An Experimental Study on Performance and Emissions of a Direct Ignition Diesel Engine with Crude Pongamia, Pongamia Methyl Ester and Diethyl Ether Blended with Diesel

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Abstract- In the last few decades biodiesel has proved to be the best alternative for the conventional diesel in many applications. Due to ever increasing demand of the mankind, the fossil fuels are depleted so much that in the near future oil scarcity is inevitable. The environmental impact that is caused by conventional diesel can be greatly reduced by using biodiesel. The present study experimentally investigates the usage of preheated crude pongamia oil (CPOP), pongamia methyl ester (PME) and diethyl ether (DEE) biodiesel blends on an unmodified diesel engine running on its full throttle. Preheating crude pongamia oil reduces its viscosity to a great extent, which is always an issue with biodiesel fuels. In the present study the performance and emission parameters are evaluated for DBD 1 (CPOP 60% and D 40%), DBD 2 (PME 60% and D 40%) and DBD 3 (CPO 60%, DEE 15% and D 25%). The experimental data obtained for performance and emission parameters for biodiesel fuels are checked in par with mineral diesel. For all the biodiesel blends, the trend for BTE is found increasing whereas BSFC followed a decreasing trend at all operated loads. Particulate emissions except HC and NOx are lesser in biodiesel blends than diesel due to the presence of dissolved oxygen. Also the addition of diethyl ether to crude pongamia has significant impact on performance improvement and reduced emissions when compared to other blends. From this experimental study it is concluded that pongamia oil because of its rich availability in India can be the best fuel for blending with diesel and using for small and medium scale energy producing vehicles.

Keywords: Diesel engine; Crude pongamia oil; Diethyl ether; Performance; Emissions.

1. Introduction

A In developed and developing countries the energy requirement is very high due to ever increasing population which makes the available fuel reserves to deplete at an increasing rate [1]. Majority of the atmospheric pollution is caused by over utilization of fossil fuels and this forces to find an alternative, and encourage the usage of biodiesel which has lesser environmental effect [2]. The source of greenhouse gases is mainly due to the emissions resulting from petrol and diesel engines, which are considered to be the backbone for transportation sector. These engines are responsible for 22% of greenhouse gases released in to the atmosphere [3]. Biodiesel is a blend of alkyl esters having higher molecular weight resulting from long carbon chain compounds which are mainly derived from vegetable oil, algae and other sources. Many researches found that most of the biodiesel which are used as fuel are having physical and chemical properties comparable with petroleum diesel because of their higher calorific values. Biodiesel which is a drop in for conventional fuel is environmental friendly, less toxic, biodegradable and also cost effective [4]. Nevertheless they have slightly lesser performance than conventional diesel because of their low energy content, higher viscosity and engine compatibility [5]. A lot of research is still in progress for designing specific biodiesel engine which gives a better performance. Biodiesel have the potential to mix with conventional diesel in varied proportions and this makes it promising source for alternate source which is more eco-friendly in nature [6]. Numerous works have been carried out for the possible utilization of oils extracted from vegetables and other different sources as fuel for running diesel engines [7-9]. Using straight edible and non-edible oils directly in the engine is constrained due to their high viscosity and some adverse properties [10]. In India "National bio fuel policy" which is framed by Ministry of New and Renewable Energy (MNRE) released a policy in 2009 which encourages the usage of different biodiesel blends. MNRE targets that at least 20% biofuels should be blended with conventional diesel/petrol by 2017 in all diesel and petrol engines [11]. Also the Ministry of Indian railways is trying to blend at least 5% of biodiesel in locomotives which are responsible for consuming around 2 billion litres of diesel every year [12].

Pongamia oil derived from pongamia pinnata seed has rich content of oil, low moisture content and can be extracted up to 99% by transesterification process. The oil derived from this seeds in India accounts to 200 million tonnes per year [13,14]. The physio-chemical properties of pongamia oil is comparable to conventional diesel [15]. Nonetheless, injecting crude pongamia oil to the engine cylinder is a because of its high viscosity [16]. Numerous methods are in hand for reducing the viscosity of biodiesel which consists of preheating, pyrolysis, dilution, catalytic cracking, micro emulsions and transesterification process. Several works are reported experimenting the use of pongamia biodiesel blended with conventional diesel to see the changes and effects on engine performance and exhaust [17-19]. Chauhan et al. [20] conducted experiments blending various proportions of pongamia with mineral diesel. The proportions of pongamia are varied in percentages of 5%, 10%, 20%, 30% and 100% respectively. It is observed from the work that the emissions namely HC, CO_2, CO are notably reduced with an increase in NOx. Srithar et al. [21] used mustard oil biodiesel blended with diesel and found that the performance and emissions of 90% diesel, 5% pongamia and 5% mustard biodiesel are nearer to diesel.

DBD 1 in this study is a blend of 60% of CPOP and 40% D. To reduce the visocsity of the blend it is preheated and is fed to the engine. From the literature [22] it is observed that preheating the blend at 90°C is the optimized value for reducing the viscosity of the biodiesel blend. Agarwal and Rajamanoharan [23] also investigated the preheated blend of pongamia with specially designed heat exchanger. It is noted that the preheated biodiesel can replace conventional diesel in internal combustion engines with better performance and reduced emissions. DBD 2 in the present study is a combination of 60% pongamia methyl ester and diesel 40%. Dhar and Agarwal [24] experimentally investigated the particulate concentration and particulate number for pongamia methyl ester at varying operating conditions. Five different combinations of blends are tested namely KOME 5, KOME 10, KOME 20, KOME 50, KOME 100. It is seen from his work that with an increase in engine speed, particulate concentration is also increased. It is concluded from the work that KOME 20 is effective in reducing the particulate emissions. Raheman and Phadatare [25] experimentally tested diesel fuel blended with pongamia methyl ester in different proportions. The blend with 40% pongamia methyl ester with 60% diesel has shown good reduction in emissions. The same has been concluded from other works carried out by Sureshkumar et al. [26]. In another work done by Nantha gopal and Thundil Karuppa raj [27] the authors used pongamia oil methyl ester with diesel in varying proportions of 20, 40, 60, 80 and 100. It is understood that the pongamia methyl ester blended with diesel can replace base diesel without any modifications on the diesel engine.

Many researchers has studied utilization of diethyl ether (DEE) as fuel in diesel engines. Because of its excellent chemical properties it can be used as substitute for conventional diesel. DEE due to its high oxygen content and absence of C-C covalent bonds it can achieve smokeless combustion which is far superior to diesel. One of the ways DEE can be produced is to dehydrate bio ethanol which is a renewable fuel. DEE can be used to blend with conventional diesel for its excellent cold flow properties, higher cetane number, higher heating value and less self ignition temperature. Various researchers has experimented blending DEE with diesel to reduce emissions. Ramadhas et al. [28] investigated DEE addition with rubber seed oil which resulted an increase in performance and reduction in emission characteristics. Iranmanesh et al. [29] used DEE with pongamia methyl ester and found that 15% DEE biodiesel blend is very promising and effective proportion. The results obtained are in par with KOME. They observed a notable reduction in NOx emissions. Similar conclusion is made from the work of Sivalakshmi and Balusamy [30]. They also suggested that 15% DEE is the optimum value that could be blended with jatropha methyl ester. Qi et al. [31] experimentally studied the effect of DEE and ethanol blended with diesel. It is observed that with the addition of DEE and ethanol smoke emissions are greately reduced at higher loads. Many research studies found a notable rise in BSFC and NOx emissions while a modest reduction in thermal efficiency is noticed. It is also acknowledged for a reduced emissions when biodiesel blends are used on unmodified engines. The authors of this paper in their previous work experimentally investigated the usage of crude pongamia and orange oil biodiesel blends on a diesel [32]. From their work it is understood that the adding orange oil to base diesel gave better performance and lesser emissions when compared with other biodiesel blend.

The present study focuses on using 60% preheated crude pongamia blend with diesel which is clearly missing in the literature. Therefore the present study investigates the effect of 60% CPOP at 90°C along diesel on an unmodified single cylinder diesel engine. Further the work is carried out for 60% PME blended with 40% conventional diesel and the corresponding characteristics are studied and compared with preheated crude pongamia oil diesel blend. Another combination of 15% DEE to 60% CPO with 25% mineral diesel is also experimentally investigated.

2. Materials and Methods

2.1. Biodiesel Properties

Growing pongamia pinnata biodiesel crop In India is quite good as it takes very less water and in the country lot of unproductive lands are in hand where cultivating this crop increases the productivity. About 40% raw oil is extracted from the seed of pongamia pinnata. A typical pongamia tree and seed is shown in Figure 1. The oil for the present study is purchased from University of Agricultural Sciences, Bengaluru.

Fig. 1. Image of typical pongamia pinnata tree and its seed

Table 1. Physio-chemical properties of fuel

Property	Diesel	CPO	CPOP	PME	DEE	DBD 1	DBD 2	DBD 3	IS 15607 Standard
Kinematic viscosity (cSt)	2.6	42.83	23.45	4.8	2.44	15.642	3.8	4.9	2.5-6.0
Specific density (g/cm^3)	0.831	0.956	0.923	0.87	0.732	0.911	0.85	0.714	0.86 – 0.90
Calorific value (kJ/kg)	43000	34879	34879	34879	33892	37663	41000	39857	37270
Flash point (°C)	68	235	–	195	-45	93	78	-40	120
Fire point (°C)	72	240	–	202	-	96	80	-40	130

2.2. Preheating of crude pongamia oil

A stainless steel tank and the heating element used for preheating the crude pongamia oil is shown in Fig. 2. Power supply to the heating element is varied by a voltage regulator.

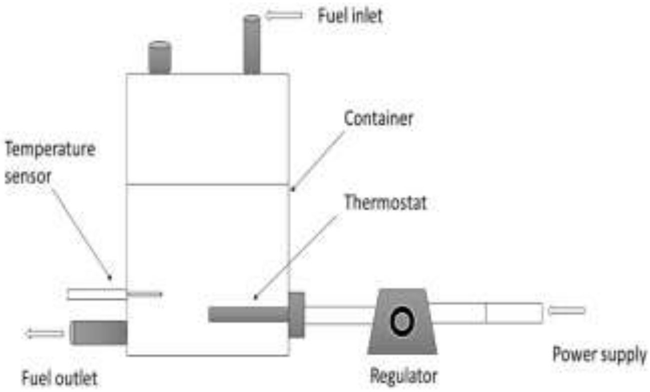


Fig. 2. Set-up for preheating crude pongamia oil

A thermocouple is fitted to the tank to monitor the temperature of the oil. From the literature [22] it is observed that preheating the blend at 90°C is the optimized value for reducing the viscosity of the blend. By this arrangement the mixture of 60% crude pongamia and 40% diesel is preheated up to 90°C. The preheated crude pongamia oil when injected in to the cylinder improves the spray and atomization characteristics. Preheating helps the fuel to undergo better combustion which results in performance improvement and emissions reduction.

2.3. Transesterification process

Of numerous techniques available for viscosity reduction of biodiesel transesterification is one of them. Figure 3 gives a basic idea on the steps involved in transesterification process. The method involves various chemical reactions which finally deliver the biodiesel as output of these reactions. First 1000 ml of crude pongamia oil is poured in to

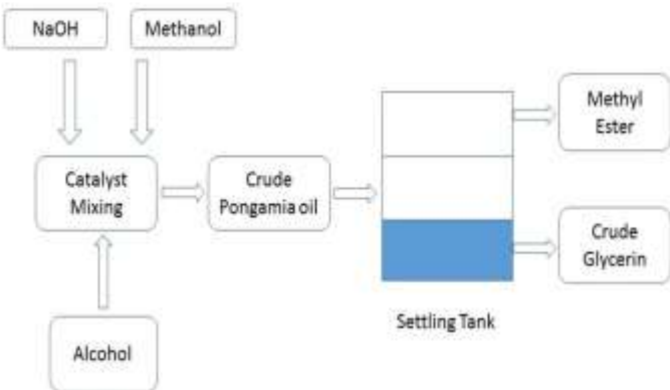


Fig. 3. Schematic diagram for transesterification process

three way flask. Chemical compounds like sodium hydroxide (NaOH 12 grams) and methanol (CH_3OH 200 ml) are taken in a beaker. Alcohol is mixed with Sodium hydroxide (NaOH) and this combination is thoroughly mixed till sodium hydroxide is completely dissolved in alcohol. This mixture is poured in to the three way flask which contains raw pongamia oil. The blend is stirred properly for good mixing. This solution is stirred constantly for one hour at 60°C. The mixture is taken in to separate container and it is allowed to settle down. The glycerol because of its higher weight settles down at the bottom and this process takes nearly four hours. The remaining is the methyl ester of pongamia which stays above the glycerol. The methyl ester obtained is taken into a separate container and heated up to 100°C. This temperature is maintained for a period of 10-15 minutes in order to eliminate any untreated methanol present in the ester. Sodium hydroxide which is added to methanol gets dissolved and forms as an impurity in the obtained ester. Water of 350 ml is added to the ester of 1000 ml to remove these impurities. The final product from these reactions gives the pongamia methyl ester used in this present study.

3. Experimental Setup and Test Procedure

A single cylinder, constant speed, water cooled DI engine is used for the present study. The technical details of the engine are preented in Table 2. The schematic diagram and the components used for the set-up are shown in Fig. 4. The engine produces a maximum rated power of 3.7 kW at 1500 rpm which is coupled to an alternator. At first, diesel is supplied to the engine as fuel and the engine is run. When the engine reaches to a state where necessary warming of the engine is obtained, the biodiesel is supplied to the engine.

Table 2. Technical details of the engine

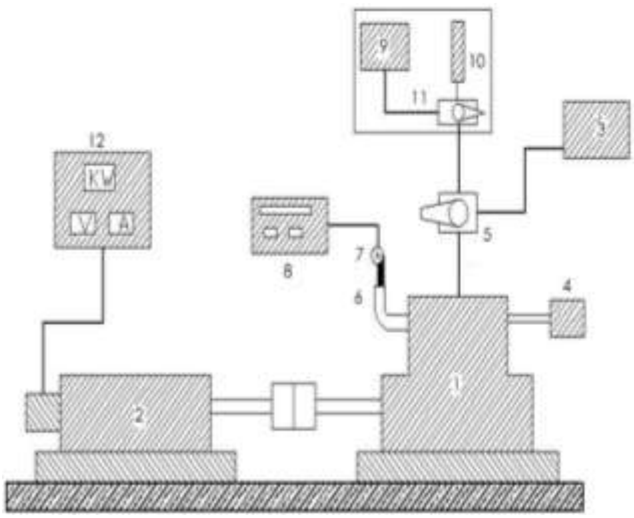
S. No	Engine parameters	Specifications
1	Diesel Engine make	KISSAN, 4-stroke stationary engine
2	Classification	water-cooled
3	Type of injection	Direct injection
4	Rated speed	1500 rpm
5	No. of cylinders	Single cylinder
6	Maximum power	3.7 kW at 1500 rpm
7	Bore diameter	85 mm
8	Stroke length	110 mm
9	Compression ratio	16.5:1
10	SFC at maximum load	240 gm/kW/hr
11	Fuel Injection timing	25^0 before TDC
12	Fuel Injection pressure	200 bar

Necessary check ups for proper lubrication of all rotating and moving parts are ensured before starting the engine. A 200 bar of injection pressure is obtained by adjusting a screw located on the injector. The experimental data is recored by running the engine at a constant speed of 1500 rpm and also with different loading conditions of (0%, 25%, 50%, 75% and 100%). For measuring the pressure inside the cylinder apressure sensor (PA2045E V2 AVL) is used which is placed on the cylinder head. The lubricating oil, coolant, intake air and exhaust temperatures are measured by K-type thermocouples. An alternative fuel tank of 250 cm^3 along with standard burette is used to measure the amount of fuel consumption.

Table 3. Specifications of QRO tech gas analyser

Measuring Item	Measuring Range	Resolution	Display
CO	0.00-9.99%	0.01%	4 digit 7 segment LED
CO_2	0.00-20%	0.10%	4 digit 7 segment LED
Air surplus rate	0.00-2.00	0.00%	4 digit 7 segment LED
HC	0-9999 ppm	1 ppm	4 digit 7 segment LED
O_2	0.00-25.00 %	0.01%	4 digit 7 segment LED
AFR	0.00-99.0	0.1	3 digit 7 segment LED

The gas analyser used emission analysis is QRO tech five gas analyser. Important emission constituents like HC, O2, NOx, CO_2 and CO can be measured using this analyser. The specifications of five gas analyser are presented in Table. 3.



1. DI diesel engine, 2. Alternator, 3. Diesel tank, 4. Air filter, 5. Three way valve, 6. Exhaust pipe, 7. Probe, 8. Exhaust gas analyser, 9. Alternative fuel tank, 10. Burette, 11. Three way valve, 12. Control panel

Fig. 4 Schematic diagram representing the experimental setup

In the present study 60% preheated crude pongamia oil at 90°C is blended with 40% diesel to obtain the biodiesel blend (DBD 1). The esterified crude pongamia oil (pongamia methyl ester) is also mixed in the proportion of 60% with 40% diesel to obtain the biodiesel blend (DBD 2). DBD 3 biodiesel blend is obtained by blending 60% CPO with 25% diesel and 15% DEE. For all the blends the crude pongamia is maintained at 60%. The performance and emissions obtained using biodiesel blends are compared with diesel.

4. Results and discussion

The performance and emission tests are performed on the DI diesel engine running at constant speed and at varying load conditions.The injection pressure is maintained constant at 200 bar. Intially pure diesel is used as fuel, performance and emissions for diesel are determined. Later other biodiesel blends DBD 1, DBD 2 and DBD 3 are used as fuel and these are then compared with diesel.

4.1. Performance parameters

4.1.1. Brake thermal efficiency (BTE)

BTE is defined as how efficiently the chemical energy of fuel may be utlizied to produce maximum mechanical power by the process of combustion. It is greatly influenced by the lower calorific value of the fuel and is a strong indication of how efficient the combustion has taken place in order to produce effective power [33]. Figure 5 shows the variation of BTE for diesel and biodiesel blends with 0%, 25%, 50%, 75% and 100% loading conditions at constant 1500 rpm. It is quite evident from the figure that all the fuel blends tested follows an increasing trend with increase in engine load. BTE values of all other blends at all loading conditions is observed to be lesser than the diesel due to their lesser calorific values. Also the smaller ignition delay which

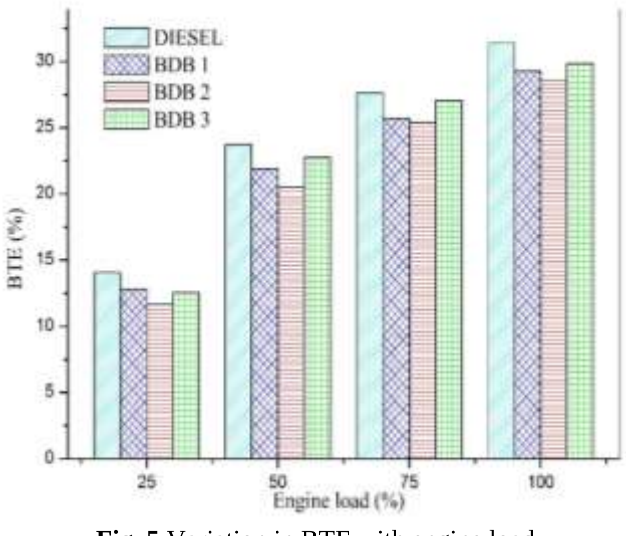


Fig. 5 Variation in BTE with engine load

requires an additional compression work from the engine which finally reduces the BTE of the biodiesel blends. Another important reason for lesser BTE of biodiesel is that the higher viscosity and low warming characteristics which creates poor atomization and leads to fuel vaporization. Also all the blends tested attained maximum efficiency at 100% loading conditions. The highest value (31.41%) of BTE is obtained for diesel at 100% loading conditions. Apart from diesel the values of BTE for DBD 3 are very close to that of diesel. This is attributed to the addition of DEE to the crude pongamia oil which minimize the viscosity of the blend resulting in better mixing, and combustion. From the analysis, it is found that blending 15% diethyl ether with raw pongamia diesel blend gave superior performance that by preheating crude pongamia oil or by esterifying it. The similar trend for BTE is observed from other researchers [34-37].

4.1.2. Brake specific fuel consumption (BSFC)

BSFC indicates the quantity of fuel consumed per unit brake power for one hour. It is always inversely proportional to BTE. Figure 6 shows the trend of BSFC with varying load conditions. It is noted that all the blends follows a decreasing trend with increase in loading conditions. The BSFC values for diesel are lesser to other biodiesel blends. The dissolved oxygen content in biodiesel blends results in better combustion but the biodiesel fuels due to their lower calorific value uses much fuel for producing the same power as compared to diesel. Also the higher viscosity of biodiesel fuel results in poor mixing with air and leads to poor atomization which consumes more fuel. From Fig. 6 it can be seen that the DBD1 closely resembles the BSFC as that of conventional diesel. DBD 1 is followed by DBD 3 during this analysis. This is due to the reason that due to preheating of the DBD 1 blend better mixing and better spraying of fuel is achieved. The BSFC values are least at full load conditions

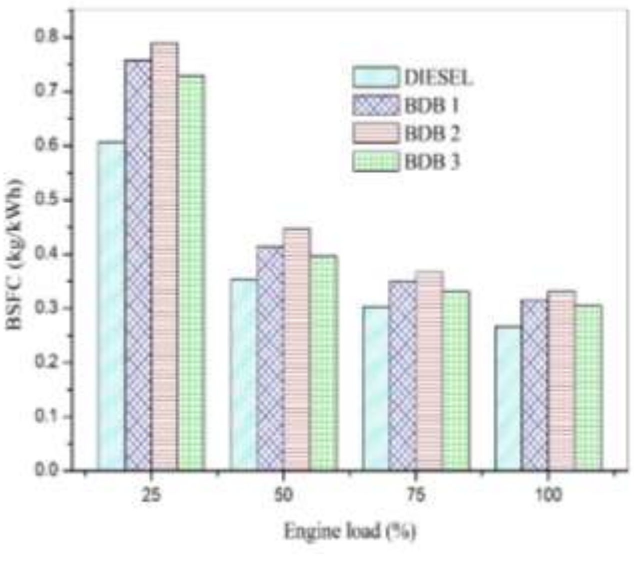


Fig. 6 Variation in BSFC with engine load

when compared to other loading conditions. It is also clear from the Fig. 6 that a notable reduction in fuel consumption is seen from 25% to 50% loading. The results obtained for BSFC with different loading conditions are almost similar to the work carried out with different biodiesel blends [33-34, 36-37].

4.2. Emission parameters

4.2.1. Hydro carbon emissions (HC)

The HC emissions are one of the most principal parameters for determining the emission characteristics of the engine. Incomplete/partial combustion of fuel inside the engine cylinder leads to the formation of HC. The HC trend of tested fuels is shown in Fig. 7. It is obvious to say that the HC emissions are higher for all other biodiesel blends in comparison with diesel at all loading conditions.

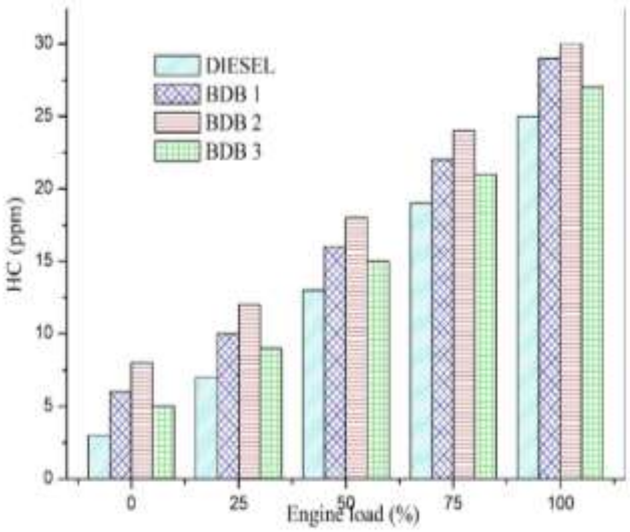


Fig. 7 Variation in HC with engine load

Hydrocarbon emission increases with increase in engine load for all the tested fuels due to more quantity of fuel being injected. HC emission is greatly influenced by the nature of combustion and this value is a minimal for complete combustion. The biodiesel have more oxygen content compared to diesel and hence it is expected that the HC emissions for biodiesel should be less than neat diesel. This is because higher oxygen content may lead to better combustion. But in this study, HC emissions increases with biodiesel and this is because even though the oxygen content is more, the kinematic viscosity of all the biodiesel blends are higher than neat diesel as given in Table. 1. This higher viscous nature of DBD blends results in poorer atomization of fuel, improper mixing of fuel with air and results in incomplete/partial combustion and thus ultimately leading to higher HC emissions [36, 38, 39]. Of the DBD blends investigated DBD 3 has minimum HC emissions and this is because the addition of DEE increases the cetane index of the blend resulting in comparatively complete combustion [40]. It is expected that HC emission of crude pongamia blend DBD 1 should be higher compared to esterified pongamia oil DBD 2. But a reverse trend is observed, which clearly indicates that preheating of DBD 1 favours better combustion compared to the esterification process carried out in forming DBD 2.

4.2.2. Carbon dioxide emissions (CO_2)

The effect of engine varying load on CO_2 is depicted in Fig. 8. It can be understood from the figure that CO_2 emissions are lesser at lesser loading and went on increasing till full load for all the fuels tested. Lesser concentration of oxygen at lesser loading, and increasing oxygen concentration at higher loads may be the reason for the variation in CO_2. This larger quantity of carbon at higher loads is oxidised to CO_2 have resulted in higher CO_2 emissions at higher loads. It is also noticed from Fig. 8 that the diesel fuel is having higher CO_2 emissions when compared with other biodiesel blends at all varying conditions. Higher oxygen content in biodiesel is the reason for lesser CO_2 emissions. Thus it is found that addition of diethyl ether to biodiesel blend has significantly reduced CO_2 emissions which is lowest for the fuels tested. Swaminathan and Sarangan [41] also got little similar results for CO_2 in their work.

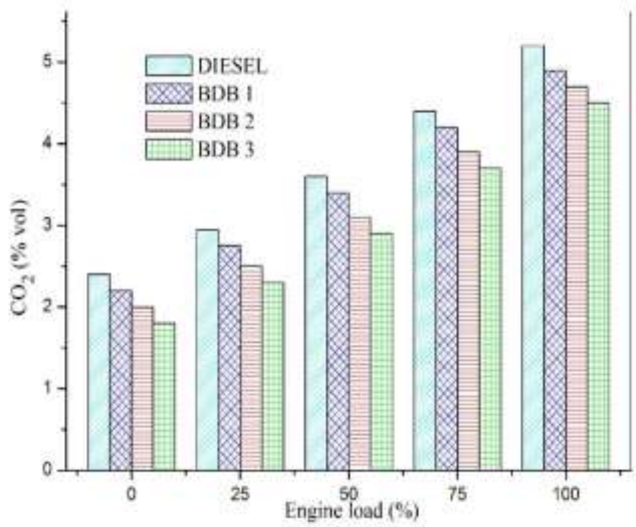


Fig. 8 Variation in CO_2 with engine load

4.2.3 Carbon monoxide emissions (CO)

The variation in CO emissions with respect to different loading conditions is shown in Fig. 9. CO emissions are resulted from incomplete combustion of fuel. Carbon monoxide reacts with excess oxygen to form CO_2 by complete combustion. When incomplete or partial combustion takes place CO is formed the carbon that is present in biodiesel.CO emissions are produced from the burnt fuel when the fuel air mixture is rich than Stoichiometric. Another important reason for CO formation is due to slower flame temperature. It is seen from the Fig. 8 that CO emissions are more at higher load and less lower loads. This is because at higher loading condition the fuel consumption rate is high and exhaust products also increased. Moreover at full load, since fuel injection rate is

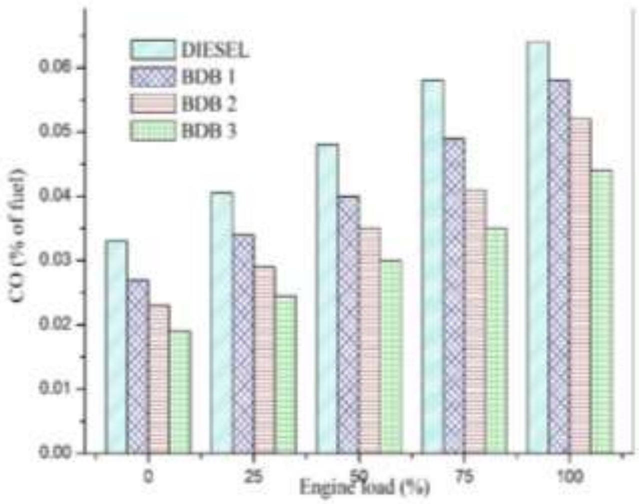


Fig. 9 Variation in CO with engine load

more within the same injection duration, complete combustion at higher loads is relatively lesser as compared with lower loads. The CO emissions are low for the blend DBD 3 out of all tested fuels. It is also noticed that diesel is having higher emissions when compared with other biodiesel fuel. Lesser CO emissions are observed due to rich oxygen content in biodiesel. Thus it is inferred that the introduction of diethyl ether to the biodiesel blend has helped in attaining complete combustion for the tested fuels investigated. The results in the present study for CO is almost same with the work done by Wakil et al. [37].

4.2.4 Nitrogen oxide emissions (NOx)

The NOx emissions are seen to be higher for all biodiesel blends than diesel at all operating conditions and is one of the major limitation in implementing biodiesel fuels for normal practise. NOx is formed when the pressurized air inside the cylinder, having nitrogen constituent reacts with oxygen during combustion at higher temperatures.

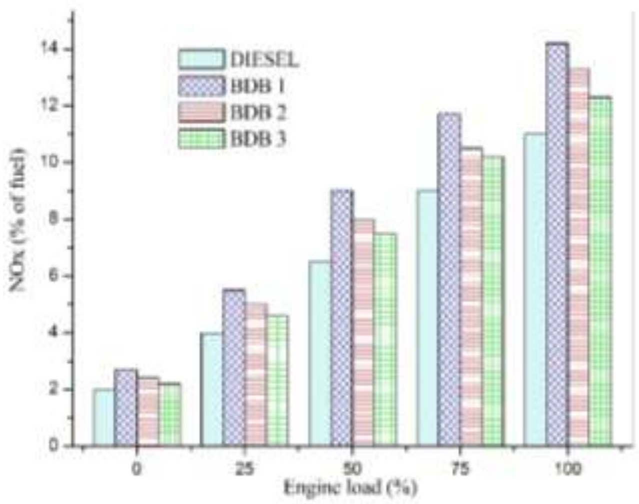


Fig. 10 Variation in NOx with engine load

Figure 10 shows the variation in NOx emissions at different loading conditions. It is observed from Fig. 10 that NOx emissions are increased with increase in engine load for all the fuels tested. NOx emissions are considerably less at no load for all the fuels. The reason biodiesel fuel exhibits more NOx emissions is due to excess oxygen and favourable combustion temperature when compared to diesel. With usage of biodiesel many researchers [35, 42] observed an advance in injection for biodiesel blends. Out of all tested biodiesel blends irrespective of diesel DBD 3 showed lesser NOx emissions at all tested conditions. The others who got similar results for NOx emission with various biodiesel blends [34, 36].

4.2.5 Exhaust gas temperature (EGT)

EGT indicates the quality of combustion which has taken place inside the combustion chamber. It is a well-known fact that for producing more power, engine requires more amount of fuel which increases the EGT with an increase in engine load. Figure 11 shows the contrast between EGT of the engine for all the tested fuels. It is seen that the EGT values of diesel are higher than other biodiesel blends. EGT value of all the tested fuels rises with a increase in engine load. The

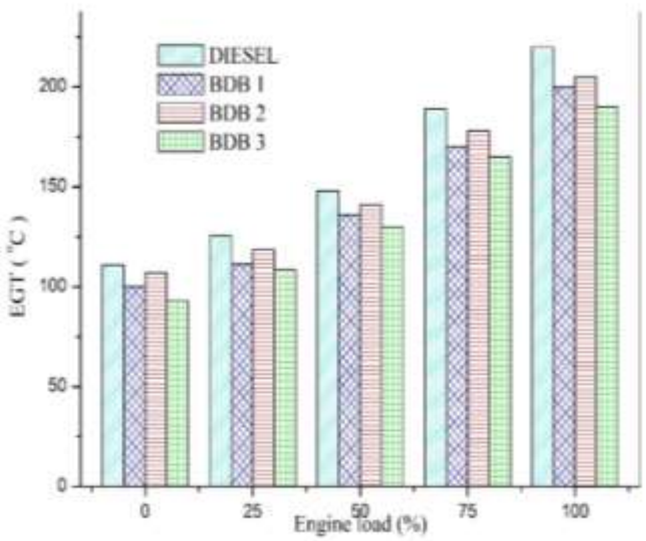


Fig. 11 Variation in EGT with engine load

presence ofoxygen and lesser calorific values of biodiesel blends are the reason for lesser EGT temperatures for all the biodiesel blends at all loading conditions. The least value of EGT is observed for DBD 3 at all loading conditions. Senthil et al. [43] from his work got similar trend for EGT using different biodiesel blends.

5. Conclusion

Experimental investigation on direct ignition diesel engine on the performance and emissions is carried out with 100% diesel, DBD 1 (60% CPOP + 40% D), DBD 2 (60% PME + 40% D) and DBD 3 (60% CPO + 25% D + DEE 15%). In all the tested blends other than diesel 60% pongamia is maintained constant. The following are the crucial remarks observed: The thermal efficiency at all conditions for all blends is found to be lesser than the petroleum diesel. Apart from diesel for all the biodiesel fuels used DBD 3 is very nearer to diesel. BSFC of all the fuels followed a decreasing trend with diesel having minimum value of BSFC. The next closer value for BSFC is seen for DBD 1. CO_2 and CO emissions are found to be lesser for DBD 3 while the neat diesel is having maximum emissions for both CO_2 and CO at all test conditions. NOx emissions are found higher for all the biodiesel fuels when compared with conventional diesel. Where as introducing diethyl ether to pongamia has considerably reduced the NOx emissions. The least NOx emissions among biodiesel fuels are seen for DBD 3 because of diethyl ether composition. Exhaust gas temperature trend is seen increasing with engine load for all fuels and least EGT values are observed for DBD 3.

From the present experimental study, it is determined that DBD 3 has best performance and lesser emissions when compared with DBD 1 and DBD 2. Henceforth DBD 3 with volumetric proportion of 60%, 25% and 15% can be an effective alternative for diesel.

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Nomenclature

AFR	–	Air fuel ratio
bTDC	–	before top dead centre
BP	–	Brake power
BSFC	–	Brake specific fuel consumption
BTE	–	Brake thermal efficiency
CO	–	Carbon monoxide
CO_2	–	Carbon dioxide
CPO	–	Crude pongamia oil
D	–	Diesel
DBD	–	Diesel biodiesel
DBD 1	–	60% CPOP + 40% D
DBD 2	–	60% PME + 40% D
DBD 3	–	60% CPO + 25% D + DEE 15%
EGT	–	Exhaust gas temperature
HC	–	Hydro carbons
NOx	–	Nitrogen oxides
PME or KOME	–	Pongamia methyl ester or Karanja oil methyl ester
ppm	–	Parts per million