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Effect of biodiesel and nano particles on the performance and emission characteristics of CI engine at various fuel injection pressures–critical review

Simhadri K.[1,2,*], Srinivasa S.R.[2] and Paswan M.[3]
[1]Department of Mechanical Engineering, GMR Institute of Technology, Rajam, A.P., India.
[2]Department of Mechanical Engineering, Centurion University of Technology and Management, Odisha, India.
[3]National Institute of Technology, Jamshedpur, Jharkhand, India.
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*to whom all correspondence should be addressed: e-mail: simhadri.k@gmrit.edu.in, simhadrikambala@gmail.com
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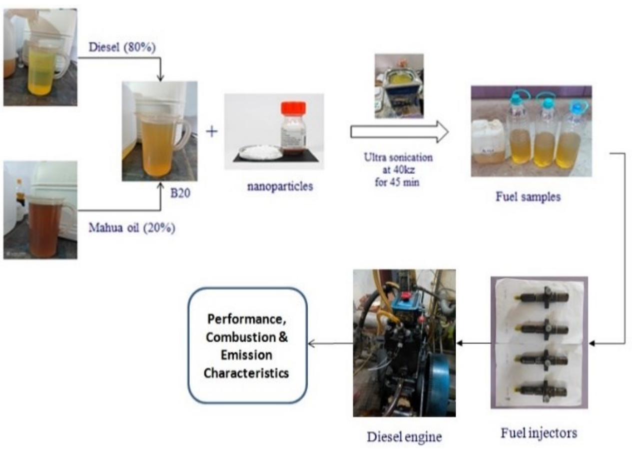
Graphical abstract



Abstract

In recent years, Due to the depletion of petroleum reserves and rising environmental concerns, alternative fuels have attracted a lot of attention. This study investigates the combustion, emissions, and performance properties of diesel engines running on biodiesel-diesel blends. Recent developments in nanotechnology have made it possible to use fuel injection pressures and nanoparticle fuel additives in internal combustion engines. By adding nanoparticles to biodiesel-diesel blends, the amount of brake specific fuel is reduced. Additionally, nanoparticles have a high thermal conductivity, which improves combustion and brake performance. According to the reviews, NOx emissions increased while HC, CO, and PM emissions reduced. The results show that biodiesel and biodiesel blends as a fuel for CI engines might significantly enhance performance while reducing emissions by adding nanoparticles and also the fuel injection pressure is the main vital parameter for improving the performance and emission characteristics.

Keywords: Biodiesel, additives, performance, combustion, emissions and fuel injection pressures

Nomenclature

CI	Compression Ignition
FIP	Fuel Injection Pressure (unit: bars)
FIT	Fuel injection Timing
BTE	Brake Thermal Efficiency (unit: %)
CO	Carbon Monoxide (unit: ppm)
HC	Hydrocarbon
NO_X	Oxides of Nitrogen (unit: ppm)
C.R	Compression Ratio
CO_2	Carbon Dioxide (unit: ppm)
BSFC	Brake specific fuel consumption (unit: g/kW·h)
EGT	Exhaust Gas Temprature (unit: °C)
DI	Direct Injection
BTDC	Before Top Dead Centre (unit: °C)
EGR	Exhaust Gas Recirculation

1. Introduction

Biodiesel

Biodiesel is a principal component of vehicle fuel. Similar to fossil fuels, biodiesels are good fuels with similar characteristics that can be utilised in diesel engines. Different vege\ oils and animal fats can be used as a feedstock for biodiesel extraction. The ASTM defines biodiesel as a fuel consisting of long-chain fatty acid alkyl esters (methyl, ethyl or propyl) obtained from different oils from plants and fats from animals (Soloiu *et al*. 2013). The methyl esters of fatty acids (FAME) and another term for biodiesel are methanol and ethanol, as much of the available alcohol is used in biodiesel production. Small concentrations, including B20, are best referred to as biodiesel blends. A decent number of biofuels are utilised in our day to day lives, labelled as a first-generation, including ethanol production from maize fermentation, sorghum and sugarcane and biodiesel produced in our daily lives. Raw coconut oil, raw sunflower oil, raw palm oil, raw peanut oil are all the first generations of edible oil. Raw jatropha oil, raw mahua oil, raw Pongamia oil, etc., are the second-generation of non-edible oils (Banapurmath *et al*. 2009). The essential properties of fuel for the engine's combustion chamber system, fuel system of vehicles, storage of fuel, and dispensing system of fuel. The fuel characteristics will affect the engine performance, emissions reliability, fuel efficiency and durability of vehicles. In determining the safe risk presented by fuel, fuel properties are essential. Fire and blow-up risks occurred because of the flammability of fuel. The high quantity which complies with conventional biodiesel fuel requirements is the most crucial point of biodiesel.

2. Literature review

In a 4-stroke, one-cylinder, water-cooled CI engine with a mechanical fuel injection system and a variety of engine loads, the engine's efficiency and biodiesel emissions from coconut oil were examined. This biodiesel has led to higher NO_x levels compared to diesel (Suryawanshi, 2006). Biodiesel from Mahua oil its blends has been assessed in the Richard E6 CI engine at various fuel injection timings, compression ratios, and high-speed diesel contrasts. As well as petrol, the B20 displayed finer performance (Raheman and Ghadge, 2008). Investigation of the impact of different FIPs on the CI engine run with Honge oil methyl ester biodiesel blend. Brake thermal efficiency enhanced with a peak injection pressure of 260 bars, was assigned to enhance the air-fuel mixing rate (Banapurmath *et al*. 2009).To evaluate the exhaust emissions and rate of heat liberation at different FIP (215, 235 and 255 bars), it was reported of 30 percent orange peel waste powder with neat diesel results in-Cylinder pressure and rate of heat liberation at 235 bar FIP while exhaust emissions were greatly compared to other FIPs (Purushothaman and Nagarajan, 2009). They claimed that BTE is greater at 240 bar of fuel injection pressure (FIP), while CO emissions are lower than emissions from neat diesel (Puhan *et al*. 2009). It raised BTE and NOx emissions were seen in the research of the effects of different FIP on the CI engine running on a 50% blend of pure biodiesel, while when the fuel's FIP was increased, lower levels of CO, HC, and smoke emissions were noticed (Belagur and Chitimini, 2010). Although HC and CO emissions were reduced, NOx emissions were increased due to the fuel mixes' increased oxygen content (Kim and Choi, 2010). Annona methyl ester biodiesel of 20%blended with neat diesel of 80%, calculation of enhancement in engine working parameters such as FIP, FIT and C.R. of 190 to 250 bars, 24 to 33^0BTDC and 16.5:1 to 19.5:1 (Ganapathy *et al*. 2011). Rapeseed oil's effects on CI engine characteristics were studied, and It was discovered that higher injection pressure resulted in lower smoke and carbon monoxide emissions but slightly higher HC emissions (Kegl, 2011). Emissions of CO and HC were reported as decreased than diesel. Conversely, BSFC and emissions of CO_2 were higher for soybean biodiesel and revealed higher NO_x emissions (Özener *et al*. 2014). The outcome of biodiesel fuel extracted from canola oil at various injection pressures was studied, and the results of various engine loads showed that the high rate of heat liberated and maximum pressure increase rate (MRPR) slightly reduced with raise in biodiesel blends (Sayin *et al*. 2012). With an increase in engine speed, fuel consumption rate, BTE, and EGT increased while BSFC, CO2, CO, and NOx decreased (Adaileh and Alqdah, 2012).

Biodiesel blend from fish oil methyl ester at various concentrations was utilized as a working fuel in direct injection diesel engine and selected 20 percent FOME showed promising results of NO_x reduction using ECR (Bhaskar *et al*. 2013). At a high fuel injection rate, biodiesel of n-butanol used as a fuel in the DI diesel engine results in a 90% reduction in soot emissions and a 50% reduction in NOx emissions (Soloiu *et al*. 2013). The study showed that the Opacity emissions from C.O., H.C. and Smoke were lowered while the NO_x and CO_2 emissions were raised (Chauhan *et al*. 2013).

The B10 and B20 blends of jatropha biodiesel were tested for their performance and emission characteristics. While CO and H.C. emissions are declining, NOx emissions are increasing by 3% and 6% (Mofijur *et al*. 2013). The investigation of various biodiesel blends from Ceibapentandra at various engine speed outcomes, C.O., Hydrocarbon and smoke visibility in terms of exhaust emissions were reduced (Silitonga *et al*. 2013).

Due to their higher densities and lower calorific value than diesel, these mixes have a higher BSFC. Emission characteristics such as H.C. and C.O. were dropped, and CO_2 and NO_x were raised for these fuel blends compared to diesel (Liaquat *et al*. 2013). MOME to meet emission criteria of the central pollution control board (CPCB)either by raising the FIP of Fuel to 275 bar or by delaying the FIT of Fuel to 21^0BTDC (Mohan *et al*. 2014). The outcome shows at lower FIP, HRR and cylinder pressure was increased. The engine is enhanced at lower fuel injection pressure, resulting in improved thermal brake efficiency as well as BSFC charging conditions for entire engine operation (Agarwal *et al*. 2014). Three distinct concentrations of B5 and B20 (30 ppm, 60 ppm, and 90 ppm) were used effects fuel consumption decreased by 4.50 percent, engine efficiency parameters improved, i.e. torque and power. Up to 18.9 percent reduced NO_x. C.O. decreased by as much as 38.8% (Mirzajanzadeh *et al*. 2015). For the biodiesel study, lower H.C. emissions were noticed for all loads with better NO_x, Smoke and C.O. emissions (Balaji and Cheralathan, 2017). The study indicated lower engine noise and emissions of PM, H.C. and C.O. (except for NO_x) compared to diesel fuel (Magno *et al*. 2015).

The study was also carried out for all conditions at various timings for exhaust gas injection and EGR. Improved engine efficiency, combustion and emissions have been noted in alternative fuel tests (Millo *et al*. 2015). Citrullus vulgaris (watermelon) waste seeds of fuel blends were studied. Higher NO_x emissions with drop-in Smoke, H.C. and C.O. emissions were observed because of oxygen presence in biodiesel blends (Panneerselvam *et al*. 2017).

When B20 and smooth diesel, soybean biodiesel, and ethanol blends were tested with aluminium oxide (Al_2O_3) as a nano additive, the CO emissions for D80SBD15E4S1 were 66 percent higher than B20 and smooth diesel at 25 percent load and 40 percent lower compared to at full load. (Shaafi and Velraj, 2015).

It was noticed that the BSFC of pure diesel and AONP 25 were almost similar, while the AONP 50 showed a 6 percent decrease when compared with other fuels. With the application of AONP to biodiesel, the rate of heat liberation is increased (Aalam *et al*. 2015). NO_x emissions were dropped by 55 percent, and when the engine cylinder accepted 15 percent of EGR, soot emissions raised by 15 percent (Can Ö *et al*. 2016). Lemon grass oil nano emulsion included 30 ppm of CeO_2 nanoparticles on diesel engines, BTE and BSFC were assessed as a result of the greater surface-to-volume ratio of CeO_2 nanoparticles when compared with LGO and LGO emulsions (Annamalai *et al*. 2016). The B10 sample was also found to be lower in smoke emissions than B20 and diesel at all load conditions (Kakati and Gogoi, 2016). The single-cylinder Lister Petter (TS1) model engine with pistacialentiscus oil resulted in increased fuel consumption compared to diesel and minimal C.O., Smoke and H.C. concentrations were detected (Khiari *et al*. 2016). For biodiesel blends, at the expense of NO_x emissions, vehicle exhaust emissions including C.O., Smoke and Hydrocarbon have been significantly lower than diesel (Parlak *et al*. 2013). The base composition of fuel which is a mixture of biodiesel (20 percent), diesel (70 percent) and ethanol (10 percent) (BDE) using ultrasonic, aluminium oxide (Al_2O_3) nanoparticles were analysed and blended with a 25 ppm fraction of BDE mixture investigated on an air-cooled, single-cylinder DI diesel engine (Venu and Madhavan, 2016).

The result was a decrease in NO_x concentration for certain blends. At the higher pressures and temperatures nitrogen oxides were forming (Karthikeyan *et al*. 2016). Research on DI diesel engine with different fuels showed improved characteristics of performance of the diesel engine are when compared to pure biodiesel blends (Hosseini *et al*. 2017). The effect of CalophyllumInophyllum methyl ester (CIME) dispersed ZnO and TiO_2 nanoparticles at different concentrations of 50 and 100 ppm was distributed by using ultrasonic homogeniser resulting in H.C., smoke and C.O. were minimised considerably (Nanthagopal *et al*. 2017).

Biodiesel blends, smaller in-cylindrical pressure and heat liberation rate than petrol were detected on all ITs. Raised NO_x emissions have been noticed (Ashok *et al*. 2017). Biodiesel of 20 per cent prepared from castor oil with 80 per cent diesel was studied. High emissions of C.O., Smoke and H.C. were noticed, with decreased NO_x emissions (Deep *et al*. 2017). The effects of C.R., FIP, and FIT on combustion characteristics, performance, and emissions improved BTE by about 7.14% at a maximum of 19.5:1 of C.R., and the emissions of H.C., C.O., and smoke were decreased except NOx (Ramalingam *et al*. 2017).

Biodiesel exhibited features of lower efficiency than diesel at all loads without affecting emission characteristics (Senthur *et al*. 2017). These samples implied peak fuel consumption compare petrol and were found to contain lower C.O. and H.C. smoke concentrations (Soukht Saraee *et al*. 2017). Relative to pure diesel, the BTE increased 13.97 per cent respectively. H.C. and C.O. emissions were decreased but NO_x raised (Heydari-Maleney *et al*. 2017). It was observed that improved BTE and reduced consumption of fuel, the emissions like C.O., H.C., NO_x, P.M. and noise were relatively low compared to neat diesel. (Chaichan *et al*. 2017). BTE was reported higher in these blends and B.P. was similar to that of diesel. The emission characteristics such as C.O., H.C., CO_2 and NO_x were reduced when compared to diesel (Kathirvelu *et al*. 2017). NO_x emissions can be brought down by EGR, slowed down I.T. and higher I.P (Nair *et al*. 2017). In this study, Better efficiency and emissions than diesel were demonstrated by biodiesel blends (Das *et al*. 2018). Tamarind seeds with the use of NaOH transesterification as a catalyst, with fuel mixtures such as the B10, B20 and B30 diesel engine testing. Consequently, compared to diesel, the B20 sample displayed better combustion, performance, and emission characteristics (Dhana Raju *et al*. 2018). It showed lesser emissions of C.O., Smoke and H.C. (other than NO_x) (Subramani *et al*. 2018).

The inclusion of TiO_2 raised brake torque and power of the engine by 10.20 per cent and 9.74 per cent (Örs *et al*. 2018). It found that the mean decrease in BSFC of 27° BTDC compared to 23° BTDC. The presence of Nickel oxide nanofuel in neat fuel at 100 ppm shows higher BTHE (Srinidhi *et al*. 2019). The BD100 aggregation of nanoparticles is experiencing a large decrease in smoke emissions (Radhakrishnan *et al*. 2018). Reported reduction in H.C. emissions by 5.7 and 13.7 per cent respectively, drop in CO by 8.4 per cent and 16.7 per cent and drop in NO_x by 1.8 per cent and 4.7 per cent (Shrivastava *et al*. 2018). Emissions of C.O., H.C., NO_x and Smoke were reduced with raise in proportion of octanol in the fuel blend (Mahalingam *et al*. 2018). NO_x and CO_2 emissions were raised with raise in concentration of biodiesel in fuel blends (Abed *et al*. 2018). Blends with nanoparticles released lower C.O. and H.C., but higher CO_2 than blends without nanoparticles and normal diesel (Ranjan *et al*. 2018). NO_x emissions were dropped at 38μM at 50 and 70%of engine load (Hosseinzadeh-Bandbafha *et al*. 2019). It is capable of oxidising H.C. and P.N. and deoxidising NO_x through reversible reactions, reducing NO_x by 21 per cent compared to D.F. (Zhang *et al*. 2019). It was noted that with raised engine load BSFC reduces but raised with raise in FIP. The temperature of the cylinder has no influence on the NOx emissions' composition (Shrivastava and Verma, 2020). Here the investigation of biodiesel blends obtained from pumpkin seed oil methyl ester used. BTE and BSFC were higher. C.O., H.C., P.M. and smoke emissions were reduced but NO_x were raised (Wang *et al*. 2020). It was suggested that grape seed biodiesel blend B5 exhibited better performance and combustion characteristics compared with remaining blends and near to ultra-low sulphur diesel (Azad and Rasul, 2019). It showed that cylinder pressure and HRR were somewhat lower than with diesel, and that pollutants like NOx, CO, and UHC were reduced by 80, 80, and 65 percent, respectively (El-Seesy *et al*. 2018). The results indicated that BTE of B20 exhibit near values compared to normal diesel while remaining were lesser than normal diesel (Rathore *et al*. 2019). The exhaust emissions like Smoke, NO_x, UHC and C.O. were reduced notably when compared to normal diesel (Raman and Kumar, 2020).

BTE was raised with raise in torque for all the blends. The emissions such as THC, CO_2, CO, SO_2 were decreased, while NOx emissions were raised (Ogunkunle *et al*. 2020). Smoke, PM, H.C., CO, and other emissions like NOx and CO_2 were also slightly higher (Subramaniam *et al*. 2020). It revealed that B20 blends of MECSO and MERBO develop little small B.P. and high BSFC compared with diesel. B20 blend of MESCO and MERBO produced fewer C.O. and H.C. compared with diesel (Udayakumar, 2020). Performance and combustion characteristics of biodiesel obtained from tallow oil at various proportions with diesel as B10, B20 and B30 used as a fuel in a diesel engine. BTE was around 5 per cent lesser for biodiesel than normal diesel (Gautam and Kumar, 2020). Overall the emissions of UHC and C.O. were reduced, but NOx emission was raised (Shekofteh *et al*. 2020). Emissions of UHC and C.O. reduced for all blends, but NOx emissions were raised (Hoseini *et al*. 2020). J20C50 indicated reduced C.O. and NOx compared to J20. J20C100 indicated reduced smoke emissions and J20T25 indicated reduced H.C. emissions compared to J20 (Gad and Jayaraj, 2020). In compared to base fuel (diesel) operation, NOx emissions rose with the introduction of hydrogen (Mathanraj *et al*. 2021). Results revealed that while using a diesel engine, higher compression ratios reduced pollutants and the ignition delay (Ravikumar *et al*. 2022). It was possible to efficiently reduce CO_2 by up to 90% while concurrently lowering HC and CO levels (Solomon *et al*. 2022). At all loads, LWME/diesel blends demonstrated worse brake thermal efficiency than pure diesel. Diesel emissions are decreased when LWME is added, with barely any performance loss (Yuvarajan *et al*. 2022). The fuel injection pressure is the main vital parameter for improving the performance and emission characteristics because it enhances the fuel droplet size as a result performance characteristics increases (Siva Prasad *et al*. 2021; Prasad *et al*. 2023; SivaPrasad *et al*. 2022)

3. Conclusion

A alternative fuels to replace petroleum-based fuel has been sparked by the issue of diminishing petroleum reserves as well as increased awareness of the environmental damage caused by petroleum fuel emissions. Biodiesel has quickly grown in popularity because it is eco-friendly and made from renewable resources.

Many studies were conducted on Non edible oils like Jatropha oil, Mahua oil, Calophylluminophyllum, Castor oil, Neem oil etc. due to their versatility, have received much attention as alternative fuels.

From the above literature, a nano-blended biodiesel-powered diesel engine's performance, combustion, and emission characteristics are examined. In this regard, enhancing the fuel's characteristics or modifying the engine's operating conditions may improve performance, combustion and reduce emissions in a diesel engine powered by biodiesel.

The BTE is significantly reduced and the BSFC is increased when diesel fuel is used in diesel engines along with biodiesel or both biodiesel and ethanol fuels. However, exhaust emissions can be significantly decreased.

Since biodiesel has a higher viscosity than diesel, researchers added alcohol as a fuel additive to biodiesel and its blends to reduce the harmful exhaust emissions.

Numerous researchers found that adding nanoparticles to the fuel blend improved the combustion characteristics of diesel engines using mahua oil biodiesel. This resulted in a higher surface-to-volume ratio, greater atomization, and shorter ignition delays in the combustion chamber.

Numerous researchers have studied ways to alter engine elements like the fuel injection pressure, injection timing and compression ratio.

Adding nanoparticles to biodiesel and diesel mixes causes BTE to rise greatly and BSFC to fall significantly. Additionally, it is possible to drastically lower the emissions including HC, CO, and PM.

In the majority of the experiments that were piloted, the addition of NPs improved the diesel engine performance for the majority of diesel-biodiesel-ethanol, diesel-biodiesel diesel blends used in diesel engines.

Finally, using nano articles and varying fuel injection pressures in diesel engines have the potential to significantly increase engine performance, combustion, and exhaust emission characteristics.

Scope of future work

To assess the characteristics of morethan 100 ppm nanoparticles and their influence on engine parameters to find the suitable nanoparticle dosage with optimum engine parameters towards improved performance and reduced emissions

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