"Experimental Analysis of CI Engine Fuelled with Calophyllum Inophyllum Biodiesel and Diesel with Ethanol as an Additive"

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Abstract
The aim of this present work is to extract biodiesel from a new potential non edible oil known as Calophyllum Inophyllum (tamanu oil). The extracted finished biodiesel is further blended with the reference baseline fuel i.e. straight diesel and ethanol in proposed percentage and to test the performance parameters such as brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and emission characteristics such as exhaust gas temperature (EGT), smoke density experimentally on 4.4kW rated power, single cylinder four stroke compressed ignition engine. It was found that B20E15D65 showed 7.2% reduction in BSFC, 20.2% increase in BTE, 6.7% reduction in EGT, 12.38% increase in smoke density whereas B100 gave maximum reduction in smoke by 15.97% with 4.53% increase in BSFC and marginal increase in EGT by 0.53%.
Keywords: Biodiesel, Diesel engine combustion, Ethanol, Engine performance

Introduction

Due to growing transport vehicle, other automobiles and industries there has been sharp increase in pollution level particularly CO2 causes global warming and other emissions like UHC (unburned hydrocarbon), NOx, CO, particulate matter etc. which not only affect environment but also human health associated with these pollutants and consequently increased demand of fuel with increase in no of automobiles. The growth in transportation and constant increase in petroleum raises concerns for the environment as well as for human being because of which it compels India to adopt stern emission norms. India is to adopt Bharat Stage (BS)-VI (equivalent to Euro-VI) norms emission norms by 2020 that means the vehicles are not allowed to emit pollutants above the emission norm set [1]. Accordingly, the vehicle manufacturing industries have to either redesign their vehicle such as combustion chamber for better combustion and efficiency or add auxiliary parts e.g. catalytic converter, exhaust gas recirculation (EGR) etc. to reduce harmful emissions which cost company money and time. On the other hand, fossil fuels are exhausting and is also expected that it may be available less than 50 years at present rate of consumption.

Biofuels are seen as a way to give a higher level of national energy security which being eco-friendly, inexhaustible, viable and ecological. Biofuels are making a resurgence due to increasing petroleum prices, diminishing oil reserves. Biofuels are an inexhaustible asset since they are constantly recharged. Non-renewable energy sources then again are not inexhaustible since they require a great many years to form. There are more than 350 oil bearing crops that are considered among most commonly used vegetable oils. The major oil crops include palm rapeseed soybean sunflower and shelled nut oil etc are known as potential fuel for diesel engines [2,3]. A new plant that are being most researched now a days because of its attractive properties incorporates mustard oil, jatropha curcas and Calophyllum Inophyllum oil (tamanu oil) cotton seed. Penaga Laut is generally known as Calophyllum Inophyllum in Malaysia which is a non-consumable oilseed evergreen tree having a place with the Clusiaceae family. Calophyllum Inophyllum plant is accessible in Africa, Asia, and Pacific areas. It is an individual from the mangosteen family. It is otherwise called Alexandrian Laurel, Tamanu, Pannay Tree, Sweet Scented Calophyllum, Punnai, and so on. In India, these trees are discovered for the most part in beach front territories, which are planted to counteract soil disintegration. They develop around 2-3 m in tallness with thick harsh trunk having broken barks. The leaves are solid and circular fit as a fiddle and blossoms are orchestrated in auxiliary cymes which transmits sweet lime-like aroma. They blossom twice every year and yield various circular drupes that are orchestrated in groups. Each seed is around 50 mm in diameter across having smooth epidermis layer taken after by hard cover which encases a fairly light-yellow piece of around 25 mm in measurement weighing roughly 7g [4,5]. Logical name of "Calophyllum" originates from the Greek word for "beauty leaf" [6]. The unique properties of this oil make it possible for alternate fuel for energy source to be utilized in diesel engines after transesterification.

Another major transport biofuel under consideration is ethanol because of its simple accessibility, inexhaustibility and better physio-chemical properties. Numerous scientists found that ethanol can be mixed with diesel fuel with or without utilizing emulsifier or surfactants that outcomes in better performance and emission characteristics [7-11]. India has approximately 330 refineries which can create more than 4 billion liters of refined liquor every year. Of this aggregate around 162 refineries have the ability to distil more than 2 billion liters of ordinary ethanol. India produces regular bioethanol for the most part from sugar molasses and from grains [1].

Several researchers conducted experiments on Calophyllum Inophyllum biodiesel with diesel for anticipating performance parameters and emissions [13,14,15] and on mathematical modelling using either single zone or two zone zero-dimensional model for validation purposes or analyzing the effects of engine parameters such as compression ratio, ignition timing (injection pressure, start of injection), equivalence ratio etc. out of which few of them are discussed below. Ong, H.C et al**.** did comparison among palm oil, jatropha seed oil and tamanu oil for biodiesel production. Calophyllum Inophyllum oil which are developed in tropical and subtropical atmospheres nation. Jatropha has advantage over other non-eatable oil sources as it was a dry season safe plant fit for getting by in deserted and rural land. Plus, tamanu oil could be considered as diesel replacement biodiesel fuel and could be utilized by extricating biodiesel [6].

Deepan kumar Conducted experiments on, performance and emission characteristics of tamanu oil biodiesel in CI engine. In this work, diesel and Tamanu oil biodiesel in proportion of 15%, 25%, 50%, and 100% biodiesel fuel blend were utilized for leading the performance and emission characteristics from no load to full load. Results demonstrated that, the most extreme BTE acquired was discovered 30% for B15, which was higher than diesel. Among different blend B15 was having brake specific fuel consumption at all loads. With 100 % biodiesel mechanical efficiency was higher at all load condition. Smoke density increased with increment in load and B100 delivered more smoke at all load condition. The NOx emission was higher as the load was increased on the engine [14].

Krishnan investigated the performance and combustion and emission characteristics on a variable compression ratio (VCR) of single cylinder multi fuel engine fueled with tamanu oil biodiesel with conventional diesel fuel. It was found that as the load was increased, the brake thermal efficiency of the fuel blends was also increased. For the different fuel blends of biodiesel i.e. 10%, 20%, 40%, and 60% with diesel the brake power was decreased while comparing with diesel fuel. NOx emission from the tamanu oil biodiesel blend B40 (40% biodiesel and 60% diesel) was found slightly lower with respect to diesel fuel. But in case of 100% load the nitrogen oxide (NOx) emission with B40 blend was higher than that of standard diesel, while the other blends showed closer approximation with that of the standard diesel. The carbon monoxide emission of the blend B40 was found to be higher for lower and medium loads but closer to that of standard diesel [15].

Pugazhvadivu studied the ethanol blending with biodiesel-diesel blend. The ethanol addition to 100% biodiesel (B100) and 50% biodiesel and 50% diesel (B50) created from pongamia oil demonstrated decrease in brake thermal efficiency. Nox emission at peak load was decreased. The smoke density was also lower for B100 and B50 fills. The expansion of ethanol to B100 and B50 brought about noteworthy abatement in smoke emission as compared with diesel [10]. Krishnan reported that adding rice bran oil methyl ester (ROME) in diesel slightly decreased the brake thermal efficiency of engine, however the blending with ethanol in proportion of 1%, 3% and 5% the performance of the engine increased 10 times than the performance of 20% ROME and it was close to the diesel fuel. Therefore, the blending with ethanol and rice bran oil biodiesel can be favorable for compression ignition engine at various operating conditions [16]. Mofijur studied the use of both biodiesel–diesel and ethanol–biodiesel–diesel blends which showed reduction in CO emissions due to inherent oxygen contents present with biofuel and. About 5–10% of ethanol with 20–25% biodiesel could be added with petroleum diesel to reduce exhaust gas emission. Thus, it was recommended to further conduct the study on controlled and uncontrolled emission of ethanol–diesel–second generation biodiesel (e.g. Beauty leaf) as very little work had been done using second generation biodiesel in the ternary blend [8].

In this present work performance parameters such as brake specific fuel consumption, brake thermal efficiency running on 4.4kW rated power, single cylinder four stroke compressed ignition engine were examined. The engine parameters such as engine speed, compression ratio, injection timing, inlet temperature and pressure were constant.

Methods

Most of the vegetable oils poses higher kinematic viscosity, the beauty leaf oil also contains higher viscosity because of which it causes increased drag forces in the fuel system, injection pump, and wear in the fuel supply pumps and injectors which in turn affect the fuel spray, air fuel mixture formation consequently combustion process affecting engine performance and emissions. Therefore, the use of raw vegetable oils directly as fuel in diesel engines are not considered suitable. Thus, to avoid this type of difficulty, raw vegetable oils are converted into low free fatty acid, lower kinematic viscosity, the chemical process used for this conversion is known as transesterification process making its physical and chemical properties very close to conventional petroleum-based fuel (diesel) and can directly be used in diesel engines [5,6].

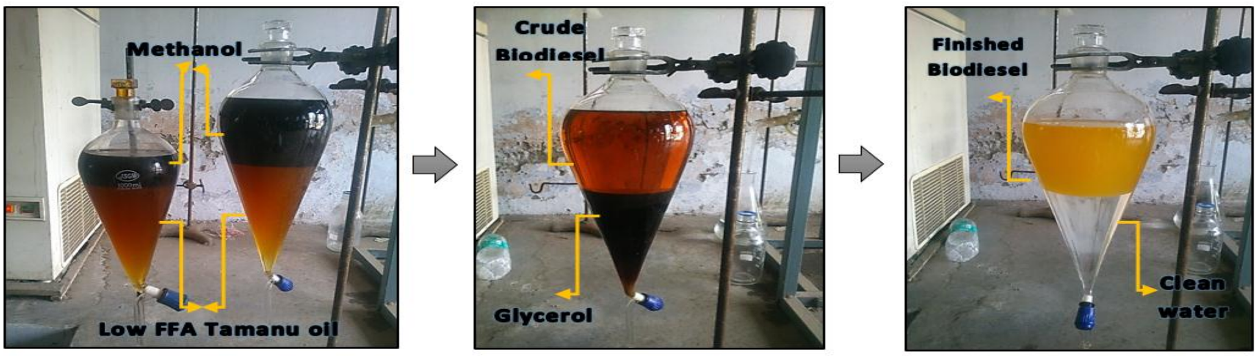
In the present investigation biodiesel was obtained from Calophyllum Inophyllum (tamanu oil), and blends were prepared with diesel and ethanol as an additive. The investigation of these different blends has been studied by measuring its properties and performing these blends on a 4.4 kW/6HP, single cylinder four stroke diesel engine of which specification is shown in **Table 1** and schematic diagram of engine test rig is shown in **Fig. 2.**

The raw tamanu oil was purchased from Tamil Traders 87N/1 Majeeth Street Old Suramangalam Salem, Tamilnadu**.** But the problem with biodiesel conversion of tamanu oil is that free fatty acid (FFA) of the raw vegetable oil is more than 3% thus reacting with alkali catalyst can produce soap and biodiesel yield will be affected. Thus, reducing FFA content in the raw vegetable oil it requires a two-step esterification. The first step known as pre-esterification process in which raw vegetable oil is reacted with acid catalysts such as sulphuric acid thus by reducing FFA content. Then this low free fatty acid is again reacted with base catalysts such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) known as transesterification process. The temperature set in the pre-esterification process was 75°C, 10% by weight of oil acid catalyst sulphuric acid H_2SO_4, methanol to oil ratio of 30:1 and the mixture was continuously stirred for 2 hours. In transesterification process the temperature set was 55°C in reactor setup, 7.5:1 methanol to oil ratio, 1% by weight NaOH as base catalyst, and the mixture was stirred continuously for 1 hour. The conversion efficiency was found to be approximately 89%. All the parameters were set according to the findings of Jahirul et al. [4] where Jahirul et al**.** studied the optimum condition for conversion of biodiesel from Calophyllum Inophyllum oil.

After the pre-esterification once the chemical process was completed in the reactor, the mixture was transferred into separating funnel from where two layers were formed after settling- methanol and low FFA Tamanu oil (shown in **Fig. 1(a)**). The upper layer (methanol) was removed and low free fatty acid tamanu oil was again put on reactor for base-catalyst transesterification process after mixing with specified parameters above. Once it was completed and again poured into separating funnel where after settling, two layers were visible- biodiesel (upper layer), glycerol (bottom layer) **(**shown in **Fig.1(b)).** The important fuel properties for all the blends were determined and is tabulated in **Table 3.**

Table 1 Specification of engine test rig

Parameters	**Specifications**
Made	Kirloskar
Model	TAFI
Rated BP	6/4.4
Rated Speed	1500
Number of	1
Bore x Stroke	87.5 x 110
Displacement	661
Connecting rod	230
Injection timing	23°BTDC
Compression	17.5:1
Cooling System	Air Cooled
Lubricating	Forced Feed
Starting System	Manual hand start



(a) (b) (c)

Fig. 1. A photographic view of esterification product (a) pre-esterification acid catalyst product (b) transesterification base-catalysts product (c) Water wash

Glycerol was removed and crude biodiesel was processed for water wash to remove the excess methanol and impurities remained after esterification. The water wash was done in successive steps with hot water to avoid trapping of air bubbles for four number of times to have visibility of completely clean water and due to higher density, it was collected at the bottom part **(**shown in **Fig.1(c)).** Eventually the finished biodiesel was heated to about 50°C in oven for 15min to remove moisture trapped into it during water wash. Further blends were prepared once finished biodiesel was obtained with respect to diesel as baseline fuel with ethanol. The composition and nomenclature of each fuel is shown in **Table 2.**

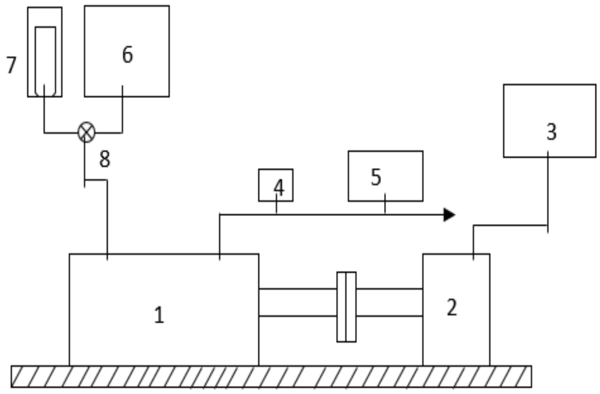
The kinematic viscosity of diesel was found to be 2.52 cSt. Kinematic viscosity of Tamanu oil methyl ester (B100) was found to be 5.27 cSt at 40˚C. In present study ethanol value was found to be 1.65 cSt at 40˚C. The higher heating values (HHV) of diesel was 45.86 MJ/kg. HHV of tamanu oil methyl ester (B100) obtained from present experiment was 40.1 MJ/kg and for ethanol was 27.42 MJ/kg.

The relative density of diesel was found to be 0.823 gm/cc at 15°C temperature. Relative density for tamanu oil methyl ester (B100) and ethanol were 0.88 gm/cc and 0.794 gm/cc respectively. The cloud point and pour point of diesel was found as -2˚C and -10˚C respectively. The cloud and pour point of tamanu biodiesel (B100) was found as 5˚C and 10˚C in present study. The flash point and fire point of diesel was found to be as 60˚C and 63˚C respectively. The flash and fire point of tamanu oil biodiesel was obtained as 180˚C and 193°C respectively.

Table 2 Proportions and nomenclature of fuel blends

Sl.No.	Biodiesel	Diesel	Ethanol	Nomenclature
1.	0	100	0	Diesel
2.	20	80	0	B20D80
3.	20	70	10	B20E10D70
4.	20	65	15	B20E15D65
5.	20	60	20	B20E20D60
6.	100	0	0	B100

Fig. 2 Schematic diagram of engine test rig



1. Engine
2. Eddy current dynamometer
3. Torque applier
4. Thermocouple
5. Smoke density analyser
6. Diesel tank
7. Burette for blends
8. Control valve

Results and Discussions

All the blends were performed on constant speed 4.4kW single cylinder four stroke of constant speed diesel engine and the engine performance test such as brake specific fuel consumption, brake power, brake thermal efficiency, exhaust gas temperature and smoke density were determined.

Brake specific fuel consumption

Fig. 3 shows the variation of brake specific fuel consumption versus load (%) for various blends fuels. The brake specific fuel consumption (BSFC) decreases as percentage of load increases for all the test fuels due to better combustion and lower heat losses. The brake specific fuel consumption for diesel were obtained as 0.544, 0.386, 0.330, and 0.322 kg/kWh. With the addition of 20% biodiesel with diesel (B20D80) the BSFC at 25% and 75% load increases marginally by 0.94%, 0.50% respectively otherwise is reduced at 50% and 100% load by 0.38%, 0.75% respectively. Further testing with small percentage of ethanol (from 10 to 20%) the BSFC was reduced for all the test fuels. The highest reduction in BSFC among them reported was 7.31% at full load for B20E15D65 as shown in **Fig. 3.** The BSFC with tamanu oil methyl ester (B100) at all loads were 0.565, 0.397, 0.351, and 0.337 kg/kWh increased by 3.75%, 2.93%, 6.36% and 4.4% respectively. This may be due to lower calorific value, higher viscosity and poor atomization of B100 and addition of ethanol further increases BSFC due to reduction in calorific value of the blend, lower heat release rate and more energy consumption.

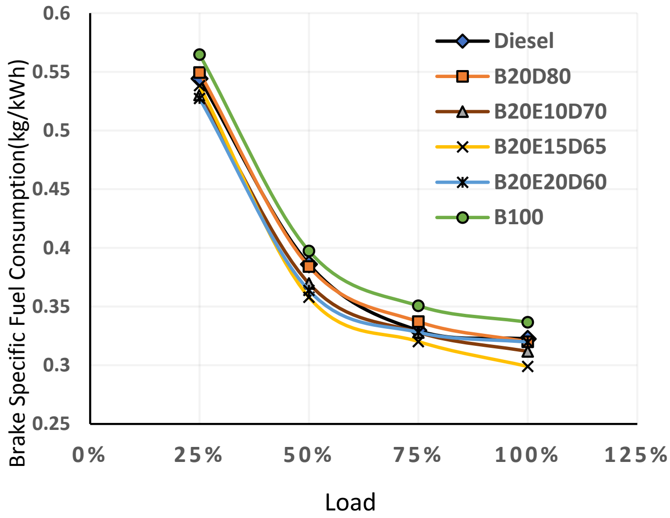


Fig. 3 Variation of brake specific fuel consumption of Diesel, B20D80 and its ethanol blends

Brake thermal efficiency

Fig. 4 shows the comparison of brake thermal efficiency (BTE) versus load (%) for all different test fuels. For all the test fuels, the brake thermal efficiency was increased as the load was increased due to lower heat losses at higher loads. It was observed that the brake thermal efficiency (BTE) for B20D80, B100 and Diesel was about 25.37%, and 24.35% respectively at full load and the percentage increase was 4.2%, and 9.56% with respect to diesel. The addition of ethanol to tamanu oil biodiesel reduces the viscosity of the fuel, increases volatility and the inherent oxygen (i.e. 32%) in ethanol improves the combustion phenomenon. Ethanol addition in 20% biodiesel (B20D80) shows higher brake thermal efficiency as compared to diesel. But further increase of percentage of ethanol in blend reduces the calorific valve of fuel which intakes more amount of fuel to develop the same power, and hence the brake thermal efficiency for B20E20D60 was reduced at 50% and 100% load. The highest brake thermal efficiency was 24.54% at 50% load for B20E20D60 increased by 20.73% with respect to diesel as shown in **Fig. 4.**

The BTE with B100 was found to be 15.90%, 22.60%, 25.61%, and 26.67% at 25, 50, 75, and 100% load respectively with a percentage increase of 10.25%, 11.12%, 7.55%, and 9.56% with respect to diesel.

Table 3 Fuel Properties of all the Blends

Fuels samples	Density (gm/cc)	Cloud	Pour	Kinematic	Flash	Fire	Calorific
ASTM standards	0.860-0.900	-3 to 12	-15 to 10	1.9-6.0	-	-	-
Diesel	0.823	-2	-10	2.51	60	63	45.86
B20D80	0.833	-2	-7	3.24	68	73	44.34
B20E10D70	0.832	-1	-6	2.73	48	50	42.31
B20E15D65	0.826	-2	-8	2.60	38	42	41.14
B20E20D60	0.825	-1	-9	2.29	28	30	40.32
Ethanol	0.794	-15*	-	1.66	17	36	27.42

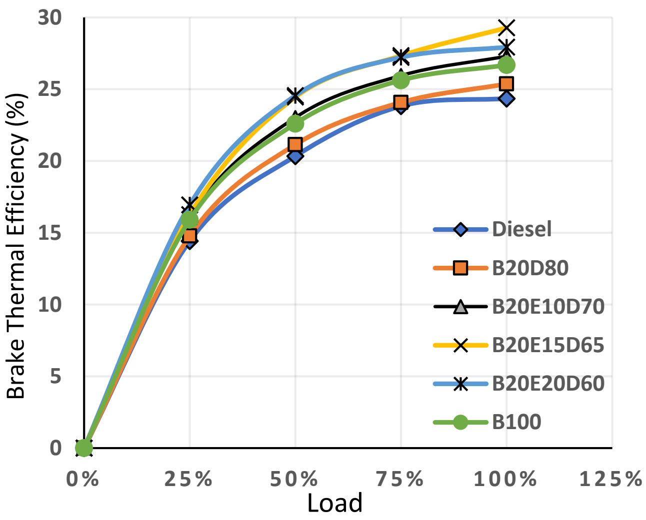


Fig. 4 Variation of brake thermal efficiency of Diesel, B20D80 and its ethanol blends

Exhaust gas temperature

Fig. 5 shows variation in exhaust gas temperature for various test fuels versus load (%). The exhaust gas temperature (EGT) increases as the percentage of load increases for all the tested fuels. This increase in EGT was because of the fact that at higher load, extra amount of fuel is required to be injected to develop more power. The exhaust gas temperature for Diesel, B20D80, and B100 was 375°C, 361°C, and 377°C at full load. However, blending with ethanol for 20% biodiesel (B20D80) showed highest reduction in exhaust gas temperature as compared to diesel was 4.17% for B20E15D65 at full load as shown **Fig. 5.**

The reason for higher EGT might be due to poor atomization of vegetable oil because of higher viscosity which causes slow combustion thus producing higher temperature at the exhaust. But addition of ethanol caused lower exhaust gas temperature because of inherent oxygen content present in the ethanol which causes complete combustion with blends and due to

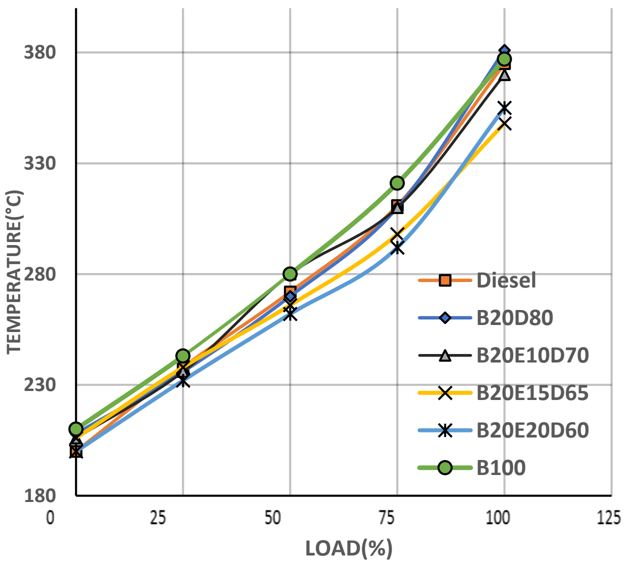


Fig. 5 Variation of exhaust gas temperature of Diesel, B20D80 and its ethanol blends

heat of vaporization and lower heat losses in exhaust gases. The exhaust gas temperature with B100 was found to be marginally increased as compared to diesel with highest increase by 1.71% at 75% load.

Smoke density

Fig. 6 represents the variation of smoke emission with respect to load. The smoke emission increased as the percentage of load was increased due to more requirement of fuel at higher load to develop the power. The smoke density (HSU %) with Diesel, B20D80, and B100 at full load was found to be 39.9%, 46.68%, and 33.52% respectively that indicated increase in smoke as the percentage of biodiesel was increased which might be because of higher viscosity and higher volatility thereby leading to poor combustion due to improper atomization of fuels. The smoke density was lowered as the percentage of ethanol blending with biodiesel-diesel was increased with respect to diesel due to the complete combustion process with oxygenated ethanol, lower viscosity and reduced fuel rich regions in the combustion chamber.

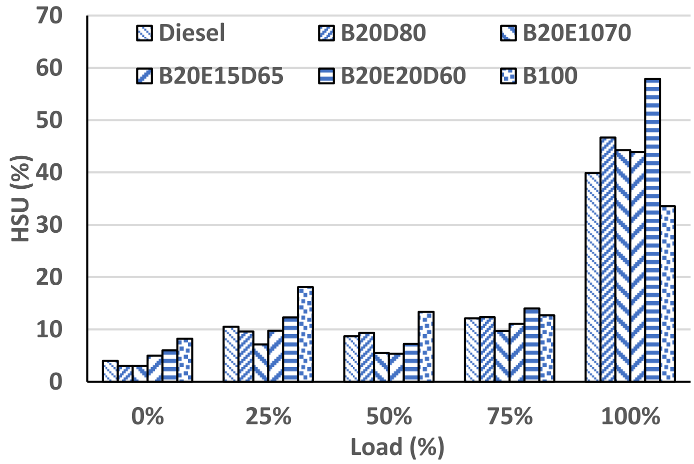


Fig. 6 Variation of smoke density with Diesel, B20D80 and its ethanol blends

Conclusion

The performance evaluation of diesel engine on selected fuel blends were found acceptable on the basis of brake power, brake specific fuel consumption and brake thermal efficiency. The engine was able to develop similar and accepted close results of brake power for all blends as compared to diesel. It shows that the engine running on Calophyllum Inophyllum biodiesel as well as ethanol as an additive was found to be very influential. Even 10 to 20% addition of ethanol, improves the properties, performance as well as emission characteristics of the fuel. But in present investigation where ethanol was added in diesel-biodiesel blends, it was observed that at 20% ethanol blend showed influential results with 40% of tamanu biodiesel by its smoke density reduction of the fuel at selected load condition and reduction in the exhaust gas temperature which is considered to be the main cause of NOx formation.

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