. Metallic nanoparticles reduced ignition delay, enhanced calorific value, and boosted oxidation rates for full and cleaner burning. Guo et al. [41] examined diesel engine thermal oxidation and chemical structure using diesel, xylene, butanol, coconut oil, and toluene. An IC diesel engine tested each fuel. Fuel identity affects thermal oxidation and chemical structure. Biodiesel soot reacts more, losing bulk at lower temperatures.

Several nations produce and test biodiesel. Biodiesel may be better than diesel because diesel is more costly. Large cars, marine engines, and machines use biodiesel. This review research summarises diesel-biodiesel mix experiments to improve performance and reduce harmful emissions. The literature compares the performance of biodiesel mix fuel with conventional diesel fuel. However, biodiesel additive review articles are few. Thus, this study briefly discusses how methanol, ethanol, butanol, and propanol diminish exhaust emissions.

A. Characteristics of Biodiesel

The performance of an engine may be affected by a variety of characteristics, including the fuel quality, the flash point, the pour point, the cetane number, the density, the kinematic viscosity, the heating value, and the calorific value. Standardization organisations such as the ASTM, EN, and ISO have developed minimum specifications for the physical and chemical features of biodiesel blends [42]. These requirements include both the blend's physical and chemical characteristics. The classification of these demands might be accomplished by the use of physical, chemical, or mechanical standards. Because it is possible that combining at least two different types of biofuels with diesel and other components might result in an enhancement in the fuel's overall quality, this practise has gained popularity over the last several years [43-46]. It is possible that the engine's performance and emissions may be impacted, depending on the physical and chemical characteristics of the biodiesel mix fuels [43][45][47].

a. Calorific value

The amount of energy that can be converted into work by a fuel is determined by its calorific value [45]. Knowing a fuel's calorific value is essential. The calorific value of jatropha is 39.80 MJ/kg, which is higher than the calorific value of palm oil (40 MJ/kg), which is higher than the calorific value of coconut oil (38.50 MJ/kg). [46, 48] Blends of biodiesel and diesel have a calorific value that is more than that of pure biodiesel but less than that of ordinary diesel fuel. High-energy materials include things like petroleum (46 MJ/kg), oil (42 MJ/kg), and coal (32-36 MJ/kg), all of which may be found in [49]. It is possible to increase the performance of the engine by lowering the amount of biofuel that is used in the mixture while simultaneously raising the calorific content of the biodiesel [50].

b. Density

The output of the engine and the emissions produced are both directly affected by the biodiesel fuel's density. Denser substances have a greater viscosity, which helps promote spontaneous combustion [27]. The density, viscosity, and cetane number of a fluid are all interconnected. Compared to pure diesel, the fuel droplets produced by biodiesel mixes are more substantial because of their higher density. A lower density value improves atomization efficiency and air-fuel proportion growth, two factors that contribute to burning quality [51][52]. Gases, most notably NOx particulate matter [53]-[55], are released at rapid rates due to the high density. The density of biodiesel varies with its origin and method of production, as seen in Figure 1. In terms of density, soybean biodiesel (931 kg/m3) is superior to coconut biodiesel (807.33 kg/m3).

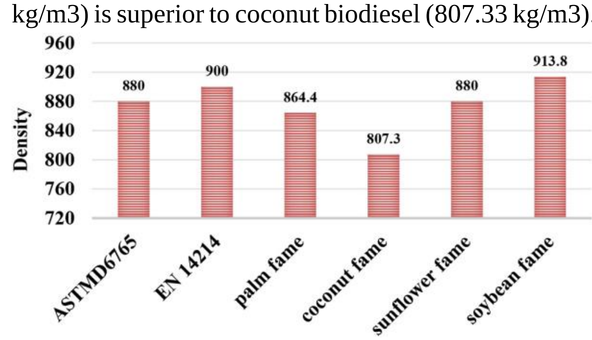

Fig. 1. Density values of bio-diesel fuel.

c. Kinematic viscosity

The viscosity of gasoline in an internal combustion engine (IC) is proportional to the speed at which it ignites [56]. High viscosity fuel causes bigger droplets during infusion and higher emission of undesired gases, whereas low viscosity fuel causes more wear and leakage [57]. Since fuel viscosity increases with decreasing temperature, incomplete combustion may occur [53], [58]. Gasoline consumption rises [59] and spray and atomization are diminished [60], [61] because biodiesel fuel is more viscous than regular diesel. The fuel produced when diesel is combined with biodiesel has a lower viscosity than diesel alone. The kinematic viscosity of biodiesel-diesel made from sunflower oil is between 4.5 and 5.8 mm2/s, whereas that made from palm oil is between 3.2 and 4.5 mm2/s. The kinematic viscosities of many types of biodiesel fuels are shown in Figure 2.

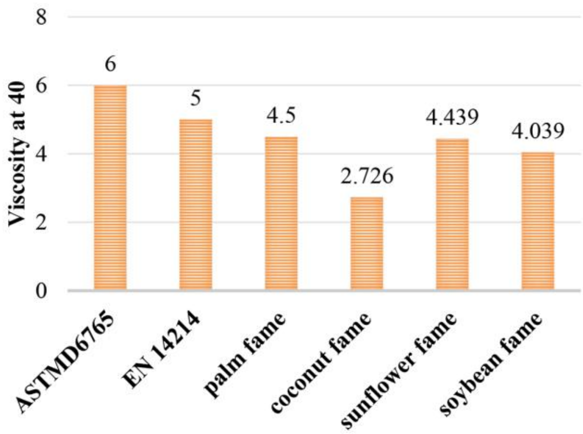

Fig. 2. Kinematic viscosity values of bio-diesel fuel.

d. Cetane number

A gasoline's ability to ignite under controlled conditions is described by its cetane number. Biodiesel fuel has a higher cetane number than diesel fuel. A higher cetane number will improve engine efficiency, reduce pollutants, and make the engine operate more quietly and smoothly [62]. Increasing the cetane number [63,64] helps to decrease the time it takes for the fuel to catch fire. More hydrocarbons and particulate particles are released when the cetane number drops. Increases in biodiesel blends with diesel result in longer ignition delays (as measured by the cetane number; [65][67]). The cetane range for biodiesel is smaller (46.8 - 49.8) than that of regular diesel (46 - 55). The cetane numbers for various types of biodiesel range from 54.6 for palm biodiesel to 37.9 for sunflower biodiesel to 53.59 for peanut biofuel to 51.6 for jatropha biodiesel [68][69].

e. Flash point

Storage, transport, and handling of gasoline are all affected by its flash point. When the flash point of gasoline is high, it is safe for transport and storage [70]. Biodiesel is safe to store and transport since its flash point is 50 degrees higher than diesel's [71-77]. Flammability refers to the lowest temperature at which the fuel contains sufficient vapour to produce an ignitable mixture above the fuel surface. Biodiesel has a flash point of 92 degrees Celsius in Europe and 120 degrees Celsius in the United States.

f. Cloud and pour point

At low temperatures, cloud and pour points are employed as primary measures to evaluate fuel performance. Gasoline that has solidified can completely or partially block fuel lines, and fuel filters that have not been properly lubricated can cause damage to engines. Higher fatty acid content biodiesel maintains a higher cloud and pour point in comparison to diesel. In cold weather conditions, diesel fuel performs much better than biodiesel [78]. Because of its low pour point and cloud point, biodiesel is difficult to utilise in the winter. Soybean biodiesel has a cloud point of 9 degrees Celsius and a pour point of 2 degrees Celsius [79], while palm oil biodiesel's values are 16 degrees Celsius and 15 degrees Celsius, respectively.

g. Iodine value

When determining if biodiesel is suitable for extended engine usage, this is a crucial attribute to consider. The iodine value of fuel is determined by adding 100 grammes of iodine to the double bond of any fatty acid [80,81]. Hevea brasiliensis has the highest iodine level at 144 mg I/g, while Simarouba glauca has the lowest at 40 mg I/g (paradise tree). Iodine levels may be measured using either the ASTM D1959 or D1541 protocols. Unfortunately, this approach cannot be employed with the cetane number, viscosity, and cold flow characteristics since these properties rely on the location of the accessible double bond [82]. Soybean biodiesel has an iodine content between 128 and 143, whereas coconut biodiesel has an iodine content of between 19 to 25.

h. Copper content

Use and storage conditions that minimise copper contamination are crucial for avoiding unintended changes in biodiesel's properties [83, 86]. Stripping chromo potentiometers are used to determine the bonding water copper content in ethanol, biodiesel, and water (SCP). Metals in gasoline, especially oils, may be detected using this method, and any remaining organic material that might cause restriction issues in the system can be removed as well [87]. A stripping voltmeter may be used to check for the presence of metals and the capacity for portable power.

Table 1. Properties of Biodiesel

	ASTMD6765	EN 14214	palm FAME	coconut FAME	sunflower FAME	soybean FAME
Cloud Point	-3 to-12	-	16	0	3.4	9
Iodine Number	-	max.120	54	-	-	142
Cetane Number	min.47	min.51	54.6	-	49	37.9
Calorific Value	-	35	-	-	-	39.76
Acid Value	max 0.50	max 0.5	0.24	0.106	0.027	0.266
Pour Point	-15	-	15	-	-	2
Flash Point	min.100-170	20	135	114.8	160	76
Cold Filter Plugging Point	19	max.+5	12	-4	-3	11
Copper Strip Corrosion (3h at 50)	max.3	min.1	1a	1b	1a	1b
Sulfur%	max.0.05	10	0.003	3.2	0.2	0.8
Sulphated Ash%	max.0.02	max.0.02	0.002	0.006	0.005	0.005

2. PERFORMANCE CHARACTERISTICS OF BIODIESEL IN IC ENGINE

Measures of engine performance that are relevant in a wide variety of contexts include braking thermal efficiency, braking power, and braking specific fuel consumption. In the next section, we are going to get deep into the intricacies of how mixing biodiesel with diesel impacts the power output, BSFC, and BTE of a diesel engine.

A. Brake Thermal Efficiency

Several reports [56][79][86] show that blended biodiesel and diesel fuel has a lower BTE than diesel fuel. According to Raman et al. [88], adding B25 to a diesel engine increased its thermal efficiency without requiring any further modifications to the engine itself. It was discovered by Murillo et al. [4] that the increased viscosity of biodiesel decreases the thermal efficiency of brakes. Due to its lower heating value, research by John panner selvam et al. [89] found that pure beef tallow biodiesel (B100) had inferior thermal efficiency than diesel fuel (B5 to B78). Moringa oil methyl ester and B20 B000 were put through their paces in a diesel engine by Rajaraman et al. [90] and their results were promising. Moringa blends significantly less effectively than diesel fuel because of its viscosity, thermal value, and density. According to Bari et al. [91], the braking thermal efficiency of diesel made from palm oil is lower than that of diesel made from petroleum. When compared to diesel made from palm oil, efficiency drops by 5% owing to a 10% increase in fuel consumption caused by palm oil diesel's lower calorific value. Fuel-borne oxygen allowed palm oil diesel to burn more efficiently. According to Vijayakumar et al. [92], biodiesel fuel blends including alcohol show great potential for improving diesel engine performance. The most effective biodiesel was a 25% alcohol-diesel blend. The efficiency of biodiesel may be improved by adding an appropriate amount of alcohol.

B. Brake Specific Fuel Consumption

Biodiesel-diesel mixes in CI engines increase brake specific fuel consumption [59][66][87][93][94]. As engine load rises, all biodiesel fuels lose BSFC. Pramanik [95] tested jatropha biodiesel with diesel blends. Jatropha viscosity decreased, which improved performance and BSFC compared to vegetable oil. Asokan et al. [96] discovered that B20 performs virtually as well as diesel fuel. Blends B20 and B30 have brake specific fuel consumption similar to diesel at full load. Arumugam et al. [93] evaluated a diesel engine using 100% palm biodiesel without engine changes. They stated that 100% palm biodiesel reduces braking power and torque by 10–12% at full load. Brakes used 4–5% more fuel. Srithar et al. [97] found that all dual biodiesel mixtures reduce BSFC and increase braking power. BSFC is good since fuel calorific value affects it. Ester's low energy content causes high energy use. Palm oil diesel has a 10% greater BSFC than petro-diesel due to its reduced calorific value, according to Bari et al. [91]. Diesel, coconut biodiesel, and triacetin were tested by Jafari et al. [98]. They constructed a parameter correlation matrix. Speed, braking power, injection pressure, brake thermal efficiency, air-fuel equivalency ratio, start of injection, start of combustion, ignition delay, brake specific fuel consumption, density, oxygen content, exhaust emissions information, and particle morphology. They also found that fuel consumption increases with oxygen concentration and that biodiesel and triacetin have a lower heating value (LHV) than diesel, resulting in a higher BSFC.

C. Power

Researchers have shown that utilising biodiesel-diesel blends derived from different biodiesel sources reduces engine power. In a series of tests conducted on a four-stroke single-cylinder direct injection diesel engine, Murillo et al. [4] observed that when the biodiesel mix was increased from 10% to 30% to 50%, the engine's power output decreased. Allen Jeffrey [99] discovered that at a certain biodiesel % and compression ratio, the effective power stays constant while the load is raised. If the equivalence ratio and compression ratio remain the same, increasing the proportion of biodiesel results in greater efficiency due to the decreased effective power. In order to improve the performance of four-cylinder, indirect ignition diesel engines, Usta et al. [100] claim that they mixed hazelnut soap stock with waste sunflower oil. A reduction in heat capacity is seen when biodiesel is mixed with diesel. There is a correlation between the oxygen content of the fuel (10%), the viscosity of the fuel, and the mass flow rate of the fuel pump. They discovered that when biodiesel content in gasoline increased, performance deteriorated.

3. BIODIESEL ADDITIVES

Additives make it easier to meet international fuel regulations and find solutions to issues posed by biodiesel in the real world. Additives also improve the quality of the gasoline. The quality of the fuel may be enhanced by adding additives, and using a mixture of diesel and biodiesel can increase the efficiency of the engine while simultaneously reducing emissions. The selection of biodiesel additives is strongly dependent on the qualities of the additives [101]. The heat of combustion, flash point, density, calorific value, and solubility are some examples of qualities that fall under this category. Additives may be able to resolve many of the technical obstacles that have historically prevented the widespread use of biodiesel, which would further enhance the potential of biodiesel as a gasoline substitute. The many benefits of using biodiesel additives are outlined in Table 1, which may be seen below.

Table 2. Properties of different bio-additives.

Additive	Kinematic Viscosity at 40^0C (cst)	Density (kg/m^3)	Calorific value (kJ/g)	Cetane number	Flash point (^0C)	Ref.
Ethanol	1.14*	791*	27.33	5-8	-	12
n-Butanol	3.00	812	34.33	25	35	12
Diethyl Ether	0.22	712	33.89	25	-	12
Methanol	0.59	790	19.62		11	13

(*- measured at 20^0C)

Oxygen is 34% heavier in ethanol. Sugarcane, sugar beets, sorghum, potatoes, sunflower, molasses, maize, wheat, cotton, and many more biomass feedstocks ferment into ethanol [104]. Ethanol in diesel creates oxygenated fuels. Diesohol is diesel and ethanol. Ethanol in biodiesel may increase brake thermal efficiency, heat release rate, viscosity, and exhaust smoke, according to many studies. Ethanol-biodiesel-diesel mixtures' physical and thermal qualities boost combustion [105].

Ethanol fermentation produces diethyl ether, an oxygenated biomass additive. This gasoline is clear. Unstable. High flammability makes it reactive to low temperatures. This product contains high cetane. Diethyl ether heats less than diesel. However, it mixed nicely with diesel and biodiesel. Its solubility makes it a good option. Several investigations have indicated that diethyl ether improves diesel-biodiesel mix performance and emissions [106].

N-butanol, a biodiesel ingredient with more oxygen, has become popular. 1-Butanol is created by fermenting a number of biomass feedstocks. Straight chain and OH group make it hydrophobic. Several scientists are considering adding n-butanol to biodiesel-diesel blends because to its high cetane number, solubility, and heat content [106].

Without cold flow additives, the biodiesel-diesel mix cannot be used below zero. Methanol, which contains more oxygen and accelerates cylinder combustion, is another addition. Analytical-grade 99.7% anhydrous ethanol. Methanol has 1109kJ/kg more latent heat than gasoline (107). After considering these aspects, biodiesel-diesel blends may include methanol.

A. Additives and Fuel Properties

They conducted research and discovered that the use of various additives in the blending process increased the fuel quality of diesel that was produced from a wide array of biodiesel feedstocks. The findings of their study were reported. According to research conducted on the parameters of the blend by [108], the density of biodiesel decreases from 845 kg/m3 to 829 kg/m3, the viscosity decreases from 4.5 cSt to 3.3 cSt, and the flash point decreases from 100°C to 92°C. It was shown that the addition of ethyl levulinate to a mix of cottonseed biodiesel and diesel considerably improved the blend's ability to flow at low temperatures and was the subject of research that was reported on by [109]. The cloud point was decreased from 4-5 degrees Celsius to 3-4 degrees Celsius, and the cold filter plugging point was recorded at 30 degrees Celsius. Researchers investigated the effects of ethanol and butanol on the cyclical variation of a diesel engine in the paper referred to as [110]. In [111], an investigation on the effects of mixing kerosene and ethanol with biodiesel made from Mahua oil was carried out. They observed that by adding kerosene and ethanol to a B20 biodiesel mix, both the cloud point and the pour point were significantly raised to a higher level. Both study [102] and study [106] investigated the effects of n-butanol and diethyl ether additives on the engine characteristics of a diesel engine that was powered by a diesel-Jatropha biodiesel blend. They discovered that the blend's kinematic viscosity decreased from 3.36 cSt to 3.16 cSt, and that the engine's performance and exhaust gas emissions improved. The influence that the inclusion of additives has on the characteristics of biodiesel feedstock fuel is outlined in Table 2.

B. Biodiesel Additives Performance and Emissions

Fuel economy and emissions were examined using additives. Rice bran oil biodiesel with 2.5% ethanol enhanced the BSFC and BTE of a 4-stroke, single-cylinder diesel engine by 6.98% and 27.82%, respectively. Researchers [114] discovered a 9% improvement in stopping power, a 6% drop in BSFC, and a 3% decrease in NOx, CO2, and Co emissions with biodiesel additives. Bio-ethanol as a fuel additive in coconut oil biodiesel blends affected engine performance, exhaust emissions, combustion, and heat release in a common-rail diesel engine [115]. Additives increased BTE and BSFC, the article showed. The engine emitted less NOx, smoke, and CO than diesel. Ethanol-added soybean biodiesel was evaluated for NOx, CO, CO2, and PM emissions [116]. Tall oil was examined as a biodiesel feedstock utilising magnesium and nickel-based additions in different proportions [117]. BSFC rose 6%. Additives in biodiesel lower carbon monoxide by 64.28 percent and smoke by 29.91 percent. Total NOx emissions fell considerably. Ethanol biodiesel-diesel combinations were evaluated at varied temperatures and concentrations [118]. CO and HC levels dropped significantly, however NOx levels rose with engine load. [119] examined how biodiesel additives like methanol and ethanol affected diesel engine emissions. Additives reduced exhaust NOx and PM. Alcohol increased exhaust CO and hydrocarbons. [120] examined biodiesel-methanol compression ignition (CI) engine exhaust emissions. Research showed lower CO2, NOx, and PM levels. The engine was tested under varied loads at a constant speed.

4. EMISSION CHARACTERISTICS OF BIODIESEL IN IC ENGINE

Emissions from CI engines consist of nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). The degree of emissions is governed by the features of the engine, the quality of the fuel, the condition in which the engine is functioning, and the design of the engine. When diesel-biodiesel blends are used instead of pure diesel, lower emissions of carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter may be attained. Pure diesel emits more particulate matter. The results of a number of experiments are summarised in Table 2, which compares the emission characteristics of biodiesel-diesel fuel blends to those of diesel fuel used by itself in a variety of engines.

A. HC Emission

Using a diesel-biodiesel blend as fuel instead of diesel lowers harmful carbon monoxide emissions [122]-[124]. Fuel mixture D70B25E5 with vane angles of 15° and air swirl air D80B10E10 produced the lowest HC emission, as reported by Motamedifar et al. [125]. High oxygen concentration in safflower biodiesel and butanol decreases HC emissions somewhat more than diesel fuel, as found by Celebi et al. [124]. And since biodiesel with a higher cetane number mixes better with butanol, the ignition delay time and flame propagation are both reduced, leading to more efficient burning. B20 has the lowest HC emissions, which may be related to a shorter ignition delay due to the higher cetane number of biodiesel compared to diesel, as shown by Goga et al. [123]. To reduce hydrocarbon emissions, reducing the ignition delay time leads to more complete fuel combustion. The longer ignition delay produced by the lower cetane number of higher alcohols, such as n-butanol, may explain why doing so increased HC emissions when added to gasoline mixes. The prolonged ignition delay period allows for the fuel to burn just partially. B20 gasoline at 20% load produced the lowest HC emissions, whereas B20 nb20 fuel at 100% load produced the greatest HC emissions. Full load had the lowest HC emission rate of 5.01 g/kWh, while 20% load had the highest at 5.31 g/kWh.

B. CO Emission

Biodiesel-diesel blends reduce CO2 emissions. Zheng et al. studied RCCI port injection of n-butanol [126]. The heavily premixed charge is spread evenly throughout the cylinder, including the crevice area and boundary layer region near the cylinder liner, where fuel is difficult to fully oxidise, resulting in substantial CO emissions. Alptekin et al. [127] found that biodiesel emits more CO2 and NOx than diesel but less CO. Compared to B20 (20% biodiesel and 80% diesel fuel), a mix with bioethanol increases overall HC emissions and slightly decreases CO emissions. Raman et al. [88] observed that CO emissions increase when the engine is underpowered. Fuel-rich mixtures at greater loads are the main cause. Biodiesel mixtures emit less CO2 than diesel engines. Ethanol decreased CO emissions 8.6% compared to B7, according to De Oliveira et al. [128]. B7E5 CO emissions grew proportionately till 30 kW engine load. At 37.5 kW, CO emissions drop to -23.1%. CO emissions peaked at 21.3% at 10 kW load for B7E10. Engine loads between 22.5 and 37.5 kW reduced CO emissions by 22.7%. B7E15 gasoline's CO specific emissions increased at all load levels except 35 kW, whereas B7E10's dropped 9.8%. This fuel increased CO emissions 38.7% at 5 kW.

C. NOx Emission

Researchers agreed that biodiesel-diesel blends emit more NOx than diesel alone. Balamurugan et al. found that diesel mixed with 4%, 8%, 4%, and 8% propanol reduced nox emissions by 6.098%, 19.668%, 11.585%, and 14.389%, respectively [87]. Adding 4%, 8%, 4%, and 8% propanol to diesel increased exhaust smoke density by 12.891%, 5.077%, 11.339%, and 14.063%, respectively. Motamedifar et al. found that NO emissions peak at 45 degrees D100 vane angle and air turbulence [125]. Higher temperature and 45-degree vane angles enhance NOx emission. Due to oxygenated biodiesel content, D70B25E5 emits.

Leite et al. [129] discovered that crambe oil production increased NOx emissions. Ashokan et al. [96] found that lower loads increase combustion temperatures and NOx emissions. B100 emits more NOx than diesel at full power. Kandasamy et al. discovered that B5E20 emitted less NOx than B5 at low to medium speeds but more at higher speeds [130]. The B5E20-fueled engine generates the least NOx at 0 h and full load performance. All fuels produce NOx at low to medium speeds when combustion completes and in-cylinder temperature peaks. After combustion, NOx generation and the greatest peak temperature in this research occur around the maximum torque zone. B5E20 emitted the most NOx at its maximum torque speed during a 500-hour durability study. Diesel engines produce nitrogen oxides based on combustion temperature, air-fuel ratio, cetane rating, and fuel oxygen. Ethanol's greater ignition delay increases B5E20 NOx generation. Ethanol mixed biodiesel (B5E20) has a lower cetane number because ethanol increases ignition delay and fuel/air mixture in the combustion zone.

D. Particulate Matter

Diesel-biodiesel mixes lower PM emissions. Zare et al. discovered that temperature, engine speed, fuel characteristics, engine load, and after-treatment systems affect particulate matter emissions [131]. Liquid and solid mixes in exhaust gas emissions are difficult to regulate because they are chemically undefined. Adding 5% waste lubricating oil increased PN by 13% at steady state and 43% at cold start. Vijayakumar et al. [92] found the greatest matter in D55 smoke particles at 20%, 40%, and 60% loadings. At 80% and 100%, D65 gasoline blends generated the greatest particulate matter smoke. All alcohol mixes generated less smoke particle matter than diesel.

Verma et al. [132] evaluated orange oil, tea tree oil, eucalyptus oil, diesel with commercial biodiesel, and diesel with gasoline. These gasoline blends have 0%–2.2% oxygen concentration. Soot aggregate fractal dimensions diminish oxygen-generated fuel main particle diameter. Diesel's aggregate geometry is complicated, nearly spherical. Oxygenated fuels have longer acoustic fringes and shorter, curvier, and more disordered edges than diesel. Verma et al. [133] utilised diesel (20–30%) and butanol as the main fuel. They observed that increasing the oxygen level of the fuel enhances soot particle reactivity, making them more compact and smaller while maintaining the needed oxygen content between 0 and 32% and 6.48%.

Verma et al. [134] utilised biodiesel blends with different triacetin levels as fuel. (B20 B50 B96 B100). Fuel oxygen content is 0–14%. Transmission Electron Microscopes study particle materials (TEM). When oxygen concentration increases, primary particle diameter and radius of gyration are less than diesel. When comparing fractions, oxygen is better than diesel in dimension. Even in fuels containing 11.01% oxygen, graphene layers in soot particles seem disordered. Table.2 shows performance and emission information from different sources.

E. Combustion Characteristics

Combustion qualities are a major point of divergence between fuels in terms of both the performance of the engine and the pollutants it produces. The ignition lag, heat output, burn duration, total heat output, and cylinder pressure are some of the indications that may be used to characterise the combustion process. In this part, we will talk about the features of combustion, such as the rate at which heat is released, the amount of time it takes for ignition, and the pressure within the cylinder. In this piece, we take a cursory look at the ways in which compression ignition (CI) engines have been able to profit from the combination of biodiesel and diesel fuel.

F. Heat Release Rate

The peak heat released by a biodiesel-diesel mix made from different biodiesels is lower than that released by diesel fuel [45][60][66][87]. Biodiesel's peak heat release rate is higher than diesel's at low engine loads (20% of full engine load), whereas diesel's is higher at high loads (95% of full engine load). According to Qi et al. [144]. At 25%, 50%, and 75% of engine load, Abu-Jrai et al. [145] analysed the diesel heat release and biodiesel-diesel blends. As the load increases, the maximum heat release rate rises to a new, lower plateau before rising again to a new, higher peak. The maximum amount of heat produced by an engine is at its TDC. Increasing the oxygen content of the injected fuel raises the maximum heat release rate and the fuel proportion in the premixed combustion phase at high engine speeds. The combustion parameters of a jatropha methyl ester biodiesel-diesel blend were examined by Lakshmi Narayana Rao et al. [146]. Maximal heat release rates were lower for higher concentrations of jatropha methyl ester biodiesel. Diesel's longer ignition delay compared to biodiesel-diesel allowed for greater fuel and air mixtures. The amount of heat generated by Diesel became higher.

G. Ignition Delay

Most investigations have indicated that a combination of biodiesel and diesel has a shorter igniting delay than diesel fuel, which is beneficial for diesel engines. According to the research of Lakshmi Narayana Rao et al. [146], increasing the percentage of jatropha methyl ester biodiesel in the mixture shortened the igniting delay across all loads. Jatropha methyl ester biodiesel is easily ignited because of its high oxygen concentration and the fact that its larger fatty acid molecules have been broken down into smaller ones, so generating more volatile matter. As shown by Jafari et al. [98], increasing the ignition delay and the engine speed may facilitate the nucleation of certain contaminants. The unburned carbon gets more tightly packed as a clump when there is more oxygen available. By increasing the amount of oxygen in the fuel, soot particle mass and number are decreased.

5. CONCLUSIONS

The engine's performance, emissions, and characteristics were measured using various methods to run, test, and reference diesel fuel. Because they have more oxygen, biodiesel-diesel blends burn faster. Biodiesel-diesel fuel with additives has a higher flash point, lower calorific value, and greater density. Better oxygen supply and combustion rate increase fuel utilisation. Many studies suggest that adding additives to biodiesel-diesel mixes decreases CO, hydrocarbon, and particle emissions. Adding a little biodiesel may increase NOx emissions. The diesel engine may just require additives and biodiesel to resist oxidation. Bio-based additives may minimise NOx and prolong engine components. In-depth study examined how additives affected biodiesel's characteristics, efficiency, and emissions as a diesel engine fuel. Results from this inquiry. Oxygen supplements abound. Additives may help biodiesel-diesel blends burn more thoroughly. Diethyl ether, ethanol, methanol, and n-butanol are oxygenated and may be added to biodiesel. The additive improved engine performance and BSFC. Biodiesel additives reduce NOx, CO, and PM.

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