ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, Vol 9(36), DOI: 10.17485/ijst/2016/v9i36/102153, September 2016 ISSN (Online) : 0974-5645

Performance Analysis of a Diesel Engine using the Soybean Oil based Biodiesel

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Abstract

This paper gives an overview of the investigation being done for the preparation of biodiesel from soybean oil using the Transesterfication technique with the help of KOH, used as a catalyst. Prepared biodiesel can be used as an alternative to the diesel that is currently being used in automobiles. Diesel being a non-renewable product is under a great risk of depletion and with the depletion of this product, life on earth would be severely affected. Thus, an alternative source of power is required to be developed. Biodiesel being a renewable source of energy comes out to be the best alternative of diesel. Biodiesel produced by using different blends of soyabean oil is being used and tested in a VCR type 4-stroke diesel engine. It has been observed that feeding vegetable oil directly to the engine for a longer period may cause working problems and disturbances to the engine. These problems are due to physical properties of oil like viscosity, volatility and polyunsaturated character. Transesterfication process comes out as an effective solution of this problem as it reduces fluid viscosity and other operational errors from the oil. Methyl ester of soybean oil (SBD) were found to be very similar to mineral diesel due to this, a mixture of SBD and mineral diesel were used to make different blends of biodiesel which were then fed to a CI engine as fuels. Engine was tested for different blend of biodiesel at 1500 rpm at different loading conditions and its performance parameters were analysed. The outcome of the investigation has proved that biodiesel exhibits physical properties which are similar to that of mineral diesel. It is to be noted that the BSFC (Brake Specific Fuel Consumption) of biodiesel is more as it has low heating point. Use of Biodiesel in automobiles has shown a notable amount of reduction in CO, HC, NO_x. So Biodiesel can be an alternative of mineral diesel.

Keywords: Brake Thermal Efficiency, CO, Diesel Engine, Emission Parameters, Hydrocarbon, No_x, Soybean Biodiesel

1. Introduction

Less Availability of fossil fuels and other unsustainable minerals has stimulated active researches in the field of non-petroleum type fuel products which are both renewable, and nonpolluting. Biodiesel comes up as a vital alternative that can be used as an renewable possible fuel and as an additive to the mineral fuels. In every year in India, a variety of non-edible oils are produced in large quantities that can be potential sources for biodiesel production to supplement other conventional energy sources.

Combustion of high viscosity oils may have an harsh effect over diesel engines. For a diesel injector operating under fixed condition, use of high viscosity fuel delays atomization. Poor atomization may have harsh effects on the combustion process. Biodiesels have higher viscosity than the mineral diesel. Due to high viscosity and less volatility of biodiesels, they have low BTH as compared to mineral diesel fed to engine of same specifications. This will also leads to heavy air pollution due to un burnt HC and CO emissions.

With the advancement of the technology, a large no of researches has been performed in the field of testing and application of biodiesel in compression ignition engines in different ratio of blending with petroleum diesel. In this investigation, Biodiesel extracted from soyabean oil is used. Fatty acid methyl ester forms about 90.3% of

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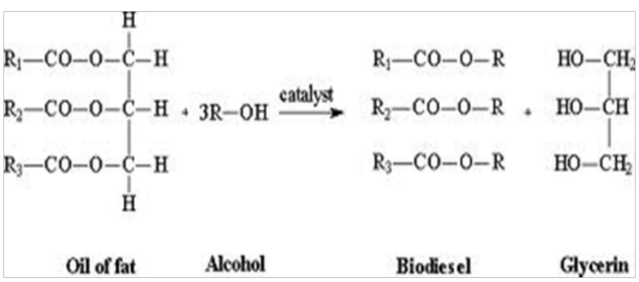
the biodiesel and rest is contained by non-hydroxylated fatty acids, mainly by oleic and linoleic acids. To note the performance analysis of biodiesel made from soybean oil (SBD), we conducted many number of tests on single cylinder CI engine at variable loads.

2. Methodology

2.1 Esterification of Soybean Oil and Technical Specifications of Biodiesel

Transesterfication is a chemical reaction process which involves (Equation (1)) yielding of fatty acid methyl esters and glycerol from oil or fat. Biodiesel is produced from high FFA Pongamia by using sulfuric acid and KOH catalysts.

The Soybean seed oil was first taken in the flask and heated on a burner. The soybean oil was mixed with methanol. The mixture of methanol and Soybean seed oil was stirred with the help of a mechanical stirrer at 350 rpm in an air closed flask for 60 min. at 70^{0}C. Alcohol affects the conversion efficiency of the vegetable oils. For the stochiometric Transesterfication, 3 moles of alcohol are needed for every one mole of the oil. However, greater molar ratio than the theoretical one helps in early completion of the reaction.



Equation (1) Chemical equation for transesterification of soybean oil.

Sulphuric acid was used (1% by volume) as catalyst in the acid-catalyst pretreatment. After the heating process with methanol, the mixture is then ready for alkaline process. A molar ratio of 6:1 to 9:1 and 0.6 to 2.0 % by wt. of NaOH is used for desired ester yield. After this process, the two layers of the mixture come into the picture. Impurities and glycerol is present in the lower layers. The top ester layer or biodiesel is separated through spraying water. For the water wash process, a sprinkler sprays water into the biodiesel container until water equals the amount of diesel in the container. The mixture thus formed is then rotated smoothly for 15-20 min, which separates out water from the biodiesel. Now the water and biodiesel separates out from the mixture. The final product is now heated up to 70^{0}C for 15 min in vacuum which forms an amber-light yellow liquid. Physical properties of the product formed matches with the physical properties to that of diesel. Product thus formed can be stored for further use.

2.2 Experimentation and Test setup

In this study, a 4-stroke, single cylinder, VCR type diesel engine is used. An eddy current type dynamometers fitted to the engine for loading purpose was operated with mineral diesel, in two different fuel blends: 05% SBD–95% diesel fuel (B5) and 10% SBD–90% diesel fuel (B10) in volume and similarly the effect of B15, B20 blends were noticed on brake thermal efficiency and exhaust emission products of the test engine. It was noticed that the viscosities of Soybean and blends decreases as temperature increases as compared to the diesel fuel (Table 1).

Initially, diesel fuel is used to start the test and then the engine was being loaded with a dynamometer, until it reaches the operating temperature.

Table 1. Properties of the mineral diesel and soybean biodiesel

Sl.No.	Properties	Test Method (ASTM)	Diesel (Petroleum)	Soybean Biodiesel
1	Specific Gravity	D4052	0.825	0.78
2	Kinematic Viscosity at 40°C	D445	4.35	5.16
3	Low Heating Value (MJ/Kg)	D240	42	38.89
4	Flash Point (°C)	D93	42.5	166.5
5	Fire Point (°C)	--------	67	193
6	Cetane Index	D4737	46	47.5
7	Acid Value (mg KOH/g of oil)	--------	0.04	1.9

Table 2. Specification of the C.I engine of the test rig

S. No	Engine Details	Specifications
1	General Details	4-Stroke, water cooled, , Direct Injection
2	Output Power	3.5 kW (Kirloskar, India)
3	Speed of the engine	1500 rpm
4	No. of cylinder	Single
5	Compression Ratio	5:1-21:1, Variable compression ratio
6	Bore	85 mm
7	Stroke	120 mm
8	Ignition	Compression Ignition
9	Dynamometer	Eddy Current Dynamometer
10	Load Sensor	Strain Gauge Load Sensor.
11	Starting	Manual crank shaft
12	Cooling	Water

Figure 1 shows the experimental setup for testing the biodiesel at different ratios with mineral diesel First of all we loaded the engine at wide open accelerator position, and we also ensured that our engine can run on three different Compression ratios of 15:1, 17:1 and 19:1. Now to note the engine speed and load we use a digital indicator of the test ring. Also for the measurement of the load we preferred to use a strain gauge type load sensor on the dynamometer a burette with a stopwatch was used to note the fuel consumption. Moreover with the help of volumetric flow rate and fuel density we were able to calculate the mass flow rate of the fuel (kg/hr). We also implanted a thermocouple near the exhaust valve for the measurement the temperature of the exhaust gases. A gas analyzer was utilized to measure the concentration of various products of exhaust gases. A gas analyzer can analyze the exhaust gas containing CO, and NOx as ppm with ± 1% and ± 20ppm accuracy respectively.

3. Results and Discussions

3.1 Brake Thermal Efficiency (BTH)

The BTH was experimented and observed for variable power output, for different blends of biodiesels and mineral diesel. It was observed that the BTH increased, when it kept with lesser proportion of SBD in blended biodiesel.

The maximum brake thermal efficiency were observed as 27.86%, 27.23%, 26.87% and 26.31% for B5, B10, B15, and B20, respectively, as against 30.01% for diesel (Figure 2). While the efficiency of B5 biodiesel showed very close proximity with the diesel when tested at its rated power output.

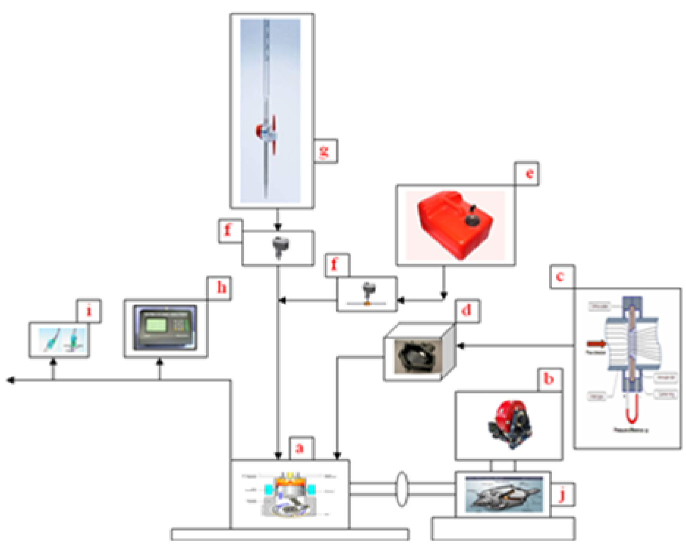


Figure 1. Detailed diagram of whole experimental setup. (a) Diesel engine. (b) Electrical load bank. (c) Orifice palte and U-tube manometer setup. (d) Air box. (e) Fuel tank. (f) Two-way control valve. (g) Burette. (h) Gas analyzer. (i) Temperature thermocouple. (j) Altemator.

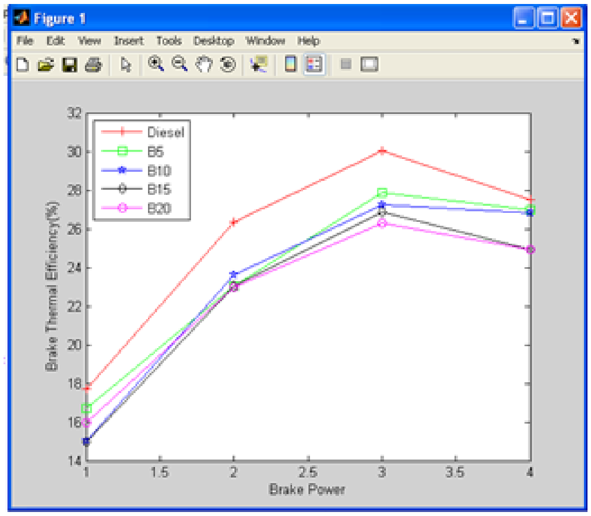


Figure 2. Variation of brake thermal efficiency with brake power for different blends of soybean biodiesel.

Table 4. The tolerances of the measurement and the uncertainty of the calculated results

Sl. No.	Measurements	Tolerance
1	RPM of the Engine	± 5 rpm
2	Temperatures of all points	± 3°C
3	Hydrocarbons	± 20 ppm
4	Nitrogen Oxide	± 20 ppm
5	CO	± 1%
6	Time	± 2%
7	Power	± 2%
8	Fuel Consumption	± 2%
9	All calculated results	Can't Say

Viscosity and volatility of SBD are inferior to diesel which affects the combustion characteristics and leads to poor atomization of the fuel.

Table 5. Indian standards used for emission analysis

Sl. No.	Constituents	Standard
1	Carbon Dioxide (CO_2)	IS:13270:1992
2	Carbon monoxide (CO)	IS:13293:1992
3	Nitrogen Oxides (NO_x)	IS:11255-(PART 7)-2005
4	Particulate Matter	IS:11255-(PART 1)-1985

This gives (Table 4.) poor BTH efficiency for higher Biodiesel blend concentrations than the mineral diesel. Moreover it was found that the BTH efficiency of mineral diesel and of bio diesel blends have no significant difference, at the higher value of CR of the engine. However B5 gives maximum BTH at a CR of 15:1 and B20 at CR of 19:1. B10 and B5 have equal BTH efficiencies at a CR of 17:1 at full load conditions.

3.2 Emission Parameters

Now we will analyse the Carbon monoxide emissions in the Figure 3. By the use of SBD blends and mineral diesel in a diesel engine at different loading conditions and CRs, we noted the least amount of CO in the emissions, when we run the engine on bio-diesel blends at increased compression ratio of 19:1. This is common for all IC engines as CR ratio decreases with increase in load and vice versa.

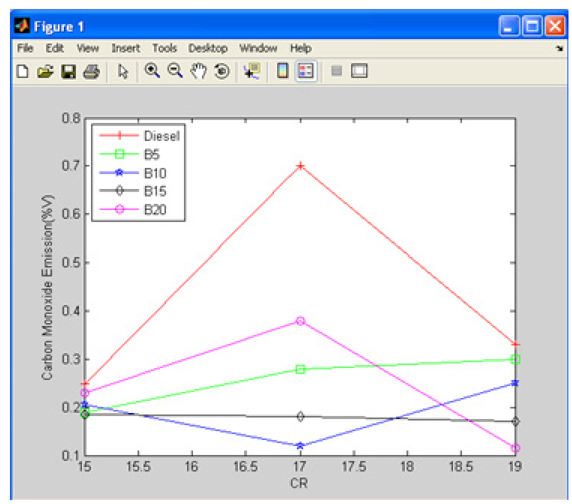


Figure 3. Variation of carbon dioxide with compression ratio for different blends of soybean biodiesel.

We can observe from the Figure 3 that CO emission measured is 0.70% by volume, which is highest and for B10 blend, at a compression ratio of 19:1, similarly we also see that and the lowest of 0.13% was measured for blend B10 while Blends B5, B15, and B20 have shown CO emission of 0.27%, 0.18% and 0.37% by volume, respectively. We can also say that the CO emissions were produced in a lesser amount due to the presence of oxygen in the biofuels.

The highest CO emissions were observed at a compression ratio of 17:1 for neat diesel. A rapid increase is observed in CO emissions for both bio-diesel blends and mineral diesel when the CR of the engine reaches to bmep (4.4-4.6 bar).

3.2.1 Observations

- The carbon Monoxide emission was found least at the CR of 15:1 and highest at CR of 19:1, when the engine was running at neat diesel.
- When the engine was tested for different biodiesel blends at variable compression ratios, CO emissions were least for B20 at CR of 19:1 and highest for B20 at CR of 19:1.
- On comparing the least values of CO emission of mineral diesel and B20 blend it was found that B20 blend emits 53% less CO that the mineral diesel.
- Blend B5, B10, B5 and B20 has shown CO emission of 0.19%, 0.12%, 0.17% and 0.115% by volume respectively. We can also say that the CO emissions were produced in a lesser amount due to the presence of oxygen in the biofuels.
- From this experimental study it is suggested that B20 biodiesel blend was safe and less toxic than other blends of biodiesel and mineral diesel, when operated at high compression ratios of diesel engines.

3.3 Nitrogen Oxide Emission

Nitric oxide (NO) emissions increase with increase in load, which varies from 10-205 ppm for SBD blend and 15-152 ppm for mineral diesel at high loads (Table 5). However, NO emissions at adequate loading are minimum for B20 blends while operating at a CR of 19:1. This blend also showed NO emissions lower by 6.31% to 36.92% relative to diesel fuel (Figure 4). In[6] biodiesels showed lower emissions of NO, this is probably due to the higher value of cetane of biofuels than that of mineral die.

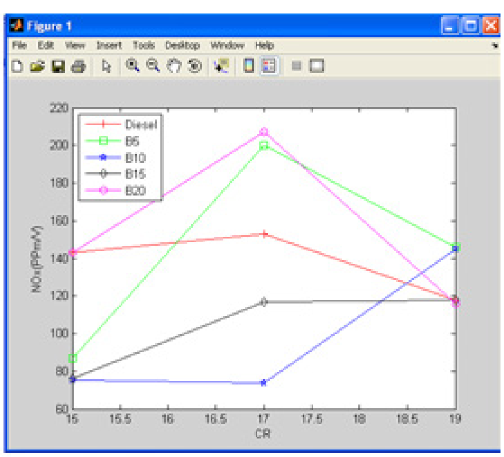


Figure 4. Variation of oxides of nitrogen with compression ratio for different blends of soybean biodiesel.

In[7] it is to be noted that the time of the premixed combustion reduces due to the reduction in ignition delay, and the ignition delay happens due to the increase of Cetane number. As the ignition delay reduces, the amount of the NO formed is also reduced, as the combustion pressure rises more slowly, and provides more time for cooling through heat transfer and dilution.

As we know that H_2O tend to dissociate at lower rate at high temperatures when we compare it with under same CO_2 conditions, in such a condition, we will get lesser NO in the engine exhaust and consequently the aromatic fuels will attain lower concentration of o radical and O_2

3.4 Hydrocarbons Emissions

In[8] the unburnt hydrocarbon emissions for all fuels were between 58 to 124 at the compression ratio of 15:1, between 50 to 93 at the compression ratio of 17:1 and between 29 to 65 at the compression ratio of 19:1. It is quite difficult to determine the factors over which HC emissions rate depends; however the graph shows that the hydro carbon emissions for biofuels proceed at lower levels than that for mineral Diesel. The SBD operation showed very low HC emissions throughout the range of compression.

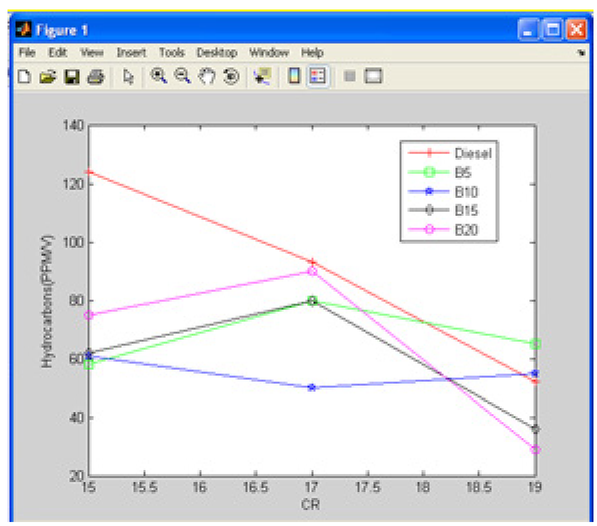


Figure 5. Variation of hydrocarbons with compression ratio for different blends of soybean biodiesel.

The plots show an increase in the HC emission at a definite Air-fuel ratio which then goes on decreasing with increase in Air-fuel ratio. It was also observed from the graph that the fuel carrying more % of SBD gives less HC emissions. A significant difference noted is the increase in emissions with decrease in Air-Fuel ratio for CR 19:1

and 15:1. The decrease in CR has shown the highest HC concentration in exhaust products in comparison to the results for increased CR. However at compression ratio of 19:1, no significant difference is in HC. Emissions were noticed for pure diesel, B5 and B10. Minimum HC emissions were noticed for B20 biodiesel and maximum HC emission were noticed for pure diesel (Figure 5). So in this way the Biodiesels have shown far better performance than pure diesel, as far as HC emissions are concerned.

4. Conclusions

The conclusions from the experiment we conducted for the analysis of performance parameters and combustion characteristics of the diesel engine when fired with blends of soybean oil (SBD) based biodiesel and diesel.

- In[9] an increase of soyabean oil in the blend may decrease the brake thermal efficiency.
- 27.86% and 30.01% are the maximum brake thermal efficiencies shown by B5 and mineral diesel respectively.
- Maximum Brake Thermal efficiency (BTH) for B5 and B20 blends are shown at a CR of 15:1 and 19:1 respectively for full load conditions whereas B5 and B10 have shown equal efficiencies at full load at CR 17:1.
- Biodiesel blends have substantially upto 20% give less Co emission without affecting Brake Thermal Efficiency (BTH) of the engine.
- Blend B5, B10, B5 and B20 has shown CO emission of 0.19%, 0.12%, 0.17% and 0.115% by volume respectively. These CO emissions are lower to those produced by mineral diesel due to presence of O_2 molecules in biodiesel blends.
- B20 blends show the minimum NO_x emissions for moderate load at a CR of 19:1. The percentage of emission is about 6.31% lower to 36.92% relatively to mineral diesel.
- Minimum HC emissions were noticed for B20 biodiesel and maximum HC emission were noticed for pure diesel. So in this way the Biodiesels have shown far better performance than pure diesel, as far as HC emissions are concerned.

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