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Numerical investigation for performance and emission characteristics of a diesel engine fueled with soybean methyl ester biodiesel - Diesel blend

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Abstract

The usage of conventional fossil fuels is reducing day by day due to the overwhelming use of business and personal automobiles for transportation, delivery, and ambulance. Factories also require conventional fuels to run their machines, which serve the primary purpose of production and factory operation. As a result, conventional fuels have a wide range of applications in our daily lives. However, there are certain downsides to utilizing traditional fuels, such as increased pollution, which adds to an increase in the temperature of the globe, causing global warming. Alternative fuels not only minimize pollution but also do not impair vehicle performance. There are other forms of alternative fuels available, including biodiesel, electricity, and solar energy, which have already gained popularity. This paper focuses on SME (Soybean Methyl Ester) as an alternative biofuel and provides a full review of the fuel by running it through an engine virtual simulation. The biofuel is combined with 20% and 80% diesel mixtures. The virtual simulation revealed that the brake thermal efficiency (BTE) and Brake Specific Fuel Consumption (BSFC) of diesel and SMEB20 is nearly identical. SMEB20 emit more NOx and CO_2 than diesel under all load whereas emit less particulate matter (PM) and smoke emission than diesel under all engine load.

Keywords: Diesel fuel, SME Biofuel, Diesel Engine, Engine Performance, Engine Emission

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1. Introduction

In the present situation, the restricted availability of fossil fuel encourages researchers to find an alternative energy source that could potentially replace the fossil fuel in diesel-powered engines because of the continual rise in the cost of fossil fuels. Another justification for seeking an alternate fuel for diesel engines is that the engine's exhaust discharges hazardous substances into the surrounding atmosphere, which not only harms the ecosystem but additionally has an impact on human health. Biodiesel is just one of the renewable fuels that could eventually be used instead of fossil fuels in diesel engines. Biodiesel has been extensively investigated for decades since it was established to be safe and has the potential to be utilized in diesel engines without any modifications. Biodiesel is generated via a trans-esterification method involving alcohol and a substance called a catalyst. Biodiesel represents one of the most exciting avenues for energy that is environment friendly for present-day worldwide sustainable growth (Shahir et al., 2014). Biodiesel can be derived from a broad range of different sources, such as jatropha (Bhikuning et al., 2018), rapeseed (Aldhaidhawi et al., 2017), carbera mangas (Bhikuning and Hafnan, 2019), coconut oil (Bhikuning, 2013), as well as waste cooling oil. Biodiesel is a clean-burning fuel with the potential to reduce the emissions of unburned hydrocarbons (HC), carbon monoxide (CO), and smoke (Imtenan et al., 2014; Rizwanul Fattah et al., 2014a). On the opposite end of the spectrum, reduced brake power (BP) and greater brake-specific fuel consumption (BSFC) have been observed as being due to fuels having a lower heating value than fuels made from petroleum (Rahman et al., 2021). Biodiesel has additionally been demonstrated to elevate NO_x emissions (Mofijur et al., 2014; Rizwanul Fattah et al., 2014b). When several feed stocks are employed, the fuel properties of biodiesel could vary. When the fuel properties of biodiesel are compared to those of normal diesel fuel, it promptly becomes apparent that biodiesel has a greater viscosity, density, and cetane number.

Over the past thirty years, numerous investigators have studied the impact of biodiesel derived from varied feed stocks on the performance as well as the emission characteristics of engines powered by diesel. These research investigations suggest that, as compared to pure diesel baseline operation, biodiesel presents similarly satisfying outcomes with only slight performance variations and statutory reductions in emissions. As an outcome, vehicles incorporating biofuels may not need changes to diesel engines. There is universal consensus that biodiesel fuel greatly decreases HC, CO, and smoke emissions while increasing NO_x emissions when compared to pure diesel fuel. Canakci and Van Gerpen (2003) evaluated the influence of biodiesel derived from high free fatty acid feed stocks on engine performance and emissions. Two distinct biodiesels have been synthesized employing animal fat-based yellow grease comprising 9% of free fatty acids and soybean oil. The pure fuels and their 20% diesel fuel combinations have been tested in a four-cylinder turbocharged diesel engine under a stable state condition. Although both biodiesel fuels substantially lowered PM, CO, and HC, NO_x increased by 11% and 13% for the yellow grease methyl ester and soybean oil methyl ester, correspondingly. Moser et al. (2009) analysed and contrasted the fundamental characteristics of the fuel and emission metrics of soybean oil methyl esters (SME) and partly hydrogenated SME (PHSME) mixtures (20% by volume) in ultralow sulphur diesel fuel (ULSD) with plain ULSD. B20 blends of SME and PHSME outperformed simple ULSD with respect to improving lubricity, kinematic viscosity, cetane number, lessened sulphur percentage, and low-temperature endurance. The PHSME mixture significantly reduced HC emissions considerably. Both of SME and PHSME B20 combinations raised NO_x emissions a bit. At the B20 blend level, a reduction of PHSME double-bonded concentration in order did not have a statistically noteworthy impact on NO_x emissions when compared to SME. The test's engine consumed a greater amount of fuel when functioning with the SME and PHSME combinations compared while operating on plain ULSD, although the rise in consumption found lesser for the PHSME blend. Many researchers executed analytical and experimental investigations in order to assess the implications of biodiesel and its mixtures on engine performance and emissions of exhaust gases to diesel fuel (Elkelawy et al., 2018). The study examined by Lahane and Subramanian (2015) the impact of different Karanja biodiesel blends on the emissions and performance of a direct injection CI engine. Results showed that each biodiesel-diesel mixture reduced the ignition delay interval, resulting in steady engine operation and slower pressure development. CO, HC, and smoke emissions decreased with the biodiesel proportion to B100 under maximum load. NOx emissions increased between 1.4 and 22.8% for all combinations. BSEC increased for both lower and maximum loads but dropped slightly at loads of 50%, 75%, and 90%. BTE was reduced in biodiesel blends compared to diesel fuel.

Ramadas et al. (2004) examined the manner in which the fuel characteristics of biodiesel impact diesel engine combustion. Bhikuning et al. (2020) analysed the method by which the viscosity, density, and surface tension of biodiesel affect spray penetration, spray angle, and Sauter average diameter in a fixed volume chamber. Schröder et al. (2012) evaluated the emissions of SME from diesel fuel. Soybeans release higher levels of NO_x compared to diesel fuel. Nevertheless, CO_2 emissions are capable of being reduced owing to the oxygen levels present in biodiesel. Al-Dawody and Bhatti (2014) examined both the combustion and emissions of SME using diesel RK through experimentation and analytically. In accordance with the findings, SME may reduce smoke opacity by up to 48.23% and exhibits greater brake specific fuel consumption (BSFC) than diesel fuel. The outcomes of the simulation illustrate an elevated degree of compatibility among these two fuels. Qi et al. (2019) evaluated SME and rapeseed methyl ester (RME) atomization process and the combustion process. The findings suggest that the fluid dimension along with droplet diameter of biodiesel are much bigger in comparison to those of diesel fuel. This phenomenon was triggered because of surface tension as well as a lack of evaporation resulting from the reduced vapour pressure. This is capable of being modified to extend the pace of evaporation throughout the atomization procedure. Aldhaidhawi et al. (2018) evaluated the impact of a 20% RME and diesel fuel mixture termed B20. According to the research findings, the BSFC of B20 is significantly higher than the equivalent amount of diesel fuel. CO and smoke emissions had been, nonetheless, significantly lower compared to diesel fuel. However, the emissions of NOx remained more significant compared to the equivalent of diesel fuel.

In regard to existing literature, a great deal of research work has previously been performed regarding SME biodiesel, and the majority of the research has been conducted through experimentation, whereas no indication of computational modelling has been noticed yet. Therefore, the authors applied virtual software for simulation to evaluate the emissions as well as performance attributes of a diesel engine operating on 20% soyabean oil-based biodiesel mixed with 80% pure diesel under various loads and compared these individuals with the performance and emissions when the engine ran on 100% pure diesel fuel.

2. Materials & Methods

2.1 Diesel RK Software Model

The computational modelling has been carried out employing commercially available Diesel RK software. Diesel RK is computational software for analysing engines. The primary benefit of employing diesel RK is the fact that it can compute thermodynamic diesel engines that run using diesel fuel, alcohol, sustainable fuel, and biofuel. Furthermore, it is capable of assessing thermodynamics in SI engines, comprising pre-chamber stimulation with gas from natural sources, pipeline gas, wood gas, and so on (Pham, 2019). The RK model is also able to evaluate the piston's geometry and the fuel-injection system. Moreover, it could set up common rail monitoring and control in combination with exhaust gas recirculation (EGR) in the exhaust system (Al-Dawody and Bhatti, 2011). The parameters which were obtained by using the Diesel RK software to evaluate the engine performance of the diesel engine are BTE, BSFC and also predict the emission characteristics of the engine by measuring the different engine exhaust pollutants comprising NO_x, CO, CO_2, HC, PM and Smoke Level. The fundamental governing equations needed to conduct simulation using software have been adapted from previous research conducted by Paul et al. (2014).

BP, is the power which is obtained at the crankshaft after the combustion process by considering the frictional losses. BP (P_b) is calculated by the multiplication of engine torque (T) and angular velocity (ω):

$$BP = P_b = T \times \omega \tag{1}$$

BTE, is the ratio of brake power to the amount of heat supplied:

$$BTE = \frac{\text{BP}}{\text{mass value of fuel} \times \text{calorific value}} \tag{2}$$

BSFC is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational, or shaft power it can be defined as the amount of fuel consumed per unit of BP:

$$\text{SFC} = \frac{\text{fuel consumption rate per second}}{\text{BP}} = \frac{m_f}{P_b} \tag{3}$$

The torque is calculated using the vector multiplication corresponding to the load that is applied and the dynamometer arm length. The amount of power produced for every cycle as a consequence of the engine's size has been determined by BMEP:

$$\text{BMEP} = \frac{T}{V_c} = \frac{BP}{V_c \times \omega} \tag{4}$$

where V_c denotes the Piston displaced volume per cylinder.

Emissions are substances that get released to the surrounding air which can be measured based on the concentrations of substances, or parts per million (PPM), of these chemicals in the atmosphere as a whole.

The model initially estimates the optimal composition of the byproducts of combustion for eighteen substances across the ignited gaseous region of phases before performing a kinetic computation of thermal NO employing the Zeldovich mechanism (Li et al. 2022). Nitrogen oxidation is an ordered response, and the fundamental steps are outlined in the following order:

$$\begin{aligned} &O_2 \longleftrightarrow 2O \\ &N_2 + O \longleftrightarrow NO + N \\ &N + O_2 \longleftrightarrow NO + O \end{aligned} \tag{5}$$

$$\frac{d[NO]}{d\theta} = \frac{p.2.333*10^7.e^{-\frac{38020}{T_Z}}[N_2]_e.[O]_e.\left\{1-\left({}^{[NO]}\!/_{[NO]_e}\right)^2\right\}}{R.T_Z.\left(1+\frac{2365}{T_Z}.e^{\frac{3365}{T_Z}}.\frac{[NO]}{[O_2]_e}\right)}.\frac{1}{\omega} \tag{6}$$

The underlying cause of the issue could include anything from a spillage of coolant in the engine's chamber to over-fuelling or incomplete combustion of fuel inside the engine's combustion chamber, or it could be a leak of oil in the chamber where the fuel is burned, allowing oil to burn alongside the fuel.

$$\text{Hartridge Smoke Level} = 100[1-0.9545\exp(-2.4226[C])] \tag{7}$$

Particulate matter emission is calculated by using an equation in terms of Bosch smoke number as given in the work of Alkidas (1984). The equation is as follows:

$$[PM] = 565\left(\ln\frac{10}{10-Bosch}\right)^{1.206} \tag{8}$$

2.2 Simulation Model

To simulate an engine in diesel RK software, general engine specifications need to be entered first. Figure 1 depicts the diesel RK software execution process. A new project requires being developed by entering the engine's parameters; after that, the project must be saved. The operating systems then need to be maintained. Adjusting the RPM on the engine in this step, establishing the surrounding temperature condition, and so forth, subsequently validates that the spray nozzle remains in a properly functioning condition. The arrangement of the components as well as the geometry of the combustion chamber must be prepared, and the particular piston bowl arrangement must be entered for the engine pursuant to examination. Then the injection properties are required to be precise and investigated. The simulation's results ought to be performed following that and the setting parameters analysed.

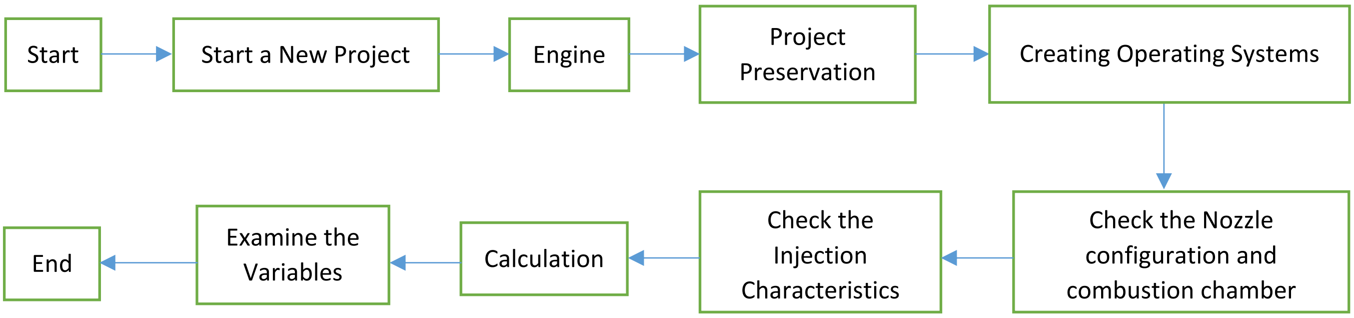

Figure 1. Steps related to Diesel RK Simulation (Bhikuning, 2021)

2.3 Engine Specification

The Kirloaskar AV1 engine data was utilised in this inquiry. The engine was operating at a constant 1500 rpm with four distinct load circumstances (25%, 50%, 75%, and 100%). Although it was modelled and investigated using the commercial software Diesel RK, it is based on a Kirloskar AV1 engine, and the following are its specification, (Table 1):

Table 1. Engine Specification Details

Engine Model	Kirloskar AV1
Cylinder Bore	80 mm
Stroke Length	110 mm
Compression Ratio	16.51:1
No. of Cylinder	1
Engine Type	AV1
Injection Type	Direct injection
No. of Nozzle	3
Nozzle Orifice Diameter	20 mm
SFC	245 g/kwh
Rated Power	3.7 kw
Rated RPM	1500
Injection Presure	200 bar
Injection timing	23° CA BTDC
Type of Colling System	Water coled
Connecting Rod Length	234 mm
No. of Injector	1
Type of Combustion Chamber	Hemispherical

2.4 Fuel Properties

In this simulation two different fuels have been used (neat diesel and blend of Soyabean Methyl Ester 20% and Diesel 80%) to analyze and compare their engine performance and emission characteristics (Table 2).

Table 2. Properties of SMEB20 and Diesel Fuel

Property	SMEB20	Diesel
Mass composition of fuel		
C	0.8496	0.87
H	0.1245	0.126
O	0.0259	0.004
Sulphur fraction in fuel	0.00105	0
Low heating value (MJ/kg)	41.18	42.5
Cetane number	48.69	48
Fuel density (kg/m3)	841	830
Surface tension (N/m)	0.03122	0.0309
Dynamic viscosity (Pa.s)	0.00334	0.001352
Specific gravity at 150 C	0.88	0.83
Acid Value	0.22	0.15

3. Results and Discussion

3.1 Engine Performance Analysis

Engine performance analysis is done to figure out the power characteristics of an engine during running condition. It is done so to figure out the optimal running conditions and the peak condition of an engine under load or to understand different fuel and environmental conditions affecting the running of an engine. BTE and BSFC are two very important terms in order to understand the characteristics of an engine.

3.1.1 BTE

In this simulation, the BTE of the Diesel and SMEB20 fuels analyzed on the single cylinder diesel engine are quite similar. It is evident that the BTE of diesel is somewhat higher than that of SMEB20 under all load conditions because the low calorific value and high viscosity of SMEB20, which causes inadequate atomization in the engine cylinder, tends to reduce thermal efficiency (Dwivedi et al., 2011). BTE is the ratio of the amount of energy generated by fuel converted to effective output of power. Figure 2 demonstrates the variation of BTE for both diesel and biofuel.

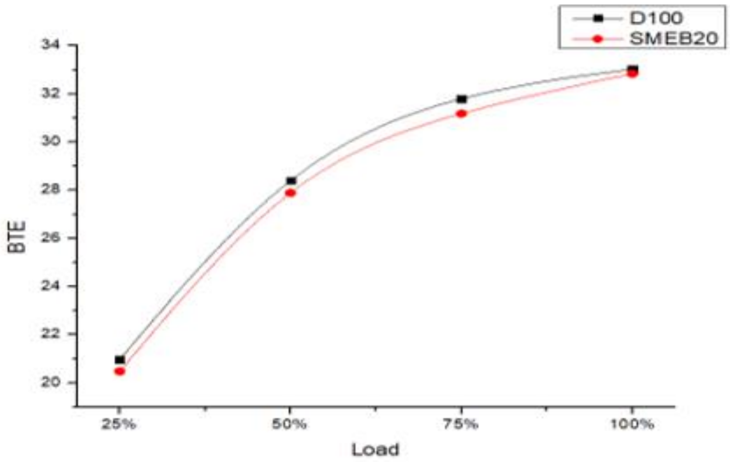

Figure 2. Variation of BTE with different percentage of loads for Diesel fuel and SMEB20

The BTE values for diesel and SMEB20 at low load are 20.98% and 20.49%, respectively. Similarly, at full load, the BTE for diesel and SMEB20 are 33.03% and 32.84%, respectively. It was observed that the BTE for each fuel is continually rising, irrespective of loads. It occurs due to the fact that when the load rises, the ratio of air to fuel decreases, which results in a rich mixture that supplies more fuel energy for producing more power.

3.1.2 BSFC

Figure 3 shows the variation of BSFC with different loads for two different fuels. This has been noticed that under all engine loads, the BSFC values of SMEB20 are slightly higher than those of diesel fuel. This is due to the fact that more biodiesel is required to provide the same level of power as compared to diesel fuel as it has low calorific value so to produce the same power output more fuel needs to be consume. The BSFC was shown to decline with rising loads across all tested fuels. The reason for this is a greater percentage of an increase in brake power with load than an increase in fuel consumption.

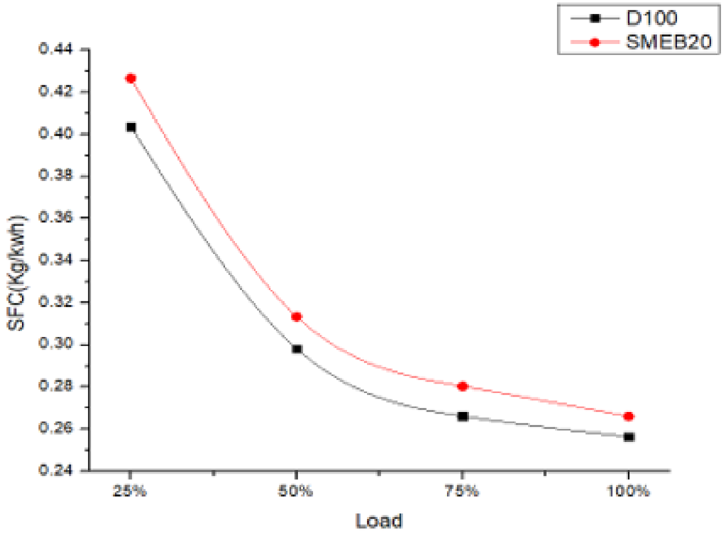

Figure 3. Variation of BSFC with different percentage of loads for Diesel fuel and SMEB20

3.2 Engine Emission Analysis

The growing consumption of petroleum-based fuels in the form of diesel, specifically in the vehicle industry, and the constantly growing emission of hazardous substances through engine exhaust tubes are significantly contributing to multiple illnesses and the swiftly deteriorating condition of the world's ecosystems. Hydrocarbons that are produced by automotive exhaust create ground-level ozone, which is an elementary ingredient in smog. Ozone affects individuals by producing breathing problems, visual apprehension and asthma. As a consequence, it is now almost obligatory to make use of any kind of fuel as automotive fuel in order to satisfy the rigorous emission standards stipulated by various regulatory agencies all over worldwide.

3.2.1 NO$_x$

The formation of NO$_x$ emissions is directly proportional to the temperature in the combustion chamber, lower enthalpy of vaporisation, and oxygen content (Sharudin et al., 2017). The incorporation of biodiesel in diesel engines has been demonstrated to raise NO$_x$ emissions when compared to regular diesel fuel. Biodiesel contains a greater oxygen content than pure diesel. Furthermore, the complete combustion of biodiesel causes an elevated temperature, which leads to the generation of valance oxygen by means of disassociation, which subsequently boosts the NO$_x$. When implied, the induced outcomes shown in Figure 4 demonstrate an upsurge in NO$_x$ emissions when the biodiesel concentration in pure blended diesel and pure biodiesel rises. Diesel and SMEB20 release 167 and 261 ppm NO_x at low load, respectively, whereas at full load, the values are 1169 and 1752 ppm. The trend of emitting NO_x emissions for each fuel continues to rise with the increase in load because, at higher loads to generate more power, the engine requires more fuel, thus leading to more fuel being burned and their residence period inside the combustion chamber at elevated temperatures becoming longer owing to the fuel's burning characteristics.

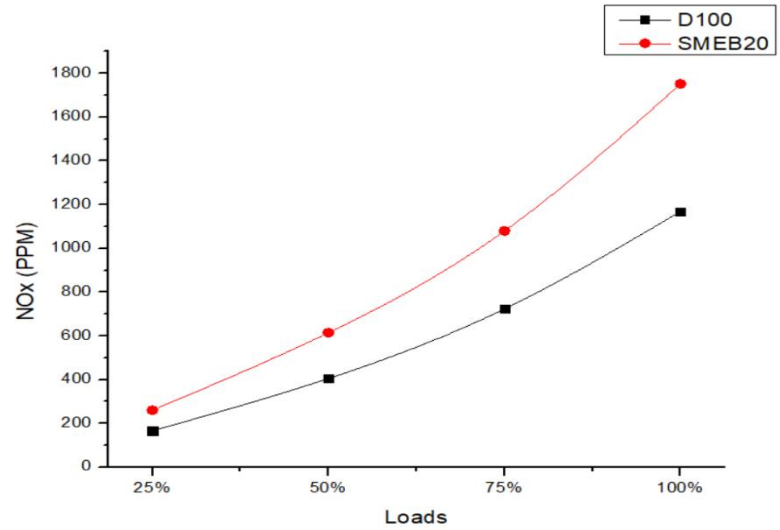

Figure 4. Variation of NO_x emission with different percentage of loads for Diesel fuel and SMEB20

3.2.2 CO_2

In overall, the intended result for any particular hydrocarbon combustible products ought to be both water and CO_2 emissions (Knothe and Razon, 2017). In this context, over all emissions, CO_2 ought to pose least worried about since the substance causes not cause as much damage and could possibly be compensated through raising biodiesel crops.

Figure 5 shows the variation of CO_2 emission for both fuels D100 and SMEB20 at constant speed and different engine loads. The figure shows the biodiesel (SMEB20) generates slightly more CO_2 emission than diesel fuel. The reason for this is largely attributed to the existence of oxygen in incorporated biodiesel fuels, which reacts to unprocessed atoms of carbon throughout the process of combustion, releasing more CO_2. Biodiesel has a greater carbon-to-hydrogen ratio and contains a greater amount of oxygen than diesel fuel, leading to complete combustion and raising the temperature inside the chamber of combustion. The more elevated the temperature gets; the more CO becomes oxidised and releases CO_2 through the engine exhaust tailpipe. Emissions of CO_2 associated with both fuels fall constantly as load climbs because of the formation of a rich mixture at higher loads. This rich mixture generates incomplete combustion, which minimises CO_2 emissions.

The diagram clearly demonstrates that from 50% to the full load, SMEB20 generates slightly larger amounts of CO2 compared to diesel fuel, although at higher loads, richer fuel zones are produced by both types of fuel inside the combustion chamber in response to their elevated O_2 content. SMEB20 burns completely to emit more CO_2 due to having more O_2.

This data point lines up with prior research, which observed that boosting biodiesel content incrementally raises the amount of emissions of CO_2. It is causing the emissions of CO_2 through complete combustion, high post-combustion, and elevated levels of oxygen enhance the overall amount of emission (Bayındır et al., 2017; Najafi, 2018).

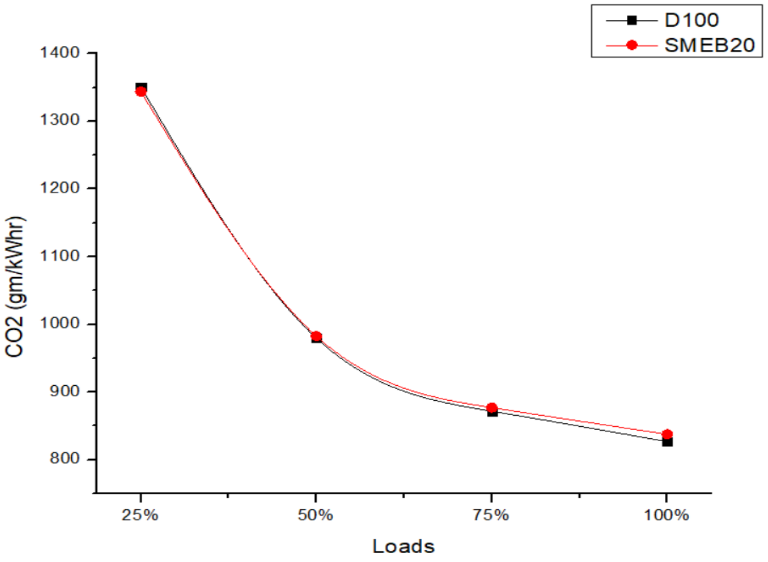

Figure 5. Variation of CO_2 emission with different percentage of loads for Diesel fuel and SMEB20

3.2.3 PM and Smoke Level

Figures 6 and 7 demonstrate how fine particulates and smoke emission vary with engine load for two different fuels. The main root cause of PM emissions from CI engines is erroneous combustion as well as the ingestion of substantial lubricating oil. Emission of smoke is caused by the formation of rich fuel combinations inside the combustion chamber at elevated pressures and temperatures (Nabi et al., 2009). In line with the research results, SMEB20 emits lesser PM and smoke than diesel fuel. Biodiesel has greater oxygen content than diesel, therefore enhances combustion quality leading to with reduced smoke and PM emissions. Both of them PM and smoke emissions generated by both fuels in the beginning exhibit an extensive declining trend, which is owing to incomplete combustion at low loads. In addition, while the engine is running at full load, the amount of oxygen concentration present in the biofuel has adverse consequences on the formation of soot significantly more than the viscosity; therefore, the PM production decreases as the oxygen level increases. However, at lower loads, the fuel viscosity surpasses the oxygen factor, raising PM emissions.

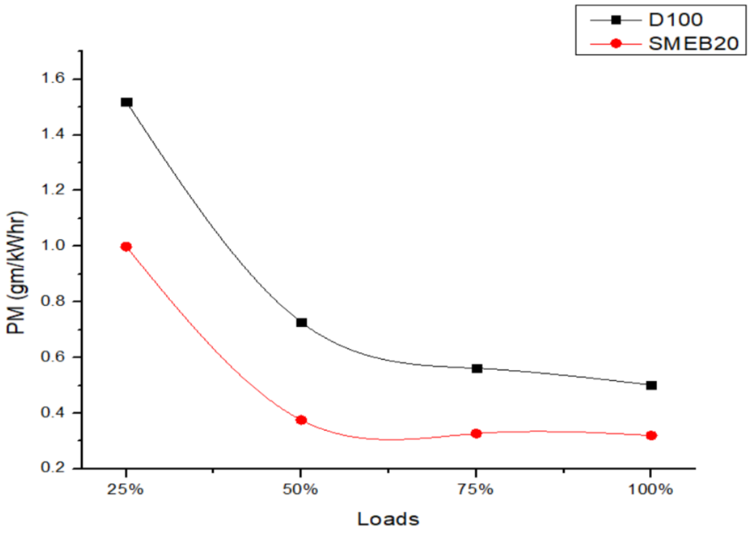

Figure 6. Variation of PM emission with different percentage of loads for Diesel fuel and SMEB20

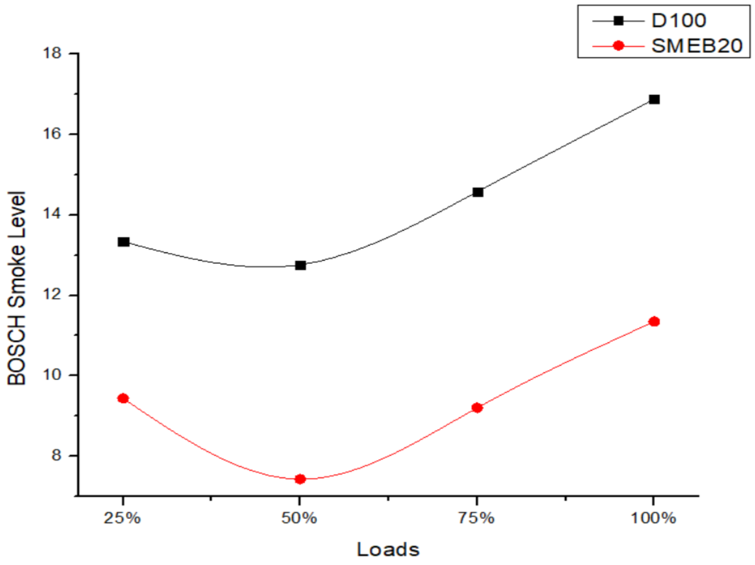

Figure 7. Variation of Smoke emission with different percentage of loads for Diesel fuel and SMEB20

As demonstrated in Figure 7, the emission of smoke is lowered more at 50% load for both fuels, and SMEB20 discharges a lesser amount of smoke than diesel fuel. Because of the lean mixture developed at low load, the smoke level ought to be kept to a minimum at 25% load. However, at low loads, the viscosity of the fuel is greater than the oxygen variable, resulting in somewhat more smoke production than at 50% load.

In the current study, experiments were carried out with four different engine loads, namely 25%, 50%, 75%, and 100%. The major goal of the testing was to study and evaluate six separate factors for two distinct types of fuels, namely D100 and SMEB20. The regulations addressed BTE, BSFC, NO_x emissions, CO_2 emissions, PM emissions, and smoke levels. Table 3 summarises the findings of the investigation, which indicate critical implications regarding engine performance as well as emissions aspects relating to these fuels under varied load conditions.

Table 3. Comparative Performance of Responses at various loads

Sl No.	Measured Parameters	25% Load	50% Load	75% Load	100% Load	Related to Engine Parameters	Desired
1	BTE	↓	-	≈	↑	Engine Performance	↑
2	BSFC	↑	≈	-	↓		↓
3	NO_x	↓	-	≈	↑	Engine Emission	↓
4	CO_2	↑	-	≈	↓		↓
5	PM	↑	-	≈	↓		↓
6	Smoke Level	≈	↓	-	↑		↓

↑ = Maximum, ↓ = Minimum, ≈ = Lesser than Maximum, - = Greater than Minimum

When evaluating engine performance as measured by BTE and BSFC, it is clear that the expected results may be obtained under a variety of load conditions. Under the maximum load, BTE and BSFC excel. This means that the engine performs most effectively in terms of energy conversion and fuel utilisation when it is fully loaded.

Furthermore, when evaluating emission variables, two separate groups emerge. On the one hand, CO_2 and PM emissions have the desired consequences at full load. This means that D100 and SMEB20 fuels emit less CO_2 and particulate matter while the engine continues to operate at its full potential. This conclusion is fascinating from the standpoint of sustainability since it suggests that running an engine at higher loads could contribute to reducing CO_2 and PM emissions, both of which have been linked to atmospheric and meteorological problems.

NO_x emissions and smoke levels, on the contrary conjunction, demonstrate the anticipated effects at a 25% and 50% load, respectively. It also suggests that when an engine performs activities at significantly lower loads, pollutant levels are reduced. NO_x emissions must be severely limited since NO_x contributes to air pollution and can harm humans and ecosystems. On the flip side of the conjunction, lower smoke levels indicated better combustion and less particle emissions, underscoring the beneficial effects on the environment of running the engine at decreased loads in this circumstance.

4. Conclusion

The investigation of the outcomes produced during the mathematical simulation leads to the following conclusions.

- The use of Soyabean methyl ester biodiesel in a conventional diesel engine decreases BTE as compared to neat diesel fuel under all the engine loads
- The Soyabean methyl ester produces more BSFC than diesel fuel.
- Use of Soyabean methyl ester biodiesel increases the NO_x emission as compared to diesel fuel due to the fact that it is having the more oxygen content in it than diesel fuel.
- The addition of Soyabean methyl ester in diesel fuel raises the CO_2 emission in exhaust tail pipe because it is having the higher carbon-hydrogen ratio as well as having more oxygen content.
- Soyabean methyl ester produces lesser amount of PM and smoke emission as compared to diesel fuel because of complete combustion as it is an oxygenated fuel.
- In summary this investigation proved how engine load and fuel type impact engine performance as well as emission characteristics. According to currently available data, the quantity of load and fuel used could possess a significant influence on quantities such as BTE, BSFC, CO_2, PM, NO_x, and smoke levels. The results provided convey helpful insights for optimising engine operation to achieve both performance and environmental goals.

This study shows that Soyabean methyl ester biodiesel can be used as an alternative fuel in diesel engines because its consumption in diesel engines produces slightly lower performance than diesel fuel while also raising NO_x and CO_2 emissions in addition lowering PM and smoke emissions.

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