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Performance and emission characteristics of diesel engine fueled with blends of Neem biodiesel

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Abstract

In this research, biodiesel produced from locally available Neem seed was used on the direct injection variable compression ratio (VCR) diesel engine without any modification. Neem seed, which contains 30-60% oil, was transformed into biodiesel through acid-base transesterification. The 1:6 of methanol to oil ratio, 1.2% (v/v) sulfuric acid during pretreatment and KOH as alkali catalyst for optimum yield was used. The characterization of prepared biodiesel was done according to ASTM standard. The effect of Neem biodiesel blends such as 10% Neem biodiesel and 90% conventional diesel (NBD10), 15% Neem biodiesel and 85% conventional diesel (NBD15), and 20% Neem biodiesel and 80 % conventional diesel (NBD20) were prepared and their performance and emission characteristics were studied. The test was performed at 17:1 compression ratio and 230 bar injection pressure with varying loads of 1 kg, 3 kg, 6 kg, 9 kg and 12 kg. The brake thermal efficiency (BTE), specific fuel consumption (SFC), torques and exhaust gas temperature (EGT) were analyzed on those different loads. The BTE for conventional diesel, NBD10, NBD15 and NBD20 were recorded as 8.12%, 7.23%, 6.56% and 6.23% respectively, at same loadings. These efficiencies increase with increment of load up to 31.25%, 28.96%, 27.56% and 27.35% respectively. The difference for specific fuel consumption (SFC) in pure diesel and NBD20 was recorded as 21.66% at 1 kg load whereas at 12 kg load this difference was 19.23%. The EGT for NBD20 was recorded higher than diesel for entire loading condition. The CO emission decreases with the increment of load and the proportion of biodiesel, whereas HC shows just reverse result. The smoke opacity was found better for NBD20 in comparison to conventional diesel. The performance and emission characteristics demonstrate that the blend of Neem biodiesel up to 20% with conventional diesel can be used as an alternative fuel in diesel engine without any change in the engine.

Keywords: Neem biodiesel; Acid-base transesterification; Engine performance; Emission

1. Introduction

The present world is surrounded with problems of depletion of fossil fuel by their excessive uses and their adverse environmental pollution. The main causes for these problems are limited resources and emission of harmful gases (carbon dioxide, carbon monoxide, hydrocarbon, and oxides of nitrogen) during combustion. These adverse problems compel to seek the alternative for petroleum product with reduction of environmental degradation.

The biodiesel derived from a wide variety of sources can be used as an alternative fuel for petrol and diesel. Among these, Neem oil and its seeds which contains 30% of oil content, is a promising source to derive biodiesel. Various researches have been done to study about the possibility of cultivating Neem plants in Nepal. Lamichhane et al. studied about the possibility for farming of Neem in terms of growth performance and survival rate in the difference places of Terai region of Nepal [1]. From their study, they illustrated that survival rate was more than 80% [1]. Similarly, several researchers have shown that different methods can be used to produce Neem biodiesel from Neem oil, and used those biodiesels in different engines to observe the performance and emission characteristics. Madai et al. produces Neem biodiesel by transesterification using catalyst of 1.7% calcined banana peel ash and 1.3% Li-CaO/$Fe_2(SO_4)_3$, and 99.8% reduction in free fatty acid value was obtained for 8:1 ratio after reacting for 53 minutes [2]. Muthu et al. synthesized Neem biodiesel by using 1% wt. of sulfated Zirconia as catalyst with 9:1 methanol-to-oil molar ratio in pretreatment processes (24.76 mg KOH/g to 2 mg KOH/g) to reduce the acid value and then followed by transesterification and adjusting the reaction time of 2 hour and reaction temperature of 65 ^{0}C [3]. Anya et al. used 0.75% v/v sulfuric acid as catalyst with 0.58 of methanol to oil molar ratio during pretreatment processes and free fatty acid value was reduced to 0.5 mg KOH/g from 29.87 mg KOH/g, before transesterification for biodiesel extraction [4]. Gopinath et al. performed experimental study on single cylinder, direct injected, air cooled, four-stroke diesel engine to observe the performance and emission characteristics of Neem methyl ester blended with diesel. The experimental results showed that 20% blend provides better result in performance and emission than other 30% blends [5]. Inayat al. used response surface methodology software for determining the optimal amount of catalyst, reaction time and methanol to oil ratio, and found that 1 wt.% of catalyst, 6:1 oil to methanol ratio and 60 minutes reaction times gives optimum yield [6]. Kannan et al. experimentally studied the performance and emission characteristics of Neem blend biodiesel on diesel engine without engine modification. Their study showed that the 20% blended biodiesel of Neem oil is suitable for biofuel in diesel engine without modification [7]. Similarly, Nair et al. experimentally studied emission and performance characteristics of four stroke diesel engine using Neem blend as a fuel. Transesterification process was followed for biodiesel extraction. 1% v/v H_2SO_4 as catalyst was used for acid esterification. Experiment was completed with blend of 10, 20 and 30% Neem blend with pure diesel, and showed that the brake thermal efficiency and reduction in emissions increased in 20% blend biodiesel [8]. Hence, the performance and emission results of the

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blends of Neem biodiesel in diesel engine prove to be better than only diesel. So, we are motivated to prepare Neem biodiesel from locally produced Neem plant via transformation of Neem oil into biodiesel through acid-base transesterification, and to evaluate the performance and emission characteristics of blended oil on single cylinder four strokes water cooled diesel engine.

2. Materials and methods

The crude Neem oil was obtained from the local Ayurvedic shop in Kanchanpur district, Belauri Municipality. All the chemical used, potassium hydroxide, sulfuric acid, isopropyl alcohol and phenolphthalein indicator were of analytical reagent grades. Potassium hydroxide (KOH) in pellet form was used as base catalyst [6]. The distilled water needed for washing of biodiesel was provided by local supplier. The conventional and most economical method, two-step transesterification process was adopted for biodiesel production [2,3]. For preventing the formation of soap during acid catalyzed esterification due to insufficient acid, free fatty acid (FFA) value was calculated and used as per needed. Pretreatment process aids in conversion of free fatty acid to its corresponding fatty acid methyl ester. In this process, methanol react with triglycerides to produce glycerol and ester. The catalyst boosts the final yield and reaction rate [6].

Figure 1: Pretreatment of crude Neem oil.

2.1. Fuel preparation

2.1.1. Determination of acid value

Crude Neem oil was taken and its acid value was determined using standard isopropyl alcohol method. The 2-g sample oil was taken in 100 mL glass beaker and 10 mL of isopropyl alcohol was added into it as the titration solvent. With the addition of 4 to 5 drop of phenolphthalein indicator in previous mixture, it was stirred for uniform mixture and titrated with 0.1 N potassium hydroxide solutions [6]. Total acid value was measured as 18 mg KOH/g and free fatty acid value was 9 mg KOH/mg. FFA value was too high for biodiesel production through single basic treatment processes. Thus, acid value was reduced below 1 mg KOH/mg by pretreatment processes. Two step acid-base reactions were conducted for biodiesel production.

2.1.2. Acid catalyzed esterification

The 250 ml of crude Neem oil weighing 226 g was taken in a glass jar and heated up to 65 ^{0}C using magnetic stirrer with hot plate (Fig. 1). The 113 mL of methanol and concentrated sulfuric acid 1.5% by weight solution was prepared. As the temperature of Neem oil reaches 65 ^{0}C, the mixture of methanol and sulfuric acid was gradually added. The mixture was heated and stirred continuously for 60 minutes using magnetic stirrer with hot plate. The mixture was kept for 6 hours for settling down. Then, the methanol water fraction at the top and residue after reaction at bottom were removed. This pretreated oil was then taken for alkali transesterification.

2.1.3. Alkali catalyzed transesterification

The pretreated sample oil was heated at 65 ^{0}C and 1% (w/w) KOH was dissolved in 1:6 molar ratio of methanol to oil was kept in reactor (Fig. 2). The reaction was carried out for 90 minutes. After completion of reaction, the mixture was allowed to settle down in separating funnel overnight. A separated layer of methyl ester at top and glycerine layer at the bottom were obtained. Biodiesel thus obtained was washed multiple times with distilled water until the traces of glycerine were completely washed and it was finally dried in hot air oven for 24 hours.

Figure 2: Prepared fuel sample.

Table 1: Engine test rig specifications.

S.N.	Features	Specifications
1	Make	Kirloskar Diesel Engine
2	Type	Four stroke, Water cooled Diesel
3	Number of cylinder	1
4	Combustion principle	Compression ignition
5	Maximum speed	1500 rpm
6	Crank radius	55 mm
7	Compression ratio	15:1 to 18:1
8	Loading	Eddy current dynamometer
9	Maximum power	3.5 kW
10	Connecting Rod length	300 mm
11	Method of starting	Electric motor cranking

2.2. Preparation of fuel

Neem biodiesel obtained after washing and drying was blended with commercially-used petroleum diesel on volumetric basis with a measuring cylinder in different proportion as follows:

NBD10: 10% Neem biodiesel and 90% diesel

NBD15: 15% Neem biodiesel and 85% diesel

NBD20: 20% Neem biodiesel and 80% diesel

2.3. Testing of thermo-physical properties of blended biodiesel

For characterization, 500 ml of 20% blended Neem biodiesel was prepared, and the sample was tested in Central Laboratory of Nepal Oil Corporation, Sinamangal Kathmandu and Bioenergy lab of National Academy of Science and Technology (NAST), Khumaltar, Lalitpur. The density, kinematic viscosity, flash point, pours point, calorific value, cetane number, cetane index and copper strip corrosion test was done to find thermo-physical properties of biodiesel.

2.4. Experimental setup and test procedure

The performance and emission test of blended biodiesel and diesel was carried out on the computerized four stroke single cylinder direct injection VCR engine. Table 1 shows the specifications of test engine. During testing, no any alteration and modification were made in the test engine.

The eddy current dynamometer was coupled with experimental device for load variation. During engine test for data collection and analyzing, computerized data acquisition system was used (Fig. 3). The injection pressure was adjusted by adjusting of spring tension of fuel injector as 230 bar. The compression ratio was maintained with the adjustment of tilting cylinder block. Allen blots were loosened for rotating the adjuster by adjusting the lock nut to set the required compression ratio of 17:1. The engine was run at constant speed of 1500 rpm with compression ratios of 17:1 and 230 bar injection pressure at different load of 1kg, 3 kg, 6 kg, 9 kg and 12 kg. Commercial diesel and NBD10, NBD15 and NBD20 of Neem methyl ester was used. The study was conducted by comparing the brake thermal efficiency (BTE), specific fuel consumption (SFC), torque and exhaust gas temperature (EGT) of blended biodiesel with pure diesel. For measurement of exhaust gases, four gas analyzers of Horiba Automotive Emission Analyzer were used. Carbon monoxide, carbon dioxide, and hydrocarbon carbon emissions were compared between biodiesel blend and pure diesel. Bosh Emission Analyzer tester (EAM) on VAAP engine was used for smoke opacity measurement under full throttle condition.

Figure 3: Computerized test engine.

Table 2: Characterization of NBD20 and pure diesel.

Properties	NBD20	Diesel	Test Method
Density at 15°C, kg/m^3	839.5	820-860	ASTM D1298
Cetane Number	59.5	30-65	ASTM D613
Calorific value, kJ/kg	39750	43200	ASTM D2382
Kinematic viscosity at 40 °C, Cst	2.47	1.9 - 4.1	ASTM D445
Flash Point (Minimum), °C	55.4	52	ASTM D3828
Pour Point, °C	-3	-11	ASTM D97

3. Results and discussion

3.1. Biodiesel production

Neem oil having initial FFA of 9% was reduced to 0.68% by acidic esterification, followed by alkali transesterification. The transesterification was carried out with 6 different samples of 250 mL. Yield of 82% was obtained during biodiesel extraction in laboratory scale.

3.2. Thermo-physical properties of fuel

The biodiesel prepared in the lab was tested as per ASTM. The standards for different properties with their values are shown in Table 2.

3.3. Performance characteristics

Performance of engine that runs with biofuel are mainly governed by the combustion process. Combustion process is influenced by its physical properties like: viscosity, volatility, density,

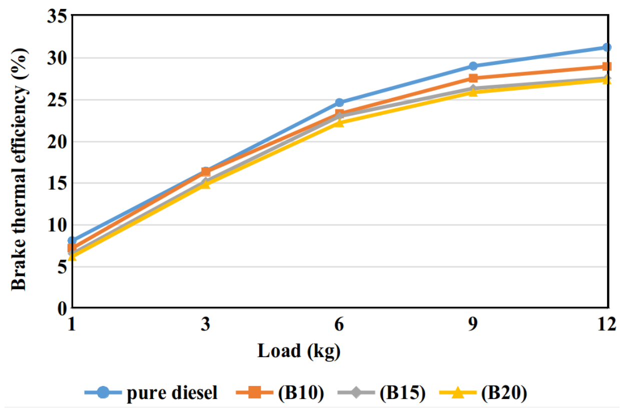

Figure 4: Variation of brake thermal efficiency Vs. load for different blend.

flash point, etc. The high viscosity of biodiesel significantly affects atomization. Increase in pressure results in the better atomization of fuel because the fuel gets splitted into smaller and finer portions as the injection pressure increases. Thus, the experimental study was conducted with commercial diesel and Neem biodiesel blend of 10%,15% and 20% with commercially-used diesel to observe their performance and emissions in a direct injection engine.

3.3.1. Brake thermal efficiency

Fig. 4 shows BTE that vary with the variation of engine load at constant speed of 1500 rpm, maintaining compression ratio of 17 and fuel injection pressure of 230 bar for three-hole nozzle. At 1 kg load, the efficiencies of blended fuel were almost similar to pure diesel whereas there is an increment in efficiency as load increases in every fueling condition. However, the efficiency of the engine decreases as the concentration of biodiesel increases. At 1 kg load, BTE for pure diesel, NBD10, NBD15 and NBD20 were recorded as 8.12%, 7.23%, 6.56% and 6.23% respectively. With the increment of load these efficiencies increase up to 31.25%, 28.96%, 27.56% and 27.35% respectively. Increase in biodiesel concentration increases the oxygen content and thus improving the combustion characteristics. But higher concentration of biodiesel results in higher viscosity and lower volatility that leads to poor atomization and lean combustion. The highest efficiency was observed at 12 kg load and it reduced when the biodiesel concentration increased [8–10].

3.3.2. Specific fuel consumption

Fig. 5 shows the comparative study of specific fuel consumption of pure diesel and blends of Neem biodiesel with variation of load. At 1 kg load, more deviation was observed among the test fuel. All blended fuel shows higher value of SFC than diesel. Increase in the biodiesel concentration shows increase in fuel consumption. However, as the load increases the fuel consumption was decreased for all fuel and beyond 3 kg load much deviation was not observed. At 1 kg load, the difference of SFC in pure diesel and NBD20 is recorded as 21.66%, whereas at 12 kg load this difference was 19.23%. The highest fuel consumption of NBD20 (1.46 kg/KWh) was due to high water content in it [8]. The decrement of specific fuel consumption at 12 kg load was possibly due to rapid evaporation of water during combustion that provides the higher in-cylinder wall gas temperature and compensates the low energy content by addition of enthalpy [5].

3.3.3. Exhaust gas temperature

Fig. 6 shows how exhaust gas temperature varies with different engine loads that are fueled with blends of Neem biodiesel and pure diesel. It was observed that EGT increases with the increase in load for all fuels. The possible reason may be due to

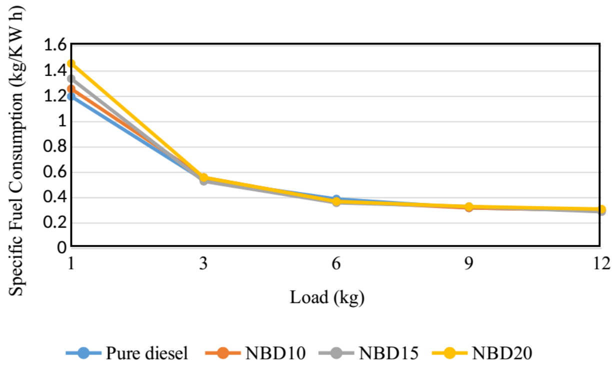

Figure 5: Specific fuel consumption Vs. load for different blend.

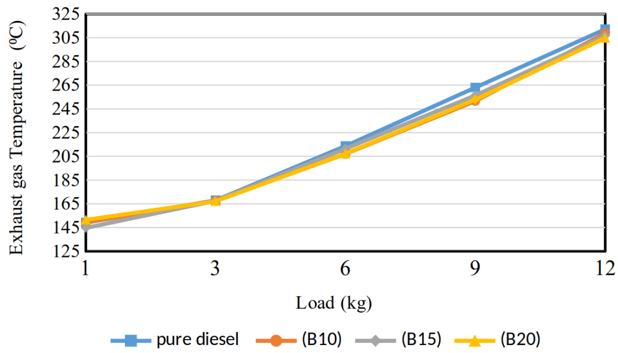

Figure 6: Exhaust gas temperature vs load.

higher cylinder temperature inside the engine when higher rate of consumption of fuel takes places for extra load generation. Further the same result could be justified with reduction of injection time with rise in load to the engine [9]. At 1 kg load, the EGT for pure diesel, NBD10, NBD15 and NBD20 were recorded as 156.36°C, 149.5°C, 144.64°C and 132.56°C respectively. These values at 12 kg load rise to 335.12%, 322.82%, 312.56% and 304.85% respectively. Higher EGT was recorded for NBD20 than other fuels for entire loading. Another possible cause for higher EGT may be the ignition delay that slows combustion.

3.3.4. Torque

Fig. 7 explains the effect of load on the torque production of the engine. The torque increased with the increase in load for all the blend of Neem biodiesel and pure diesel. The increase in fuel consumption with the increase in load may be one possible reason for increment in load. For all loadings, pure diesel produces more torque than the blended fuels. As the portion of biodiesel increases, less torque was observed due to less energy content [10]. At 1 kg load, pure diesel and NBD20 produces torque of 3.35 Nm and 2.02 Nm respectively whereas at 12 kg load this value rises up to 26.56 Nm and 23.65Nm for pure diesel and NBD20 respectively. At 1kg load, deviation of 34.32% in torque generation was observed between pure diesel and NBD20, whereas at 12 kg load, 10.95% deviation in torque generation was noticed. Further, less energy was result of higher density and viscosity and lower calorific value of Neem biodiesel. At full load condition of NBD20, 5% reduction of torque was recorded.

3.4. Emission characteristics

3.4.1. CO emission

Fig. 8 shows the CO emission pattern against the load. It illustrates that the emission of CO for diesel is more for all loading conditions than the blended biodiesel. However, as the Neem biodiesel

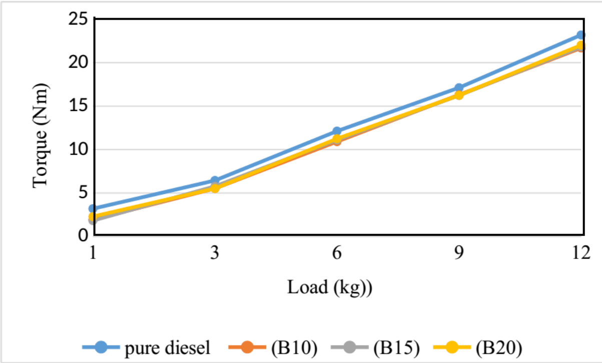

Figure 7: Torque Vs. load.

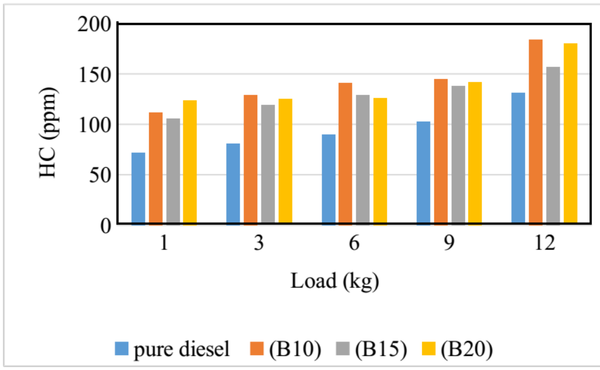

Figure 9: UHC emission for different load.

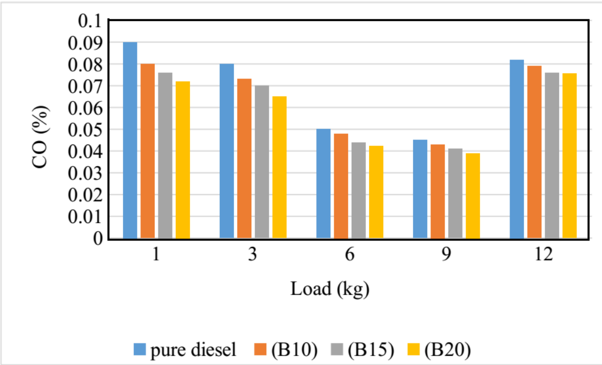

Figure 8: Effect of load on CO emission.

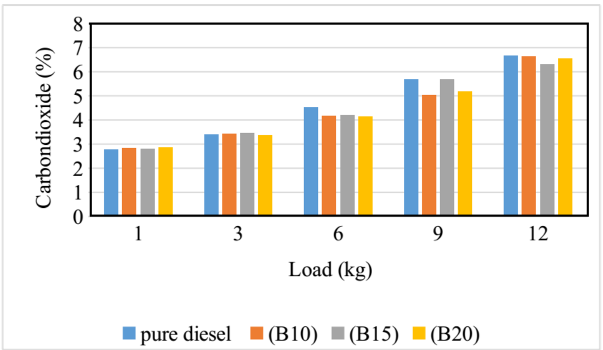

Figure 10: CO_2 emission at different loads.

concentration increases, the CO emission starts decreasing. Increase in biodiesel content increases the oxygen content and lower carbon to hydrogen ratio in the blended fuel as compared to pure diesel. Complete oxidation of blended fuel as compared to pure diesel may be another reason for lower CO emission. At 1 kg load, pure diesel and NBD20 had CO emission of 0.09 % and 0.072% but as load rose to 12 kg, the CO emission was recorded as 0.082% and 0.0758% respectively for pure diesel and NBD20. It shows that CO emission decreases with increase in load up to 6 kg, and then increases with the further rise in load. This may be due to complete combustion aided by oxygen [9]. Negative effect due to small specific gravity and high viscosity were countered by complete combustion processes. The higher load and rich oxygen mixture result in lower CO emission [10,11].

3.4.2. Unburnt hydrocarbon

Unburnt hydrocarbon (UHC) emission values against various loads are shown in Fig. 9. Hydrocarbon is a significant factor for determining the fuel combustion efficiency. UHC emission increased with the increase in load for both conventional and blended biodiesel. The direct relationship is observed between UHC and the amount of fuel injected and the engine load. UHC emissions of 72 ppm and 124 ppm were recorded for pure diesel and NBD20 respectively at 1 kg load. This value rises to 131 ppm and 180 ppm as load rises to 12 kg for pure diesel and NBD20 respectively. The increase in UHC of blended fuel may be due to heterogeneous mixture at higher load and presence of unsaturated and unbreakable hydrocarbon [8]. Another remarkable reason for increase in UHC as the concentration of biodiesel increases is due to the lower viscosity as compared to pure diesel [12].

3.4.3. Carbon dioxide

Carbon monoxide production has a significant role in the emission of carbon dioxide. The increase in CO production aids in the reduction of CO_2 emission. It was observed that at lower load of 1kg, CO_2 emission was also lower for pure diesel than NBD10, NBD15 and NBD20. It was noticed that with the increase of load, carbon dioxide emission also increased for all the engine fuels. With the increase of biodiesel portion on the diesel fuel, CO_2 emission increased. We recorded the CO_2 emission of 2.78%, 2.84%, 2.82% and 2.88% for pure diesel, NBD10, NBD15 and NBD20 respectively at load of 1kg. But the value of CO_2emission increases to 6.68%, 6.64%, 6.32% and 6.56% as load rises to 12 kg load for pure diesel, NBD10, NBD15 and NBD20 respectively. Higher exhaust gas temperature causes increase in CO_2 as load rises from 1 kg to 12 kg [8,13].

3.4.4. Smoke opacity

Fig. 11 shows the concentration of smoke against the engine load for different engine fuel at full load and full throttle condition. According to Nepal Vehicle Mass Emission Standard – 2069 provided by the Department of Transport Management, Nepal, the smoke emission is accepted up to 2.4 Hartridge Smoke Unit (HSU). The smoke opacity for pure diesel was found to be 2.02 HSU, which was below the emission standard. The increase in biodiesel concentration decreases the smoke opacity due to oxygen rich fuel [5,10,13]. Twenty percent blended Neem biodiesel is good for engine smoke opacity with 1.02 HSU, which is 55% better than pure diesel.

4. Conclusions

In this study, the performance and emission characteristics of blending Neem biodiesel in petroleum-diesel with the volumetric percentage of 10%, 15% and 20% on direct injection VCR engine at different loading condition were investigated. A two-step acid-base transesterification process was used for reducing free fatty acid (FFA) from 9% to below 1% to prevent excesses soap formation and to get maximum yield. The main conclusions are:

1. The properties of 20% blend of biodiesel, tested as per the

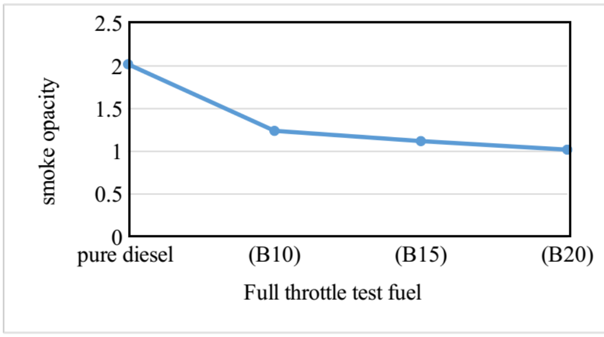

Figure 11: Smoke opacity for various engine fuel.

ASTM standard, meet the fuel criteria for diesel engine. Thus, no any problems arose while starting and running the engine.

2. At 12 kg load, BTE and torque of pure diesel and biodiesel blend were similar.

3. SFC for 20% Neem biodiesel blend was higher than pure diesel at 1-kg load but no remarkable difference was notices at 12-kg load. SFC decreased significantly with the increase in load.

4. CO emission was higher for pure diesel than blended biodiesel and it decreased with the increase in load. But for unburnt HC and CO_2, blend of biodiesel shows higher emissions.

5. Smoke opacity was found to be least for 20% blend of biodiesel at full throttle and pure diesel had the highest smoke density.

Thus, we conclude that the performance and emission characteristics of blended biodiesel are comparable with pure diesel. Therefore, blending of up to 20% Neem biodiesel in pure diesel could be used in diesel engine without any modification to the engine. This could be a very good alternative for petroleum-based diesel with reduction in harmful emissions to the environment.

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