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Performance, Emission and Combustion Analysis of Biodiesel Extracted from Acidic oil: A By-product of Soybean Oil Refining Process

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Abstract

Fast depletion of fossil fuels, rapid increase in the prices of petroleum products and harmful exhaust emissions from the engine are the driving factors in undertaking this research for finding the suitable alternative fuels. The present work deals with the Performance, Emission and Combustion characteristics of Biodiesel derived from acidic oil, which is a by-product of soybean oil refining process. Biodiesel was extracted using two-step esterification and transesterification process from the raw acidic oil. Different blends were prepared on the volume basis and one separate blend was prepared using 2% antigel additives in one of the combination. Tests were conducted with diesel and prepared blends on single cylinder, four strokes, multi-fuel, water cooled engine at compression ratio of 17.5 with different loading conditions. Present investigation indicates reduction in performance parameters as the engine is fuelled with different blends of biodiesel, but significant changes are observed with regard to combustion parameters and reduction in CO, HC. Further, increase in NOx, CO_2 is observed during the use of similar blends of bio-diesel. Further the same engine is run with the addition of 2% Antigel Additives in one of the blend, BD20, which has given results which include significant reduction in BSFC, exhaust gas temperature, NO_x percentage and integrated heat release rate. Simultaneously it is associated with increase in brake thermal efficiency, HC and CO percentage and peak in cylinder pressure. The prospective results have opened a new avenue of opportunity with regard to conversion of available waste oil to useful biofuel.

Key words

Acidic oil, biodiesel, combustion, emission, performance.

1. Introduction

Fast depletion of fossil fuels, rapid increase in the prices of petroleum products and harmful exhaust emissions from the engine jointly created renewed interest among researchers to find the suitable alternative fuels. Fuels derived from renewable biological resources for use in diesel engines are known as biofuels. Biofuel is environment friendly fuel similar to petrol and diesel from the observation of their combustion properties. Increasing environmental concern, diminishing petroleum reserves and agriculture based economy of our country are the driving forces to promote biodiesel as an alternate fuel. To minimize the reliance on edible vegetable oil feedstock for biodiesel production, alternative sources, such as non-edible feedstock, have been sought for biodiesel production. Soybean has come to be recognized as one of the progressive agricultural crops today for various reasons.

The Soybean Processors Association of India [1], popularly known as SOPA, is the only national level body representing the soybean processors, farmers, exporters and brokers in India working towards the aim to strengthen soybeans as a viable crop survey the oil seed production in World. Annual worldwide soybean production has averaged 325 million metric tons per year from 2016 to 2017, which is significantly greater than annual production averages for other oil seeds. Over 80 percent of all oilseeds are crushed for production of meals and oils. Acidic oil is the least valuable by-product from oil processing and it is generated at a rate of about 6% of the volume of refined crude soybean oil, amounting to as much as 0.8 million metric tons in the United States annually. Studies conducted by different researchers around the world revealed that biodiesel is proven as a substitute for mineral diesel and at the same time reducing the emission significantly [2, 3, 4, 5].

Ashok Kumar et al. [6] had worked on biodiesel derived from pinnai oil which was tested in VCR engine with blend proportion of 10% and 20% by volume at different loading conditions. The results show that the brake power of biodiesel is little more than that of diesel for all compression ratio in part load condition. Kommana et al. [7] investigated the performance and emission characteristics of palm karnel and eucalyptus blends using VCR CI engine. They tested diesel fuel and blends of Eucalyptus oil with methyl ester of palm karnel oil in 5%, 10% and 15% by volume proportion and at compression ratio 19:1 with different loading conditions. The investigation shows the improvement in combustion and reduction in emission for 15% blend when compared to diesel at full load condition. Channapattana et al. [8] investigated the emission and thermal performance of VCR engine using blends proportion of 20%, 40%, 60%, 80% and 100% biodiesel with diesel. The results show that at CR 18, the BTE of engine with 100% biodiesel is 8.9% less than that of diesel and BSFC for biodiesel is found to be higher than diesel with significant reduction in CO and HC is observed.

Aalam et al. [9] analysed the effect of aluminium oxide nanoparticle blended mahua biodiesel in different proportion on CRDI engine. Their experimental results show substantial enhancement in BTE and marginal reduction in harmful pollutants for the aluminium oxide nanoparticle blended biodiesel. Sorate et al. [10] found the effects of adverse biodiesel properties like cold flow properties, oxidation stability, corrosive and acidic nature resulting in non-compatibility with automotive fuel system materials. They also discussed the excellent lubricating behaviour of biodiesel and its positive impact. Their experimental result shows that the additive treatment with biodiesel has found to be suitable for improving the low temperature properties.

Liaquat et al. [11] observed the effect of coconut biodiesel blended fuels on engine performance and emission characteristics. This investigation shows that the coconut biodiesel with 5% and 15% blends proportion with diesel can be used in diesel engine without any modifications. Same authors [12] carried out the engine performance and emission characteristics tests of diesel engine using jatropha, waste cooking oil (5%, 10% blending proportion) blends without any engine modifications. The results show that there is average power reduction, average increase in BSFC, reduction in HC and CO with increase in NOx by using biodiesel blends compared to diesel fuel.

Study conducted by Ozsezen et al. [13] was carried out using four strokes, 6 cylinders, water cooled, direct injection diesel engine using Canola oil methyl ester (COME) and Waste palm oil methyl ester (WPOME). Investigation result report that Peak pressure measured for COME and WPOME was 8.33 MPa and 8.34 MPa respectively at 6.75° CA ATDC, while the peak cylinder gas pressure for diesel was 7.89 MPa at 7° CA ATDC and also maximum heat release rate (HRR) of 0.41kJ/° CA was obtained at 4.5° BTDC for diesel while maximum HRR of 0.73kJ/°CA at 4.5° BTDC for COME and maximum HRR of 0.34 kJ/°CA at 5.8° BTDC was obtained for WPOME. Gumus et al. [14] conducted experiments using Hazelnut kernel oil methyl ester and its blend and the results show that peak cylinder gas pressure was found to be increasing for the engine load of 10 Nm due to increased biodiesel blend ratio. The peak cylinder gas pressure occurred between 6.61 MPa and 7.05 MPa at 10 Nm engine loads, while peak cylinder gas pressure was obtained between 7.54 MPa and 7.96 MPa for the 20 Nm engine load. A review of the prospective of WTE technologies in KSA is carried out by Nizami et al. [22]. They claimed that the food and plastic waste are the two main waste streams with total production of 7.7 and 2.7 Mt/year with generation rate of 0.7 and 0.3 kg/capita/day respectively. Arapatsakos et al. [23] described the load and the gas emissions measurement of outboard engine.

Most of the studies have reported the performance, emission, combustion characteristics of biodiesel derived from vegetables oil or edible oil. Very few studies have been conducted on biodiesel with addition of antigel additives. Hence, it is decided to extract biodiesel from non-edible waste soybean oil and further addition of antigel additives in the same and checking of the performance, emission and combustion characteristics with various blends in diesel engine in this research work.

2. Extraction of Biodiesel

The blend which is to be used for preparation of biodiesel is extracted from acidic oil, which is a by-product of soybean oil refining process. The raw oil is obtained from the Ghodawat group of Industries, Jaysingpur, Maharashtra.

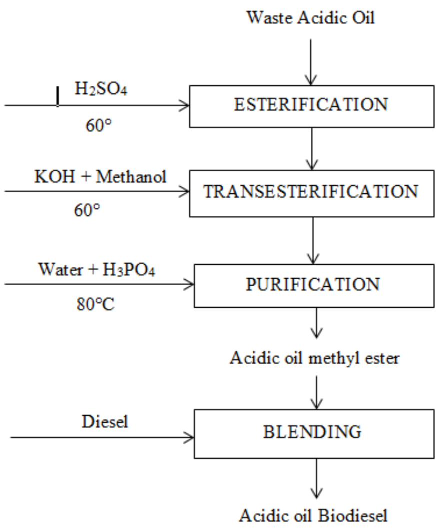

Fig. 1. Flowchart of Biodiesel Production Process

2.1. Bio-diesel Production

Experiments were conducted in a laboratory scale apparatus to extract biodiesel from acidic oil. This is performed by different processes like Esterification, Transesterification and Purification with the help of Beaker, Thermometer, Magnetic stirrer, separating flask, Oven as shown in Fig.1. Acidic oil is preheated in beaker and then methanol (40% v/v of oil) and H_2SO_4 (0.7% v/v of oil) is added based on free fatty acid content of oil. The solution was heated up to 60°C and maintained for 1 hr with continuous stirring. Then the solution is transferred to conical separating funnel and then cooled for 12 hrs. There is a formation of two layers in the conical separating funnel in which the upper layer is crude biodiesel and bottom layer is glycerine. The crude biodiesel is used for transesterification. In the alkali catalyst transesterification process, the KOH (1.5% w/v of oil) is used as an alkali catalyst and dissolved into crude biodiesel oil. The solution was heated up to 60°C and maintained for 1 hr with continuous stirring. Then the solution is transferred to conical separating funnel and then cooled for 12 hrs again in conical separating funnel, again obtained two layers, the upper layer is un-purified biodiesel and bottom layer is glycerine. The un-purified biodiesel was purified using multi washing with water extraction. The purification results in methyl ester separation. The washing of methyl ester is done by adding distilled water at temperature of 80°C step by step up to distilled water reaches 300% volume of oil.

2.2 Preparation of Blends for Carrying Out Tests

Acidic oil methyl ester (AOME) was added to diesel at low stirring rate. The mixture was stirred for 60 minutes and left to reach equilibrium before analysis. Acidic oil methyl ester was added in volume percentages of 5%, 10% and 20%. One more mixture is prepared by addition of 2% antigel additives to the blend of 20%.

2.3. Evaluation of Properties

The fuel characteristics of Acidic oil biodiesel such as Density, Kinematic viscosity, Flash point, Fire point, Cloud point, Pour point, Cold filter plugging point, Self-Ignition temperature, Cetane number, Calorific value are determined and are shown in Table 1. It is observed that the properties of the fuel fulfil the ASTM standards. These properties are compared with the properties of standard fuel i.e. diesel.The density and viscosity of Acidic oil methyl ester was seen to be 1.09 and 3.61 times higher than the diesel at 40°C. Flash and Fire point was seen to increase 3 times than that of diesel. There was not much difference in the calorific values and cetane number for all the blends when compared with those of diesel. Reduction in cold flow properties were seen to be -5 to -6° C for cloud point and -15 to -17° C for pour point for blend containing antigel additives.

3. Experimental Setup for Engine Testing

A 3.5 kW @1500 rpm, multi-fuel, single cylinder, four stroke, water cooled, direct injection diesel engine was used for the present study. The engine is operated at a compression ratio of

17.5:1 with a constant speed and fuel injection start at 23° Crank angle (CA) before TDC. Eddy current dynamometer is connected to the engine for loading purpose. It is provided with necessary instruments for measurement of combustion pressure, crank angle, airflow, fuel flow, temperature and load measurement. These signals are interfaced to computer through high speed data acquisition device. The specification for the engine test setup are shown in Table 2.

Table 1. Comparison of Some Selected Specifications of Acidic Oil Biodiesel-diesel Fuel Blends with Biodiesel Content

Properties	Units	ASTM Standard	Fuels					
			Diesel	BD5	BD10	BD20	BD22	AOME
Density @ 40°C	kg/m^3	D941	808.8	811	818	825	823	886
K. Viscosity @	mm^2/s	D445	3.123	3.255	3.789	4.60	4.422	10.328
Flash Point	°C	D93	54	58	60	64	62	158
Fire Point	°C	D93	64	66	68	73	68	170
Cloud Point	°C	D5772	-14	-10	-8	-5	-6	9
Pour Point	°C	D5772	-27	-21	-19	-15	-17	5
CFPP	°C	D6371	-22	-19	-17	-13	-15	7
Self-Ignition	°C		210	210	217	224	230	293
Cetane No.		D613	48	49	50	53	53	54
Calorific Value	MJ/kg	D5865	42.00	41.91	41.53	41.01	41.94	39.90

The tests were conducted using diesel and acidic oil biodiesel with various proportions of blends. According to the Norms given by Engine Manufacturing Association and Indian Biodiesel Policy, only 5% biodiesel can be blended currently. Here, we have decided to find the effect of higher blending percentage on the performance of engine, 5%, 10%, 20% and 2% antigel additive blend percentage of acidic oil biodiesel in diesel was selected.

Table 2. Diesel Engine Test Set up Specification

Features	**Specification**
Model	VCRE SI- CI Series
Type	Single cylinder, 4 stroke, Water cooled, Multi-fuel
Bore, Stroke, Connecting rod	87.5mm, 110mm, 232mm
Rated Power	5 BHP @ 1500rpm
Compression ratio	12 to 20
Injection timing	23° before Top dead centre
Method of loading	Eddy current dynamometer

The engine has to be operated on the diesel and biodiesel at compression ratio of 17.5:1 with a load range of 0 to 20 Nm at constant speed. In every test all the performance parameters like brake specific fuel consumption, brake thermal efficiency, exhausts gas temperature, mechanical efficiency are determined. Netel's NOx Analyser emission measurement system is used to measure the exhaust gas which constitutes Carbon monoxide (CO), Oxides of Nitrogen (NOx), Hydrocarbon (HC), Carbon dioxide (CO_2).

4. Result and Discussion

The trials are conducted with selected blend percentages as explained earlier. The effect on some of the prominent performance parameters is mentioned hereunder.

4.1. Mechanical Efficiency

The Variation of Mechanical efficiency with load for diesel and biodiesel blends is shown in Fig.2. It has been observed that, with increase in load, the mechanical efficiency increases for all the blended fuels used. There is no change in mechanical efficiency for different blend percentages during the test. At full load condition, the mechanical efficiency was observed to be equal to 59%, 58.1%, 59.56%, 58.06% and 57.96% for Diesel, BD5, BD10, BD20 and BD20+2AA, respectively, which indicates a very meagre difference between them.

4.2. Brake Thermal Efficiency

The effect of variation of load on Brake thermal efficiency (BTE) for acidic oil biodiesel blends with diesel was analysed. It is observed that with increase in load, the Brake thermal efficiency increases for diesel and acidic oil biodiesel blends. Figure 3 shows the related results. Further a marginal drop in brake thermal efficiency is observed with increase in blend percentages at various loads. This may be attributed to deterioration in combustion due to higher viscosity and lower calorific value of biodiesel blends. At full load condition, the BTEs were found to be 30.14%, 29.64%, 29.34%, and 28.04% for Diesel, BD5, BD10, and BD20 respectively. But with the addition of 2 % Antigel Additives in BD20 the BTE seen to be 29.1 %.

4.3. Brake Specific Fuel Consumption

Figure 4 indicates the brake specific fuel consumption (BSFC) for diesel and biodiesel blends as s function of load. Good engine performance in terms of fuel economy is reflected by BSFC. It is noted that BSFC of all the blends of BD5, BD10, and BD20 is higher than that of diesel at various loading conditions. This is because of the high density and viscosity of biodiesel blends. At full load condition, BSFC were found to be 292.11 g/kWh, 298.2 g/kWh, 300.98 g/kWh, 312.95 g/kWh for diesel, BD5, BD10 and BD20, respectively. It is further observed that the BSFC of BD20 + 2AA is nearly equal to that of the diesel but comparatively lower than the the same with a blend of BD20.

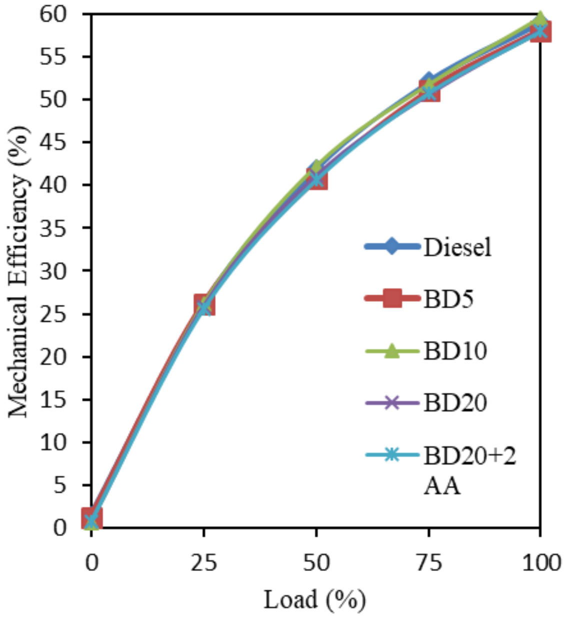

Fig. 2. Effect of Blend Percentage and Load on Mechanical Efficiency

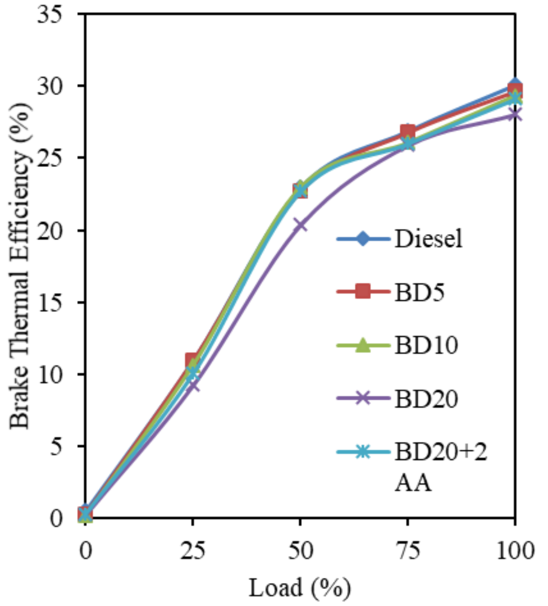

Fig. 3 Effect of Blend Percentage and on on Brake Thermal Efficiency

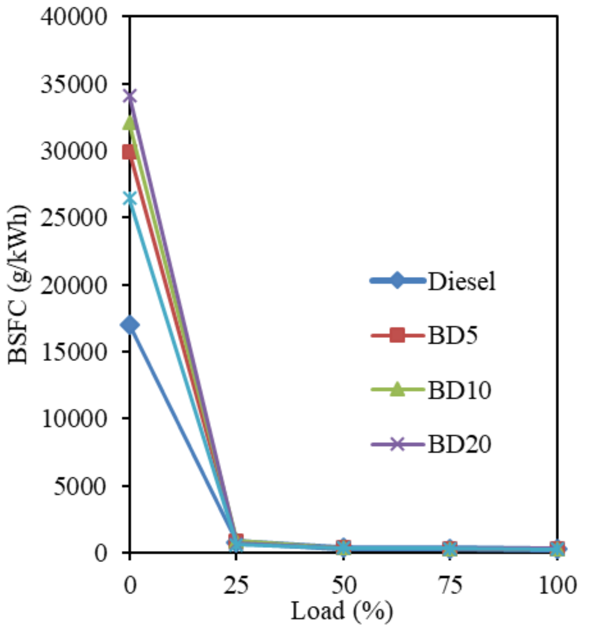

Fig. 4. Effect of Blend Percentage and Load on Brake Specific Fuel Consumption

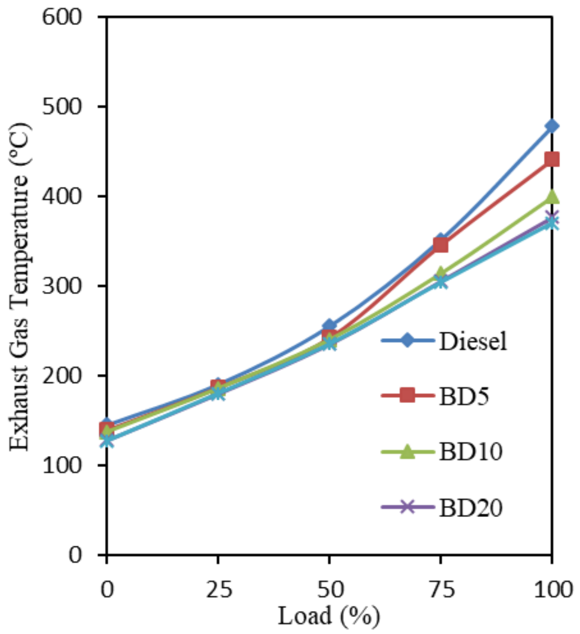

Fig. 5 Effect of Blend Percentage and Load on Exhaust Gas Temperature

4.4. Exhaust Gas Temperatures

Figure 5 depicts Exhaust Gas Temperature (EGT) of test runs at various loading conditions and different blends of biodiesel with diesel. The results indicate that the EGT is decreasing for all blends when compared to that of diesel and continuously increasing from no load to high load condition. At no load condition, the value of EGT for diesel, BD5, BD10, and BD20 is observed to be 477.90°C, 441.2°C, 399.4°C and 376.3°C respectively. With the addition of 2 % antigel additives results in the lowest exhaust gas temperature when compared to all other tested fuel combinations and it is found to be 127.1°C at no load condition. It is due to the slow combustion, maximum gas temperature inside the combustion chamber and low value of peak pressure inside the chamber.

4.5 Effect on Emission Parameters

Emission measurement is carried out using NO_x analyser during all the tests using Netel's five gas analyser. The effect on emission parameters is explained here.

4.5.1 Carbon Monoxide (CO)

Figure 6 shows the variation of CO for different loading conditions and different blends of acidic oil methyl ester with diesel. It is seen that increase in load and blending concentration results in decrease of CO emissions. It is colourless, tasteless, odourless and highly toxic gas. Quantitatively, the percentage of CO is observed to be 20.37%, 29.62% and 31.48% respectively, for BD5, BD10 and BD20, which seems to be less than CO emission from conventional diesel engine running at rated loading condition. However, with addition of 2% of Antigel Additives in BD20, CO emission increased by 14% than that of BD20 combination. This is due to fact that increase in blend concentration causes the saturation of oxygen in fuel and hence during combustion more carbon combines with oxygen to form carbon dioxide and thereby reducing the CO emissions. Decrease in cylinder temperature and incomplete combustion of fuel also tends to decrease CO emissions.

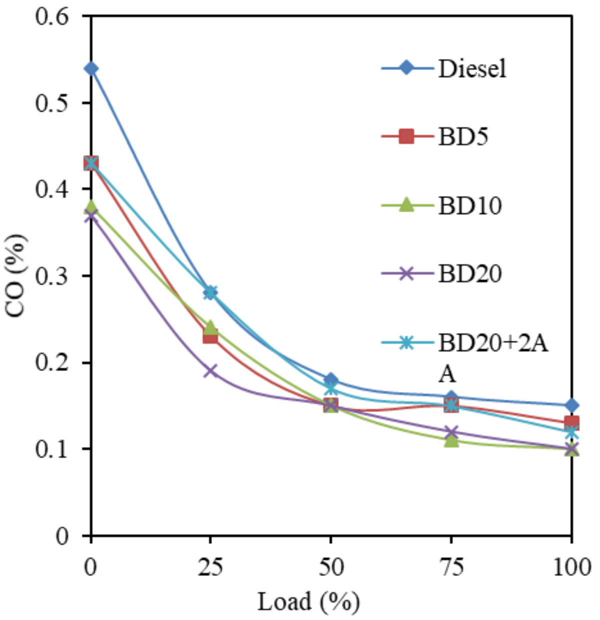

Fig. 6. Effect of Blend Percentage and Loading on CO

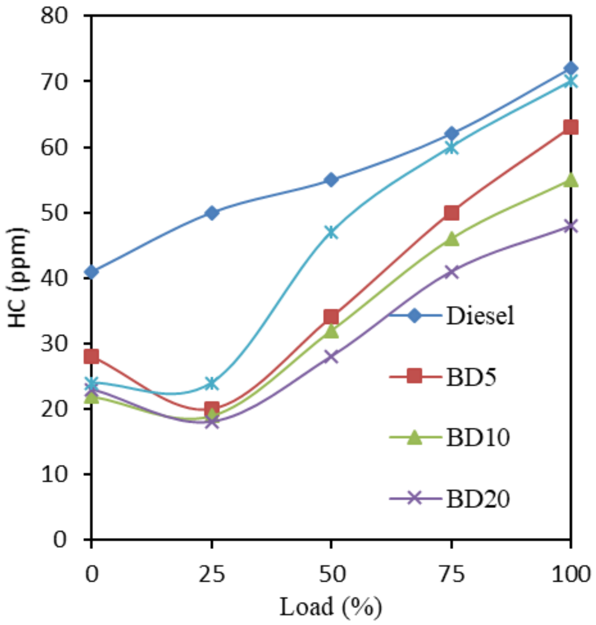

Fig. 7 Effect of Blend Percentage and Loading on HC

4.5.2 Hydrocarbons (HC)

HC emission for diesel and biodiesel fuel for different loading and blending proportion are shown in Fig. 7. There is a decrease in HC emissions is observed with increase in blend proportions, but tends to simultaneously increase with increase in load. The HC emission of the BD5, BD10, BD20 blends at the no load condition is measured to be 28ppm, 22ppm, 23ppm, whereas for diesel the same is 41ppm. At full load condition, with the addition of antigel additive in BD20, the HC emission is observed to be increasing by 21ppm than that for BD20 blended fuel. This is due to the presence of more amount of oxygen in biodiesel which leads to better combustion of biodiesel which is responsible for more HC emissions. Higher cetane number of biodiesel contributes in reduction of HC emissions by delaying the combustion period.

4.5.3 Nitrogen Oxides (NOx)

The effect of load and blend proportion for acidic oil biodiesel is shown in Fig. 8. The NOx emission for blends BD5, BD10, BD20 at maximum loading condition is noted to be 646 ppm, 665 ppm, 680 ppm respectively, which seems to be higher than the same with the conventional diesel fuel. The NOx emission of the BD20+ 2AA blend at maximum loading condition is 665ppm. Presence of abundant amount of oxygen in biodiesel leads to rapid combustion, thereby increasing the temperature of combustion chamber which further leads to increase in NOx emissions.

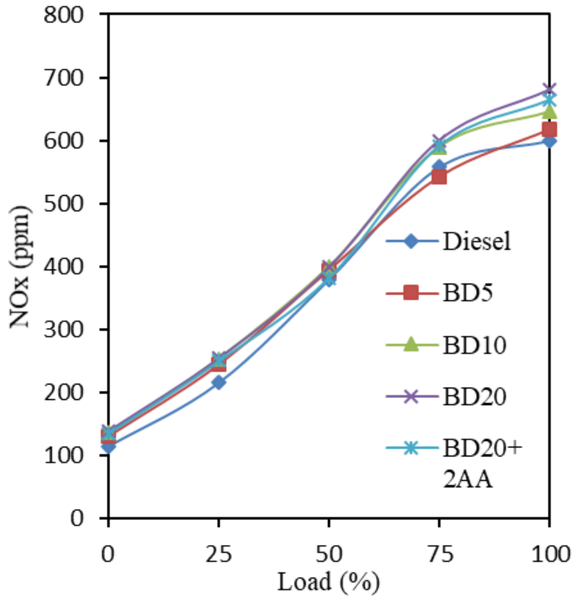

Fig. 8. Effect of Blend Percentage and Loading on NOx

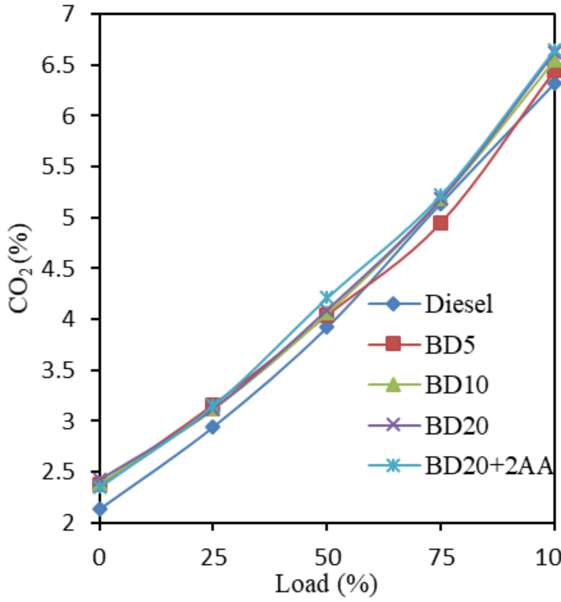

Fig. 9 Effect of Blend Percentage and Loading on CO2

4.5.4 Carbon Dioxide (CO_2)

The carbon dioxide emission for Acidic oil biodiesel blended fuels at various loading conditions is shown in Fig. 9. It is seen that the carbon dioxide emission is increasing for all blended fuels when compared with emission from diesel fired engine. As shown in Fig. 8, the increase in CO_2 compared to diesel fuel at full load condition is 6.45% for BD5, 6.55% for BD10, 6.62% for BD20 and 6.65% for BD20 + 2AA. This increment is seen due to more presence of oxygen in biodiesel which reacts with the unburned carbon atoms during combustion which leads to combustion of fuel. Complete combustion of fuel indicates the high CO_2 emissions.

Conclusion

The biodiesel is extracted from acidic oil and different blends are prepared with diesel. The engine performance is analysed by using the various biodiesel blend concentration in diesel and also by addition of Antigel Additives in one of the blend and further compared with performance parameters using diesel as a fuel. The following salient results are obtained in diesel engine with function of blend proportion and changing engine loading conditions.

(a) The Brake thermal efficiency of BD5, BD10 and BD20 is reduced by 1.52%, 2.52% and 6.84% compared to the same using diesel, however Brake Specific Fuel Consumption is increased by 2.04%, 2.94%, 6.65% compared to diesel at full load condition.

(b) It is concluded that, increasing the biodiesel blend concentration in diesel fuel results in the reduction of exhaust gas temperature by 7.68%, 16.42% and 21.25% for BD5, BD10 and BD20 compared with diesel fuel at full load condition.

(c) In case of engine exhaust gas emission, reduction in HC is found to be 12.5%, 23.61%, 33.33% and reduction in CO is found to be 13.33%, 33.33%, 33.33% for BD5, BD10, BD20 compared to diesel. However, NOx emission were found to be increased by 2.75%, 7.12%, 11.75% and CO_2 emission increased by 2.01%, 3.51%, 4.53% for BD5, BD10, BD20 as compared to diesel fuel at full load condition.

(d) The combustion analysis showed that with the addition of biodiesel in diesel fuel increases in cylinder pressure and reduce the integrated heat release rate.

(e) The addition of 2% antigel additives in BD20 results in reduction in BSFC by 5.6%, increase in BTE by 3.64%, reduction in exhaust gas temperature by 1.56%, reduction in NOx by 2.20%, increase in HC by 31.42%, increase in CO_2 by 0.45%, increase in CO by 20%, compared to BD20 blend.

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