

Performance Characteristics of Pine Oil Mixed Diesel Fueled Single Cylinder Four Stroke Diesel Engine

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Abstract

In this study, biodiesel from the stem of *Pinus roxburghii* was prepared by steam distillation process. Consequently, the physical and thermal properties of pine biodiesel (P100), and 20 % pine-biodiesel and 80 % diesel (P20) were tested on American Society for Testing and Materials (ASTM) standards. The test results confirmed that the thermophysical properties of pine biodiesel and its blend were suitable for the fuel in diesel engine without any modification in the test engine. Eventually, the engine performance and combustion parameters were evaluated for pine-biodiesel blend for 5 % biodiesel and 95 % diesel (P5), 10 % biodiesel and 90 % diesel (P10), 15 % biodiesel and 85 % diesel (P15) and P20, and compared with diesel on Kirloskar Single Cylinder Compression Ignition Engine for a compression ratio of 15:1. In the midst of those in different blends evaluated, P15 showed the better brake specific fuel consumption (BSFC) i.e 18.75 % lower than diesel fuel particularly up to 50 % of the engine load. However, at higher load, decrease rate in BSFC of P15 fuel is lower than engine load up to 50 %. Similarly, brake thermal efficiency (BTE) of P15 increases to 13.5% mainly on 50 % loading condition of the engine. At above, increment rate of BTE of pine oil biodiesel compared to diesel decreases. The brake power (BP) and brake mean effective pressure (BMEP) of P15 also found nearer to diesel. However, the BP of P15 found higher compared to diesel in all loading conditions. Thus, from the experimental investigations, P15 blend of pine oil biodiesel was found to be amenable for its use in compression ignition (CI) engine without any modification, as the BTE and SFC were found to better and, BP, indicated power (IP) and BMEP were also found nearer to diesel fuel.

Keywords: Diesel engine, Pine oil, Engine Performance, blended biodiesel.

1. Introduction:

In current years, the stipulate for energy is rising day by day. The total principal energy expenditure from crude oil is about 29.45% [1]. The speedy diminution of crude oil reserves and their unpleasant effects on the environment leads to research curiosity in renewable energy fuels.

The search for the renewable energy source has become more pronounced in recent era.

Biofuel, which is one of the renewable energy fuel produced from biomass, can be important substitute for fossil fuels. Biodiesel, an alternative instead of diesel fuel, is extracted from renewable biological sources such as

vegetable oils and animal fats. It is environment friendly due its biodegradable and toxic free properties [2]. Methanol and ethanol are two established alternative fuels, which possess the potential substitute of diesel fuel [3]. Biofuel produces more complete combustion than that of conventional diesel fuel due to the additional oxygen content compared to diesel fuel [4].

Normally, plants yields two types of oils, i.e. triglyceride oil (TG oils) and turpene oil (light oil). Among them, triglyceride oil is obtained from plant seeds, whereas turpene oil is obtained from plant parts [5]. Turpene oils are available in some plant species namely eucalyptus, pine tree, etc.[6]. Because of its inherent oxygen content, Pine oil obtained from the pine tree has high calorific value and good solubility, which is comparable to that of diesel fuel [7]. It has been reported that crude plant oils can be used as fuel, either straight or blended with diesel fuel, in diesel engines [8]. Considering these mentioned facts, many researchers have focus their attention to evaluate the performance of CI engine fuelled with biodiesel blends experimentally varying different parameters.

Hariram V et.al. studied on the influence of compression ratio on combustion and performance characteristics of direct injection compression ignition engine. Their studied concluded that BSFC and exhaust gas temperature were increased on reducing the compression ratio. However, BTE was decreased on reducing the compression ratio [9]. Tamilselvan P et.al. conducted their research using pine oil of *Pinus sylvestris* species experimentally and evaluated the performance of CI engine. Their results showed that the BTE was slightly higher than diesel fuel due to the improved atomization, fuel vaporization and combustion of less viscous fuels. However, BSFC was somewhat lower compared to that of diesel fuel because of the combined effect of lower viscosity and higher calorific value [10]. Similarly, Nallusamy D and his team studied the performance and emission characteristics of a single cylinder direct injection diesel engine using an alternative fuel of the biofuel mixed with pine oil and its blends. Their experimental results showed that the 5% of pine oil had significantly comparable BTE and BSFC of diesel fuel. Consequently, their results also

illustrated that the HC and CO emissions level have been considerably reduced for pine oil compared with regular diesel at advanced loading conditions. On the other hand, pine oil shows an advanced level of NOX emission compared to normal diesel [11]. In the same way, Huang H et.al. studied the combustion performance and emission characteristics of a diesel engine under low-temperature combustion of pine oil-diesel blends. Their experimental results showed that the equivalent BSFC of all blended fuel were slightly higher than that of pure diesel. However, BSFC of 50% diesel and 50% pine oil blend fuel had only 2.08% to 3.5% higher than pure pine oil [12]. Hakkı M et.al. focused their study on the effect of turpentine oil blended with gasoline, diesel and gasoline-like distilled engine oil on the engine performance and exhaust emissions. From their study, they illustrated that turpentine oil had a positive influence on engine performance and exhaust emissions [13].

Likewise Raman V studied on combustion performance and emission characteristics from a diesel engine fueled by pine oil biofuel using selective catalytic reduction (SCR) and catalytic converter. From their experimental study they observed that the BTE increased as the composition pine oil increase in the blend and the major emissions such as smoke, carbon monoxide (CO) and hydrocarbon (HC) were reduced by 70.1%, 67.5% and 58.6% respectively, than diesel [14]. Thus, the above mentioned investigations described the engine performance and emission characteristics of the diesel engine fuelled with different biodiesel blends. Here, our main aim of the study is to produce pine oil from the locally available resources and study the performance and emission characteristics of a single cylinder, constant speed direct injection diesel using those oil blends as an alternative fuel without any modifications of the engine.

2. Experimental Methods and Materials:

2.1. Pine Oil Biodiesel-an Overview:

Due to its comparable properties, pine oil, a renewable biomass source of fuel can be blended with petroleum- based diesel fuel [15]. *Pinus roxburghii* sarg is a species of several evergreen trees belonging to the Pinaceae and is inhabitant

to the Himalayas and dispersed all through Pakistan, India, Nepal and Bhutan [16]. The reports find that around 105 species are estimated worldwide [17]. However, only 3 Pinus species i.e. *P. roxburghii*, *P. wallichiana*, and *P. wallichiana* var. *manangensis* are found in Nepal [18]. *P. roxburghii* is a large tree attaining up to 28-55m in height with a trunk diameter reaching up to 2m [19]. The cones of *P. roxburghii* are ovoid conic and usually open up to 20 cm to release seed. Pine oil is a non-edible oil obtained from the needles, twigs and cones from a variety of species of pine, particularly *Pinus roxburghii* of the Pinaceae family using steam distillation method.



Figure 1: Pinus Roxburghii

2.2. Composition of Pine Oil:

Methyl esters, the final product of transesterification reaction by 20 % of volume and diesel by 80 % of volume was mixed by measuring with measuring cylinder for characterization of biodiesel blends.

Pine oil is pale yellow in color having a fresh forest smell, alcoholic compounds and watery in viscosity. It is obtained from oleoresin of pine tree and contains terpineol, which is a tertiary alcohol, along with pinene [20]. The oleoresin (turpentine oil), is extracted from the leaves, bark of *Pinus roxburghii* (local name: Khote Sallo). The chief active chemical ingredients of turpentine oil from *Pinus roxburghii* Sarg are α -pinene, β -pinene, car-3-ene and longifolene [21].

2.2.1. α -Pinene:

α -Pinene is an organic compound of the terpene class, one of two isomers of pinene [3]. It is an alkene and it contains a reactive four-membered ring. It is found in the oils of many species of many coniferous trees, notably the pine [22].

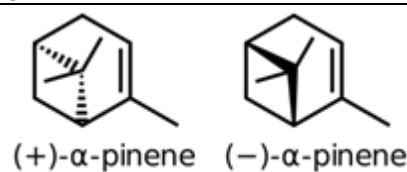


Figure 2: Alpha-pinene

2.2.2. β -pinene:

Beta-pinene (β -pinene) is a monoterpene, an organic compound found in plants. It is one of the two isomers of pinene, the other being α -pinene. It is colorless liquid soluble in alcohol, but not water. It has a woody-green pine-like smell [23].

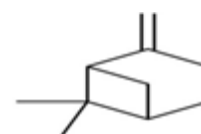


Figure 3: Beta-pinene

2.2.3. Car-3-ene:

Car-3-ene is a car-3-ene (3,7,7-trimethylbicyclo [4.1.0] hept-3-ene) that has S configuration at position 1 and R configuration at position 6. It is an enantiomer of a (-)-car-3-ene [24].

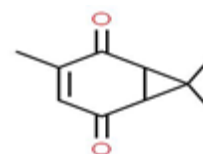


Figure 4: Car-3-ene

2.3. Preparation of Pine Oil Biodiesel:

For the extraction of essential oil, the resin was collected from *Pinus roxburghii* plant.



Figure 5: Resin Collection

The resin was collected from Dadeldhura district of Nepal. The *Pinus roxburghii* plant was identified by agriculture specialist. The collected resin was then subjected to steam distillation process at about 150 °C. After steam distillation the resin converts into rosin (solid), turpentine oil (liquid) and waste which include water vapor, inert material etc.



Figure 6: Rosin



Figure 7: Turpentine Oil

2.4. Preparation of Pine Oil Blends:

Different pine oil blends with diesel such as P5, P10, P15 and P20 were prepared in laboratory of Thapathali campus. These blends were used in the research engine to study the performance of the engine at various loading condition of 1, 3, 6, 9 and 12 kg.

2.5. Thermo-physical Properties Test of Blended Pine Oil Biodiesel Fuel:

Different fuel properties like density, viscosity, kinematic viscosity, calorific value and various other properties were tested for turpentine and P20 at “Unit-2” (D-18, Infocity Phase-II, Sector-33) of FARE Lab Delhi, India.

2.6. Engine Specifications:

The research was conducted in the Automobile lab of Thapathali Campus .The test engine was Kirloskar Direct Injection Research Diesel Engine which is single cylinder four stroke constant speed water cooled engine. The engine is designed to produce power of 3.5 kW at rated speed of 1500 rpm. The technical specification of research engine is shown in Table 1.

Engine	Kirloskar
Type	Single Cylinder, Four stroke, Constant Speed, Water Cooled Diesel Engine
Rated power	3.5 kW
Rated speed	1500 rpm
Cylinder Bore	87.5 mm
Stroke length	110.00 mm
Compression ratio	15:1
Swept volume	661.45 cc

The figure 8 shows the required setup research engine.



Figure 8: Test Engine Setup

2.7. Experimental Test Procedure:

Initially, research engine was tested on a compression ratio of 15:1, with diesel fuel at a steady speed of 1500 rpm for 15 to 20 minutes to attain stable working environment. During testing, engine coolant water should be circulated in the engine at a pressure of nearly 1atm. This can be checked by the pressure gauge setup in the engine. After that, engine was run with P5, P10, P15 and P20 as-prepared pine oil biodiesel blends. Throughout the test, an eddy current dynamometer was used to vary the applied load. The 1-12 kg load was at an interval of 3 kg i.e. 1 kg, 3 kg, 6 kg 9 kg and 12 kg at a constant speed of 1500 rpm and the required

engine performance data for different blends were taken. Correspondingly, same procedures were followed for diesel fuel to take the required data for comparison. The rate of flow of biodiesel fuel is measured using a burette and stop watch setup in the engine where fuel consumed during 60 sec time is noted.

3. Result and Discussion:

3.1. Thermo-physical Properties of Diesel and Biodiesel Blended Fuel:

The blended biodiesel prepared in the lab was tested in Fare Lab - Food Analysis and Research Laboratory, Gurgaon 1220002, India, as per the test method of ASTM standards. The obtained values of the test are shown in Table 2. These acquired numerical values of those physical-chemical properties of blended fuel were comparable to diesel.

Table 2: Properties of Diesel, P100 and P20

S. No.	Parameters	Diesel	P100	P20
1	Pour Point, °C	-25	Less than -33	-10
2	Flash Point, °C	57	45	42
3	Kinematic Viscosity @40°C, cSt	5	2.33	2.268
4	Density@15 °C, kg/m ³	853	842	840
5	Calorific Value, Kcal/kg	11110	11602	11214

3.2. Engine Performance Results:

The performance of the CI engine depends on various parameters, such as injection pressure, combustion duration, mixing of fuel with air, inlet temperature of the air, ignition delay and fuel properties like viscosity, calorific value, flash point, pour point, density, cetane number etc. Here, in this study, experiment was carried out to estimate the engine key performance parameter like Specific Fuel Consumption (SFC), Brake Power (BP), Brake Thermal Efficiency (BTE), Brake Mean Effective pressure (BMEP) of a CI engine using pine oil blends fuel. The obtained results were compared with diesel fuel and different on values on both conditions were discussed based on the properties of both diesel and pine oil

blended fuels. For each pine oil blends and diesel two set of readings were observed and the average value was then taken for consideration.

3.2.1. Specific Fuel Consumption (SFC):

The variation of SFC with different loading condition for diesel fuel and pine oil blends is presented in figure 9. For diesel and pine oil blends, SFC is found to decrease with increase in load. For all pine oil blends the SFC is lower than that of the diesel fuel at all load. The obtained results are in accordance with the results obtained by Vignesh3 et.al. [25]. When compared with diesel, SFC of pine oil biodiesel blend decreases. The lower kinematic viscosities compared to that of diesel fuel result in better atomization and disperse of fuel in the combustion chamber, which helps to accomplish a faster and more complete combustion [11]. At higher load conditions, SFC decreases compared to diesel. This is due to lower viscosity and high calorific value of pine oil and its blends. At 1, 6, and 9 kg load, P15 has lower value of SFC which are 1.40, 0.42, 0.43 kg/kWh and diesel fuel has 1.98, 0.49 and 0.44 kg/kWh at respective loading condition. At maximum load of 12 kg, P10 has minimum value of 0.43 kg/kWh and for diesel at same load SFC was found to be 0.57 kg/kWh.

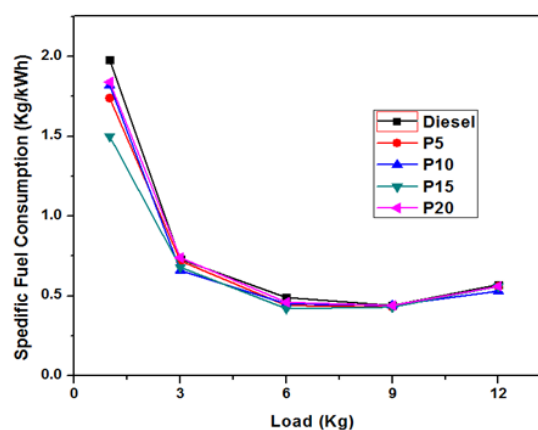


Figure 9: Load Vs Specific Fuel Consumption

3.2.2. Brake Thermal efficiency (BTE):

The variation of BTE with load for diesel and various pine oil blends is shown in Fig. 10. Mostly in all cases, BTE has the tendency to increase with increase in load, this is due to reduction in heat loss and increase in power developed with increase in load [26]. It is well

understood that BTE depends on total fuel consumption i.e., inversely proportional to each other. Since pine oil blends have equivalent calorific value towards diesel, at higher load conditions pine oil blends shows improved efficiency [25].

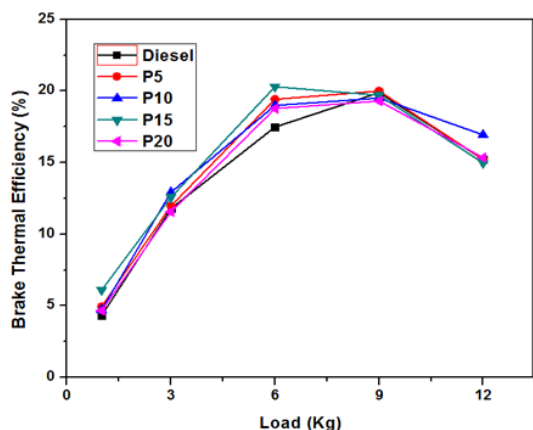


Figure 10: Load Vs Brake Thermal Efficiency

BTE is raised considerably up to 50 % of the load in all blends. Among all blends, P15 has shown better BTE. However, at higher loading conditions, the rate of increment of BTE for all blends is reduced. Here, BTE of P15 increases to 13.5 % mainly on 50 % loading condition of the engine. This is mainly due to the combined effect of lower viscosity and higher calorific value [27]. In addition, shorter ignition delay duration associated with deficiency of oxygen led to the possibility of partial combustion at full load condition resulting drop in engine performance [28, 29]. In this study, it is also evident that at high load, BTE drops and at 12 kg load, P10 has maximum value and BTE increases by 4.72 % compared to that of diesel.

3.2.3. Indicated Power (IP)

Figure 11 illustrated that the Indicated Power (IP) increases with load in diesel and all pine oil blends. P15 shows comparable indicated power at all load with that of diesel fuel. Here, IP for all blends and diesel increases with engine load. ignition delay for all fuels decreases as the engine load increases because the gas temperature inside the cylinder is higher at high engine load. thus, it reduces physical ignition delay, which increases IP [30]. At low and high loading condition of 1kg and 12kg, P10 has higher value of 2.13KW and 4.48KW, whereas

the indicated power for diesel at respective loading condition was found to be 1.95 kW and 4.29 kW respectively. Similarly, brake power of P15 at all loading conditions were also found higher than diesel. The probable reason may be affirmed as, increase in IP leads to better automization of fuel, enhanced spray characteristics and condensed physical delay period, which improved premixed combustion and rapid combustion rate [31]. This is due to the higher calorific value and lower kinematic viscosity of the pine oil and pine-biodiesel blended oils.

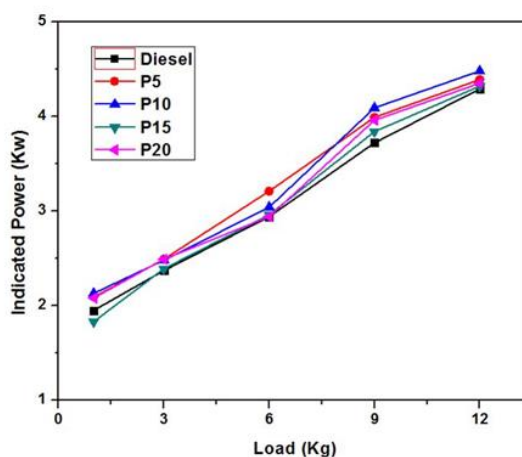


Figure 11: Load Vs Indicated Power

3.2.4. Brake Power (BP):

Figure 12 illustrates the variation of BP with load for diesel and all pine oil blends. The value of BP increases with increase in load in all cases. This designates lower frictional loss at high loads when compared to low loads. P10 has higher value of BP than diesel fuel at all loading condition.

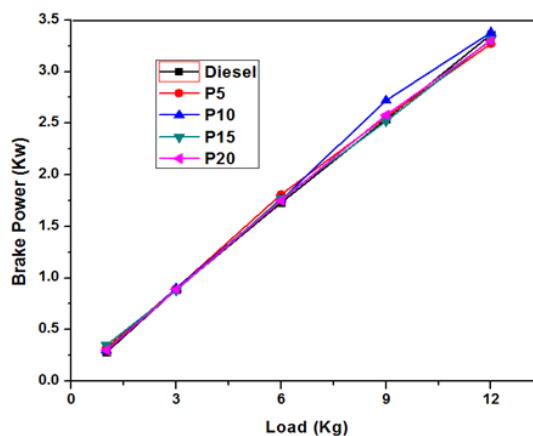


Figure 12: Load Vs Brake Power

At 1 kg and 12 kg loading condition the value of BP for P10 was found to be 0.30 kW and 3.38 kW, respectively, and at respective loading condition for diesel the value of BP was 0.28 and 3.36 kW.

3.2.5. Brake Mean Effective pressure (BMEP):

The variation of BMEP for diesel and various pine oil blends is illustrated in Fig. 13. In all cases BMEP increases with increase in load. Pine oil blends shows similar BMEP at all loading condition compared with diesel fuel. Here, BMEP of P15 and P10 at all loading conditions are better than P20 and diesel fuel.

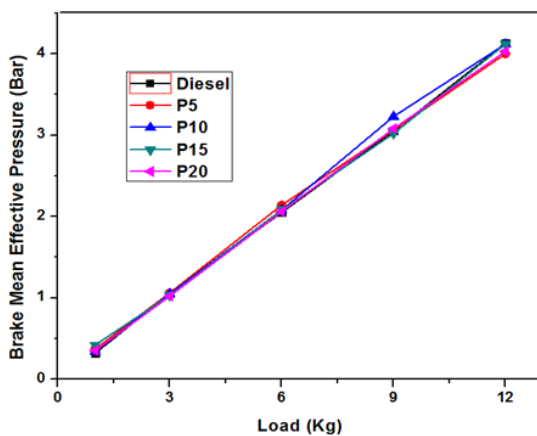


Figure 13: Load Vs Brake Mean Effective Pressure

3.2.6. Mechanical Efficiency (ME):

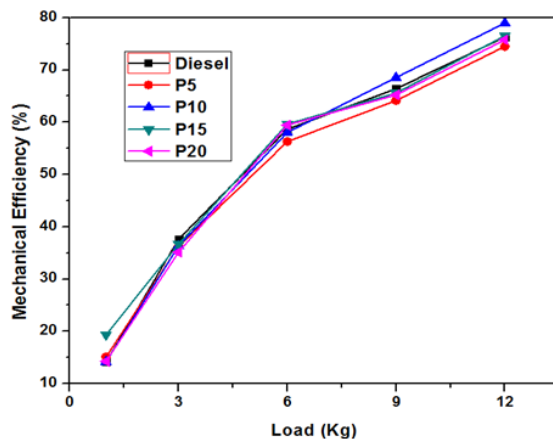


Figure 14: Load Vs Mechanical Efficiency

Figure 14 shows Mechanical Efficiency (ME) of diesel and different pine oil blends. Here, the ME increases with increase in load for various pine oil blends and diesel fuel. With increasing load, frictional losses decrease and mechanical efficiencies increase [32]. The ME for the blend

is higher than the diesel fuel due to higher calorific value of pine oil. At higher loading condition of 12 kg it was found that P10 has ME of 78.97 %, and ME increases for P10 by 2.68 % compared to that of diesel fuel at respective loading condition.

Thus, the above obtained experimental results confirmed that the increment in BTE and reduction in SFC made the blends of pine oil biodiesel a suitable alternative fuel for diesel. Moreover, among all blends, P15 showed better engine performance at average loading condition, but at higher loading condition for same compression ratio, P10 showed better performance. These variation on the blends might be likely due to the difference in the actual thermo-physical properties between the various blend ratio. Similarly, reduction of SFC and, increment BTE and ME of biodiesel blends obtained in this study were higher compared to the past research literature [9, 10, 33, 34].

4. Conclusion:

From experimental investigation following conclusion can be drawn;

- Specific fuel consumption of P15 at lower loading condition of 1kg decreases by 0.58 kg/kWh and at higher loading condition of 12kg SFC of P10 reduced by 0.14 kg/kWh compared to that of the diesel fuel, this is due to lower viscosity and high calorific value of pine oil and its blends
- At 50 % loading condition i.e. up to 6 kg, P15 shows higher BTE and lower SFC. However, decrement rate of SFC and increment rate of BTE of pine oil blended biodiesel compared to diesel reduced at higher load i.e. at 9 kg and 12 kg. Moreover, BP, IP and BMEP of P15 also obtained comparable to diesel fuel.
- The IP and BP for P10 were found to be higher than that of other blend and diesel fuel at all loading condition.
- The ME for pine oil blend was found to be higher than that of diesel fuel due to higher calorific value of pine oil. At all loading conditions, the ME of all blended fuels were found comparable to that of diesel fuel.

Thus the experimental results prove that the use of pine oil blends in CI engine is a viable alternative to diesel.

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