# Review On Effects Of Biodiesel And Its Blends In Performance And Emission Of Diesel Engines

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*Abstract*

**The growing interest in alternative and renewable fuel sources is a result of the rising worldwide energy demand and concerns about the detrimental effects of fossil fuels on the environment. A suitable option for regular diesel fuel is biodiesel, a renewable and sustainable fuel derived from vegetable oils, animal fats, or used cooking oil. This review paper summarizes the research studies on the effects of biodiesel and its blends on diesel engine performance and emissions with additives as well as the effects of hydrogen induction Compression Ignition engines.**

**Keywords – alternative fuels, biodiesel, additives, emissions**

## I. INTRODUCTION

Any nation's economic development depends heavily on energy, which is also essential for the survival of the modern economy. Energy resources are crucial for developing countries, particularly India, which ranks third in total energy consumption according to theIndia Energy Outlook 2021 report by the International Energy Agency (IEA). The hydrocarbon reserves of our country are estimated to be very less. In thepandemic year 2020-21, over 84% of India's petroleum product demand (crude oil and petroleum products) was met with imports (Fig. 1). Gross petroleum imports of about 239 million tonnes (MT) of value US$77 billion accounted for over 19% of India's total imports in 2020-21.

Apart from this, the existing automobiles run on petroleum-derived fuels, causing pollution mainly in the air, exacerbating global warming and other crucial environmental issues. And it is found that these environmental issues are caused by pollutants like $NO_x$, CO and UHC emissions from the combustion of fuel in industries and transportation (Fig. 2).

To avoid this problem in the transportation sector research is conducted on alternative fuels, additives and hydrogen energy. And most research suggests that the use of biodiesel will be fruitful. Biodiesel is a renewable and sustainable alternative fuel for CI engines, derived from vegetable oils, waste cooking oils and animal fats. There are four types of biodiesels available: First generation, Second generation, Third generation, and Fourth generation. Biodiesel can be selected from any of the above-given generations based on need. But biodiesel from first generations (derived from corn, sugarcane etc.,) may rise the demand for that food crops. In this case to eliminate this 'Food vs Fuel' problem Third generation biodiesel like Waste Cooking Oil (WCO) can be selected. The main benefit of biodiesel is it can be used in any CI engine without any modification. Using biodiesel additives like Dimethyl Carbonate (DMC), Terpineol, etc., can further reduce the emission from biodiesel blends. Hydrogen energy consumption will be complex when it is inducted as primary fuel, which will require engine design modification. However, it can be inducted along with intake air as a secondary fuel.

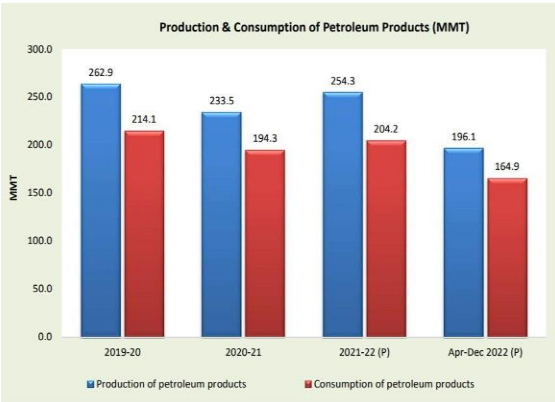


Figure 1

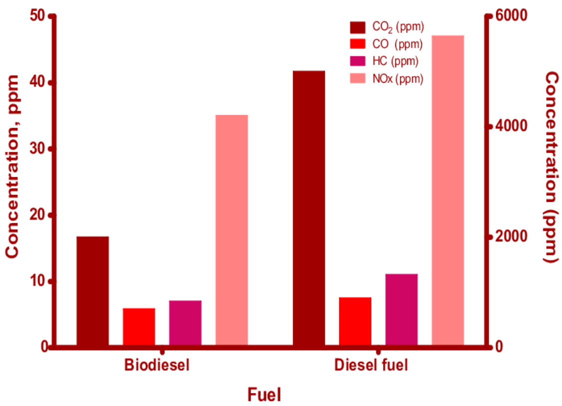


Figure 2

## II. EFFECTS OF BIODIESEL ON ENGINE EMISSION AND PERFORMANCE

C. Sowmya Dhanalakshmi et al. [1] conducted a performance study of a CI engine that runs on B20 biodiesel of Epoxidized Soya Bean Oil (ESBO). Petroleum Diesel has a higher calorific value than ESBO, Brake Thermal Efficiency (BTE) is higher than diesel anyhow and the average is 27.52%. The average Brake Specific Fuel Consumption (BSFC) is noted as 0.3 and its increases with %load. The maximum achieved BTE is 87.52% for ESBO biodiesel at higher compression ratios (17.5:1). Performance study is done by using Enginesoft software.

According to the comparative assessment of diesel engines with 3 different generations of biodiesel accomplished by Sara Tayari et al. [2] the Microalgae Chlorella Vulgaris (MCV) has long chain Fatty Acids and Methyl Esters of Eruca Sativa (MEES) has the greater calorific value as well as greater engine performance. Among the 3 different biodiesel MCV has the lowest performance which is only 78.9 to 86.1% of the output achieved by diesel. MCV is responsible for high BSFC which is about 15.2%. All three biodiesels have lower CO emissions compared to diesel, but the lowest is achieved by MCV. It seems using MCV can reduce HC emissions by up to 51.1%, but it resulted in 5.1% higher $NO_x$ than pure diesel and which is still higher than other biodiesel.

Suleyman Simsek et al. [3] compared the effects of using Animal Fat Oil Biodiesel (AFBD) and Vegetable Oil Biodiesel (VEBD) on the performance and emission of CI engines. That they have observed the BTE of VEBD is close to Diesel because of similar viscosity and the BTE of AFBD is less than Diesel due to less viscosity. Since AFBD and VEBD both have lower heating values they seemed to increase the BSFC. The higher cetane number of VEBD and AFBD tends to low CO and HC emissions. Because of greater oxygen, aromatic content, and density, $NO_x$ emissions were increased. The lowest smoke emission is achieved by VEBD100.

A comparative analysis of CI engine performance done by Edvin Geo V et al. [4] using Rubber Seed Oil (RSO) as biodiesel showed the following results. The Methyl Ester of Rubber Seed Oil (RSOME) ramps up the BTE 1.3% higher than neat RSO. Moreover, RSOME has less $NO_x$ emission than RSO about 0.6 BSU lesser. The highest efficiency of 28.5% is achieved by injecting ethanol and Diethyl Ether (DEE).

An analysis of marine diesel engines powered by Parinari polyandra oil as biodiesel done by Noor A. Ahmed et al. [5] showed that the engine performance in terms of speed, power, and thermal efficiency was found to be improved by using B10 as the optimal blend. In comparison with pure diesel or other fuel blends the engine achieves maximum speed with the B10 blend. The BSFC increases with an increase in the proportion of biodiesel in the blend.

Experimental testing has been carried out by Medhat Elkelawy et al. [6] at various engine loads for a constant speed of 1400 rpm to determine how diesel/biodiesel blends affect engine combustion, performance, and exhaust gas pollutants. 30,50 & 70 volumetric percentages of diesel/biodiesel blends are used by single-cylinder diesel engines. The engine findings reveal that B50 reduces the rate of change of CO by 33.8% when compared to diesel fuel. Due to biodiesel's low calorific value and short ignition delay, larger biodiesel blend percentages resulted in a modest drop in maximum cylinder pressure. The estimated Heat Release Rate (HRR) difference between biodiesel blends and diesel fuel at 10%, 30%, and 60% of the maximum engine power, were approximately 31.7, 52.4, and 63.5 (J/deg of CA). For diesel fuel, B70 had the biggest reduction in HC emissions, which was around 4.18%. Diesel has lower $NO_x$ emissions than biodiesel blends. B70 had roughly 0.98% more exhaust oxygen (EO) emissions than diesel. With B70, brake-specific fuel consumption (BSFC) rises till it reaches 11.43%.

S. Senthur Prabu et al. [7] have studied the effects of additives on combustion, performance, and emission using preheated Palm Oil/Diesel (PO) blends in a diesel engine. They preferred n-Butanol as an additive and they concluded that PO20+Butalytaed Hydroxyl Toluene blends consequently increase the BTE 5.1% higher and 11.4% higher fuel consumption concomitantly when compared to neat diesel fuel at 1500 rpm. Even so, the $NO_x$ emission is 1.9% greater than that of diesel fuel, however, the CO emission is 37.5% lower for PO20+butanol (20% by volume). Furthermore, compared to diesel fuel, the smoke and Exhaust Gas Temperature (EGT) is estimated to be 13% and 3.1% lower, correspondingly.

André Valente Bueno et al. [8] conducted an experimental study of performance and emissions characteristics of Castor Oil Biodiesel Fuel Blends and they observe that B10 and B20 blends do not have any significant difference in engine performance when compared to diesel. Moreover, the blending of Castor Oil did not affect the Injection timing. But both Soya Bean and Castor Oil resulted in more $NO_x$ emissions than diesel. And it is observed that during low load conditions, Castor Oil blends showed more Particulate Matter (PM) emissions than diesel.

The experimental done by R. Sathiyamoorthi et al. [9] investigated that in a way a direct injection diesel engine's combustion, emissions, and performance were affected by adding modest amounts of ethanol (2.5% and 5%) to a mixture of plain Lemongrass Oil (LGO) and diesel fuel. Comparing ethanol blends to diesel fuel and LGO25 (a mixture of 75% neat diesel and 25% neat lemongrass oil), it is found that the ethanol blends had greater combustion pressure, heat release rate, brake-specific fuel consumption, and brake thermal efficiency. However, undesirably it led to increased $NO_x$ and $CO_2$ emissions as well as decreased smoke and HC emissions. The study also discovered that the LGO25-ethanol mixes had longer combustion times and longer ignition delays.

The addition of Ethanol with biodiesel blend done by F. Aydın et al. [10] shows that the blend B2.5M5D92.5 (it denotes a mixture of 2.5% Bioethanol 5% Safflower Biodiesel 92.5% Diesel) has maximum Brake Power (BP) than any other blend when the engine runs at 2100 rpm. However, the BSFC of all blends differs less from diesel marginally. At 1600 rpm among other fuels B5M2.5D92.5 has less CO emission of less than 0.25 %, which denotes complete combustion. Use of B2.5M5D92.5 results in lower $CO_2$ emission than other blends. B5M2.5D92.5 only emits low HC emissions. The amount of $NO_x$ released decreases with increasing the proportion of Ethanol.

The addition of a Carbon Nano Tube (200 nm) additive (MENO+CNT200 blend) to Neem Oil Methyl Ester neat biodiesel done by G. Balaji et al. [11] showed to improve the engine performance and reduce emissions. In particular, when compared to utilizing neat biodiesel alone, the brake thermal efficiency rose by 4.17% and $NO_x$ emissions decreased by 7.25%. Furthermore, $NO_x$, HC, CO, and smoke emissions were decreased as a result of the use of the nano additive. After the addition of the nano additive, it was discovered that the engine performance characteristics, including the brake thermal efficiency, had improved while the brake-specific fuel consumption had dropped.

Bhupendra Singh Chauhan et al. [12] studied the performance and characteristics of a diesel engine fuelled with Jatropha Oil as biodiesel. That they have observed the following; Although the biodiesel made from Jatropha oil has a lower calorific value than diesel and a higher density, the difference is not very large. Biodiesel made from Jatropha oil has a greater kinematic viscosity than diesel. According to the testing findings, diesel fuel and Jatropha biodiesel both performed similarly in terms of engine performance. For the whole trial, jatropha biodiesel had greater nitrogen oxide levels than diesel fuel. When compared to diesel, pollutants like CO, smoke density, and HC were reduced while the engine was running on biodiesel and its blends. The complete combustion of the fuel could be accountable for these emission reductions.

The effect of biodiesel fuel on diesel engine research conducted by K.A. Abed et al. [13] showed that CO, HC, $CO_2$, and smoke emissions are lower for biodiesel blends B10 and B20 (Jatropha, algae, and palm) compared to diesel fuel. $CO_2$ emissions from biodiesel blends B10 and B20 produced from waste cooking oil are higher compared to diesel fuel. $NO_x$ emissions from all biodiesel mixtures B10 and B20 increase more than diesel fuel for all biodiesel blend B10 and B20.

## III. EFFECTS OF HYDROGEN INDUCTION WITH BIODIESEL

Jayagopal Subramanian et al. [21] concluded under the duel-fuel mode, the engine results for WFOB70D30 + H10 (Waste Frying Oil Biodiesel 70% Diesel 30% and Hydrogen 10%) waste fuel blend had a higher 4.2% BTE, 19.72% $NO_x$, and 9.09% ignition delay (ID) with a minimal range of in-cylinder pressure, volumetric efficiency and heat release rate (HRR) and a dropped rate of 4.34% brake-specific energy consumption (BSEC), 33.33% CO, 39.28% HC, 9.43% smoke, and 6.97% combustion duration (CD) related to diesel fuel at peak load.

On the effect of pilot-injected diesel blends with inducted oxy-hydrogen gas conducted by Jami Paparao et al. [22], results revealed that heat release rate, brake thermal efficiency, exhaust gas temperature, and nitric oxide emission are found to be higher by about 5.2%, 1.1%, 18.6%, and 19.6% respectively, while unburnt hydrocarbon, carbon monoxide, and smoke emissions are reduced by about 33.3%, 29.4%, and 18.7% respectively in ME20 + HHO operation compared to that of the baseline data at maximum load.

With varying fuel injection pressure of 220, 240, and 260 bar and injection timings of 21, 23, and 25° CA before the top dead centre (bTDC), Surya Kanth and Sumita Debbarma [23] investigated the effect of diesel engine injection parameters on 10 lpm hydrogen-enriched Karanja biodiesel (bTDC). The investigated results indicate that at 240 bar injection pressure and 23° CA bTDC injection time, Karanja biodiesel with enhanced hydrogen (KB20H10) raises BTE by 4% more than diesel fuel. UHC, CO, and smoke opacity emissions for blend KB20H10 are 33%, 16%, and 28.7% lower than for diesel. Nevertheless, $NO_x$ emissions have increased by 10.3%. Based on the considerable improvement in performance, combustion, and exhaust pollution reduction, it was found that 240 bar injection pressure and 23 °CA bTDC injection time were the ideal injection parameters for blend KB20H10.

Surya Kanth and Sumita Debbarma [24] analyzed the effects of edible and non-edible biodiesel on engine performance comparatively with hydrogen enrichment of 7 lpm. The findings show that adding hydrogen to fuels improves combustion and enhances brake thermal efficiency by 2.5% and 1.6% for diesel fuel and rice bran biodiesel, respectively. The improvement is negligible for Karanja biodiesel. The fuel consumption of the D + $H_2$ is reduced by 6.35%, while that of the RB10 + $H_2$ and KB10 + $H_2$ is reduced by 2.9% and 1.3%, respectively. Due to improved combustion, there are 4 to 38% fewer CO emissions and 6 to 14% fewer UHC emissions when hydrogen is present. The $NO_x$ emission from the blends RB10 + $H_2$ and KB10 + $H_2$ can increase by up to 6 to 13%, and it can increase by up to 25% for the blends RB20 + $H_2$ and KB20 + $H_2$. Overall, it is discovered that rice bran oil outperforms Karanja biodiesel in terms of performance.

On checking the effect of using Chlorella vulgaris methyl ester enriched with hydrogen, conducted by Sara Tayari, and Reza Abedi [25] revealed that it had led to lower emissions of CO, HC, and $CO_2$ and reduced engine power and torque, whereas there was a minor increase in $NO_x$ emissions. By hydrogen enrichment, CO, $CO_2$, and HC emissions decreased more, compared with the emissions of pure diesel, while $NO_x$ emissions kept an increasing trend.

An experiment conducted by Prabhu Chelladorai et al. [26] to study the effect of hydrogen induction with a grapeseed biodiesel blend in a CI engine exposed that, in comparison to biodiesel operation without hydrogen induction, $NO_x$ emission from grapeseed biodiesel with the highest hydrogen share at full load is greater by 43.61%, but smoke emission is reduced by 19.73%. BSEC falls off with an increase in hydrogen energy share. Due to enhanced combustion and the substitution of a portion of a hydrocarbon fuel with the carbon-free fuel hydrogen, the levels of smoke, HC, CO, and CO2 were significantly reduced when hydrogen was introduced into diesel, NGSO, and GSBD engines, respectively.

Mohamad Aldhaidhawi et al. [27] did an experimental and numerical study to examine the effects of biodiesel. The results show that biodiesel B20 reduces engine performance, efficiency, and emissions, except for slightly increased $NO_x$. The ignition delay on biodiesel B20 is shorter. While the $NO_x$ emissions had the same rising trend for 1400 rpm and had a barely perceptible trend for 2400 rpm, the CO emissions, smoke, and total unburned hydrocarbon emissions (THC) reduced with the addition of hydrogen (0 to 5% volume) to B20 and aspiration of the intake airflow. Diesel and B20 fuel enrichment with hydrogen has no discernible impact on ignition delay.

## IV. EFFECTS OF USING HEXANOL ALONG WITH BIODIESEL

According to Santhosh. K et al. [41] addition of 1-hexanol equally to the amount of diesel, and the combustion can be improved by advancing the injection time. The 1-Hexanol blend seems to increase the BTE up to 14.28%. Compared to standard injection timing $NO_x$ increases due to advancing injection timing but at the same time, this drastically reduces the CO and HC emissions.

A. Ramesh et al. [42] experimented to study the influence of hexanol additive with Calophyllum Inophyllum biodiesel in a CI engine and exhibited that, at all loads the ternary blend D50B10H40 has higher efficiency than B10. Adding 40% hexanol enhances the heat-releasing rate (HRR) due to better fuel atomization and higher oxygen content of blends. All the blends have lower peak pressures, and the CO emission reduces with the increase in the amount of alcohol content in the blend. The addition of hexanol gives the same amount of $NO_x$ if neat diesel is used.

## V. EFFECTS OF ADDITIVES (DIMETHYL CARBONATE)

Research on the effect of the combination of ignition improvers Dimethyl Carbonate (DMC) and Exhaust Gas Recirculation (EGR) on the Common Rail Direct Injection (CRDI) small single-cylinder diesel engine conducted by T.Ramesh et al. [36] resulted that at 20% EGR rates, the BTE for B20 + 5 ml DMC is higher than that for other test samples, but it is still 5.64% lower than for pure diesel, and the B20 blends show better results in BSFC and Smoke emission dropped when the use of 5 ml DMC proportion was 20% EGR level. Both CO and UHC emissions were reduced in the presence of DMC enhancers. Finally, it is concluded that the ternary mix (B20 + 5 ml DMC) operated at standard engine conditions and 20% EGR rates can be efficiently utilized in a CRDI-equipped diesel engine.

Dimethyl carbonate (DMC) could be considered a high-oxygenated, green additive. A. Chandravanshi et al. [37] conducted a study, where adding DMC to biodiesel increases the quality of combustion, hence reducing emissions with improved thermal efficiency. If DMC is blended with biodiesel along with 10% Exhaust Gas Recirculation (EGR), then results show higher Brake Thermal efficiency with 5% DMC in the biodiesel-diesel blend as compared to biodiesel, but lower than that with diesel. Brake Specific Energy Consumption increases with the increase in DMC in the fuel blend at medium and higher loads, which limits the use of DMC in higher content (10%, 15%). Carbon Mono oxide and Hydrocarbon emissions reduce with lower content of DMC (5%) at a higher load. There are slight increases in Carbon Dioxide at all loads, under the safe limit. The emission of Oxides of Nitrogen ($NO_x$) decreases slightly, and this decrease increases with EGR. Higher content of EGR adversely affects the performance and emission characteristics except for $NO_x$ and smoke emission. A large decrease in smoke was noted with DMC as an additive in biodiesel due to improved combustion.

The effect of Biodiesel Dimethyl Carbonate blends in an experiment conducted by Luqmann Razzaq et al. [38] results in minimum BSFC has been observed for B10+DMC as compared to all blends and the addition of 10% DMC where BTE and EGT have been improved and CO and HC emissions reduced with addition of DMC. The addition of fuel additive escalates the $NO_x$ emission due to high cetane number and high oxygen content.

To control the cold flow properties research made by Jiahui Gu et al. [39] by using Palm oil biodiesel blends results in the addition of Dimethyl carbonate volume ratio of Biodiesel in blends must be no more than 30% to keep the original cold flow performance of diesel.

DMC may be a promising additive for diesel fuel owing to its high oxygen content, no carbon-carbon atomic bonds, suitable boiling point, and solubility in diesel fuel. The experimental results have shown that Particulate Matter (PM) emissions can be reduced using the DMC oxygenated compound. The combustion analysis indicated that the ignition delay of the engine fuelled with DMC-diesel blended fuel is longer, but the combustion duration is much shorter, and the thermal efficiency is increased compared with that of a base diesel engine. This was concluded by G.D. Zhang, H Liu, et.al. [40]

## VI. WASTE COOKING OIL AS BIODIESEL

Mohammed F. Al-Dawody et al. [14] carried out an experimental study of the performance of CI engine runs by Methyl Ester of Waste Cooking Oil (MEWCO). 10% MEWCO results in 3.14% higher $NO_x$ emission than neat diesel. Adding 10% more MEWCO reduces up to 45.27% PM emissions than pure diesel. A 2.15% increase in BSEC is noted for the engine when it runs 100% MEWCO instead of diesel.

According to Gerard Byrne et al. [15] the B10 blend gives no significant change in the performance of the engine. But it differs by 2.7 and 3.7% increase in mechanical performance than the B10 scenario, for B50 and B70 blends when this case was studied at 2500 rpm. At 2500 rpm B70 blend accounts for 30% of $NO_x$ than diesel.

The study evaluated by C. Adhikesavan et al. [16] reveals that the density and flash point of both types of biodiesels were reported to fall within biodiesel standards acceptable ranges after the study looked at the properties of biodiesels made from highly degraded waste cooking oils (WCOs) of palm and sunflower. The study also discovered that the pour point of the biodiesels was not significantly affected by the Total Polar Materials (TPM) values of the WCOs. Nevertheless, the TPM of the WCOs greatly enhanced the kinematic viscosity values of the biodiesels. Although the WCO-based biodiesels had somewhat better calorific values than those made from unused oils, they also created significantly more CO emissions. The study discovered no discernible difference between the two forms of biodiesel in $NO_x$ and smoke emissions.

A study done by Dhinesh Balasubramanian et al. [17] suggests that B20 is suitable in addition to that 10% EGR rate as an optimal rate to reduce $NO_x$ emissions of about 16.34%, due to B20 exhibiting low-pressure variations in the cylinder leads to less noise. However, B20 showed a reduced BTE of about 1.85% compared to diesel at full load. Moreover, B20 exhibited greater BSFC up to 6.89% but it resulted in high flame temperature which will lead to high HRR and in-cylinder pressure. But with a maximum drop of 17% in unburned hydrocarbon (HC), 30% in carbon monoxide (CO), 14.08% in smoke, 7.35% in carbon dioxide ($CO_2$), and a 16.46% rise in $NO_x$ emission, it was determined that B20 blend fuel would be the optimum choice for the test engine.

An emission analysis completed by Ahmet Necati Ozsezen et al. [18] found that for all engine speeds, biodiesel produced 14.7% higher $NO_x$ emissions than PBDF while emitting 57% less CO, 40.3% less unburned HC emissions, 22.5% less smoke opacity, and 3% less $CO_2$ concerning PBDF. The Methyl Ester of Waste Palm Oil (WPOME) produced a longer combustion duration, which led to earlier SOI and ignition timing. The CO, HC emissions, and smoke opacity were reduced at higher speeds as a result of the prolonged burning duration and improved oxidation caused by the oxygen content present in the biodiesel.

Abin Mathew and K. Anand [19] compared the engine characteristics of biodiesels made from fresh and used cooking oils, and the results showed that using WCO increased BSFC ramps by 22% and decreased CO and smoke emissions by 6.3% and 69.2%, respectively. Undesirably, it led to 5.6% more $NO_x$ emissions than expected. Moreover, both fresh and WCO biodiesel proved to have identical engine characteristics. For instance, the SOI and SOC advance with higher peak pressures for biodiesels than diesel under higher load conditions.

G.R. Kannan & R. Anand [20] concluded the following while studying the effects of injection pressure and injection timing on waste cooking oil biodiesel-fueled diesel engines. In the first place, based on the improvement in brake thermal efficiency by 1.44% and the reduction in NO and smoke emission by 6.5% and 17.2%, it was discovered that the injection pressure of 280 bar and the injection timing of 25.5° bTDC (before Top Dead Center) were the optimum conditions for engines using biodiesel. Next to that, the maximum cylinder gas pressure and heat release rate of biodiesel at 280 bar with 25.5° bTDC were 2.1% and 1.1% greater than those of diesel fuel under typical operating conditions, respectively. Ultimately, at 280 pressure and 25.5° bTDC, the ignition delay duration of biodiesel was 10.23 ° CA, 2.56 ° CA (Crank Angle) slower than that of diesel fuel.

## VII. EFFECTS OF USING TERPINEOL WITH BIODIESEL

The study conducted by Magín Lapuerta et al. [28] found that blends with 20% volume content in hydrogenated terpenes can be used as feasible fuels with similar fuel consumption and engine efficiency as diesel. However, the blends had higher HC and CO emissions due to their higher equivalence ratio and lower cetane number. The blends also reduced particle mass emissions but increased particle number emissions, especially in the case of HT-20, which had a higher mean particle diameter in the nucleation mode and lower mean particle diameter in the accumulation mode compared to diesel.

The properties of Oxyturpentine evaluated by Rosario Ballesteros et al. [29], the mixture's viscosity is increased by the principal oxyturpentine constituents, nopol, $\alpha$-terpineol, and $\beta$-pinene, but it still resembles diesel, especially in blends with concentrations less than 20% vol. Nopol and terpineol both contribute to the blends' increased density, with just a little volume surplus in the case of biodiesel blends. Oxyturpentine enhances lubricity and has synergistic effects at low concentrations of 1-5% vol. Yet, as seen in both vapour pressure and distillation curve measurements, the volatility of oxyturpentine is higher than that of diesel and biodiesel fuels but lower than that of turpentine. The presence of oxyturpentine in diesel and biodiesel blends affects the heating value of the fuel. Oxyturpentine reduces the heating value of diesel blends, but it increases the heating value of biodiesel blends. However, the heating value per unit volume increases in both cases, which improves fuel tank autonomy. Additionally, the study found that the cloud, pour, and cold filter plugging points of diesel and biodiesel blends decrease linearly with the oxyturpentine content. This decrease reduces the occurrence probability of filter plugging by decreasing the temperature at which crystals are formed. Although oxyfunctionalization causes a deterioration in these properties, the influence of oxyturpentine on the cold-flow properties of diesel and biodiesel blends is still positive. Finally, the sooting tendency of oxyturpentine blended with diesel decreases as the oxyturpentine content increases. Therefore, the study expects a reduction in emissions of particulate material from engines using oxyturpentine blended fuels.

Duban García et al. [30] conducted an experiment that shows, due to a greater equivalence ratio and EGR, adding oxyturpentine to diesel fuel causes an increase in CO and HC emissions. The oxyturpentine mixture's high surface tension and volatility can interfere with atomization and diffusion processes, increasing gaseous hydrocarbon emissions. Because of the higher EGR and lower cetane number of the fuel, $NO_x$ emissions are reduced. The oxygen in the fuel molecules aids in the oxidation of soot, which lowers the amount of particulate matter. Despite the high concentration of a-pinene in oxyturpentine, which has a larger propensity to produce soot than nopol or even diesel, nopol's propensity to reduce soot predominates, decreasing PM emissions.

On examining the effect of pine oil and soapnut oil V. Venkatesan et al. [31] conducted a study on methyl ester blends and discovered that the blends of P100SNB0, P75SNB25, and P50SNB50 had an increase in BTE of about 13%, 10%, and 8%, respectively, at full load when compared to diesel. At full load, the blend P50SNB50 reduced BSFC by 18%, and the blends P75SNB25 and P50SNB50 reduced UHC emissions by 40% when compared to diesel. At full load, the CO emission for the blend P75SNB25 is 6% lower than for the other test fuels. At low loads, the blend P75SNB25 had a 3%-5% increase in $NO_x$ emissions when compared to diesel.

Akash Deep et al. [32] have presented an experimental investigation to replace diesel fuel with pine oil without significantly compromising engine performance and resulting in a reduction in exhaust emissions. Instead of having lower calorific values, all of the blended fuels have demonstrated near agreement in terms of the engine's BTE and BSFC. It also demonstrates that the maximum temperature of combustion for mixed fuel may be the same as diesel and that, as a result, $NO_x$ emissions are not raised. The enhanced atomization of the combined fuel and higher combustion rate is both a result of pine oil's reduced kinematic viscosity. The better combustion process is the cause of the decreased smoke opacity for mixed fuel when compared to diesel.

S.M. Ashrafur Rahman et al. [33] studied essential oils' fuel properties and emission characteristics and showed that tea tree oil contains terpinene-4-ol, γ-terpinene, and α-terpinene as major components. And other essential oils like orange oil have lower oxygen contents than eucalyptus and tea tree oil. They concluded that the use of tea tree oil results in lower CO emissions than orange oil and eucalyptus oil. Even though eucalyptus and tea tree oil have more or less the same amount of oxygen, tea tree oil gives more $NO_x$ emissions than eucalyptus oil. Orange oil diesel blend has higher HHV and similar LHV. But tea tree oil and eucalyptus oil blend have lower Higher Heating Value (HHV) than neat diesel. Compared to neat diesel fuel all the essential oil diesel blends have lower cetane numbers, flashpoints, and viscosity.

A study conducted by T. Prakash et al. [34] indicates that Pine oil is an alicyclic hydrocarbon and consists of cyclic terpene alcohols known as terpineol ($C_{10}H_{18}O$) along with α–pinene ($C_{10}H_{18}$). The study suggests castor oil as a possible diesel substitute, however excessive viscosity conflicts with cold starting and combustion. Castor oil is transformed into biodiesel through transesterification, which enhances combustion behaviour, and pine oil is combined to lessen viscosity as a solution to this problem. Nevertheless, because of issues with knocking, pine oil may only replace castor oil to a maximum of 30%. Using raw castor oil lowers the engine's brake thermal efficiency by 28%; however, COME and NCO70 + P30 mixes increase this efficiency. Castor oil operation results in lower $NO_x$ emissions than diesel, but greater $NO_x$ emissions than COME operation. In comparison to neat castor oil, COME emits less smoke.

The results of S. Nallusamy et al. [35] experiment on pine oil biodiesel blend showed that using 100% pine oil as fuel under full load conditions reduced CO, HC, and smoke emissions while increasing $NO_x$ emissions. We examined the combustion emission characteristic of a diesel engine powered by pine oil and biodiesel mixes. According to test results, the blend of 50% pine oil and 50% biodiesel performed the best. Under full load conditions, the $NO_x$ emission was comparable to that of diesel, whereas the CO, HC, and smoke emissions were each lower than diesel. The emission characteristics of a pine oil blend were investigated in a diesel engine equipped with SCR and a catalytic converter. The blending ratio of pine oil increased the thermal efficiency of the brake. CO, HC, smoke, and $NO_x$ emissions have all decreased.

## VIII. CONCLUSION

The research discussed so far resulted in the following conclusions;

1. Biodiesel and its blends having higher cetane number serves as better alternatives in diesel engines with pros and cons
   a. Lower CO and HC emissions with increasing $NO_x$.
   b. Brake thermal efficiency decreases with an increase in biodiesel proportion.
   c. Almost all the biodiesel blends resulted in higher BSFC.
2. Cetane rating and combustion properties can be enhanced by using suitable additives (Dimethyl Carbonate) with biodiesel blends.
3. Biodiesel with nanoparticles resulted in better performance with lesser emission.
4. In search of optimization between emission and performance, a new scope on hydrogen as a blend evolved that seems to be a better alternative in the future.

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