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Experimental Investigation of Emission and Performance characteristics on Diesel Engine fueled with Flaxseed Biofuel

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Abstract:

The world's transportation sector has been predominantly powered by liquid hydrocarbon fuels and these resources are limited, so they will be exhausted in future. Therefore, finding an alternative source of energy is of vital importance. In modern time, bio diesel has become more attractive as an alternative fuel for diesel engine because of it is made from renewable source and has better effect on environment. Much research has been carried out to find the suitable fuel blends to reduce the exhaust emission. This research aims to understand possibility of flaxseed oil as an alternative fuel to diesel. That is investigated by blending flaxseed biodiesel with diesel and checking the performance and emission characteristic while using this blend as fuel. Biodiesel production from flaxseed oil has 84 % yield using single stage alkali catalysed transesterification process. Performance and emission test were carried out for diesel, FB10, FB20 and FB15+B5 fuel. FB10 showed far better emission characteristics than other fuel. Biodiesel blends didn't have any significant effect on performance parameter such as brake thermal efficiency (BTHE) and brake specific fuel consumption (BSFC). It reduced CO and HC emissions up to 50% compared to pure diesel. Addition of Butanol increased CO emission and reduced all other emission compared to FB20 blend

Keywords —*Flaxseed, Biodiesel, Blend, Linseed, Performance*

1 Introduction

India still depends heavily on crude oil imports for its domestic consumption requirements. However, Conflict situations in the world market could affect the supply of crude oil in developing countries significantly. India has been gifted with abundant renewable energy resources by nature. So, use it Indian government has introduced "National Policy on Biofuels 2018". The policy aims to achieve 20% blending of biofuel with fossil fuel by 2030. Biodiesel of required quantity can be produced from different vegetable oils that are widely available in India.[16] Majority of the fuel source currently available are non-renewable and limited in nature. The increasing population demands increasing energy consumption. The constant increment in the rate of use of the fossil fuels, increase in population and vehicles, and the urbanization in the present-day world has increased the use of fuel resource. Diesel engine has been widely used for heavy duty vehicles as it has a higher thermal efficiency compared to petrol engine in case of internal combustion engines.

Biodiesel can be produced from different vegetable oil such as, corn, cotton seed, flaxseed, peanut, rapeseed, sunflower, jatropha, sesame, soyabean, palm, neem oils.[14] Research has been conducted to find a suitable source to produce biodiesel. Biodiesel produced form different vegetable oil has different properties.[1,14] Table 1 Shows properties of different biodiesel generated from vegetable oil. Specifically the properties and diagram of flaxseed are significant for this study and are covered in Table 1.

Table 1 Properties of various biodiesel fuels

Vegetable oil	Kinematic Viscosity At 38° (mm^2/s)	Cetane Number	Heating Value (MJ/kg)	Cloud Point (^{0}C)	Pour Point (^{0}C)	Flash Point (^{0}C)	Density (kg/L)
Corn	34.9	37.6	39.5	-1.1	-40.0	277	0.9095
Cotton seed	33.5	41.8	39.5	1.7	-15.0	234	0.9148
Flaxseed 	**27.2**	**34.6**	**39.3**	**1.7**	**-15.0**	**241**	**0.9236**
Peanut	39.6	41.8	39.8	12.8	-6.7	271	0.9026
Rapeseed	37	37.6	39.7	-3.9	-31.7	246	0.9115
Sunflower	33.9	37.1	39.6	7.2	-15.0	274	0.9161
Jatropha	42.0	57-62	40.53	-	3	182	0.862
Sesame	35.3	40.2	39.3	-3.9	-9.4	260	0.9133
Soya bean	32.6	37.9	39.6	-3.9	-12.2	254	0.9138
Palm	41	42	39.649	31.0	17	260	0.9250
Diesel	**3.06**	**49**	**42.85**	**-40**	**-25.0**	**64**	**0.8330**

(Source: Royal society of chemistry journal)

Flaxseed has excellent potential for by product development, and it has a prominent level of oil. Under optimum conditions flaxseed can yield up from 33–47% oil content.[7] Alteration to the fatty acid profile and increased yield would make it a perfect candidate for use within the bio-diesel industry.[3] Flaxseeds have about 30-40% fixed oils including linoleic, linolenic, and oleic acids, viscous plant juice, protein, and glycoside. The flaxseed oil obtained from plant seeds is used in dyeing, linoleum production and nutrient industry. The fibres are used in linen yarn production and textile industry. It is an annual species of the linaceae family, growing to a height of 0.3–1 m, which is cultivated to produce textile fibre, seed, and flaxseed oil. Flaxseed is best suited for fertile, fine textured and loamy soils: a crucial factor is the amount of rainfall during the growing period. Adequate humidity and cool temperatures, particularly during the period from flowering to maturity, seem to favor both oil content and oil quality. The seed is in the extremities of the branches in round capsules, every capsule has from one to ten seeds. In India, flaxseed is cultivated for seeds, used for extracting oil. In India various states have sufficient forest area for the plantation of Flaxseed. Madhya Pradesh leads in yield and acreage, followed by Uttar Pradesh and Maharashtra, Bihar, Rajasthan, Karnataka, and West Bengal also grow flaxseed in large areas. Madhya Pradesh and Uttar Pradesh together contribute to the national flaxseed production to the extent of about 70%. India accounts for about 1.9 million hectares, with a seed production of 4.98 lakhs of ton, the crop in northern India gives higher yield than in central and peninsular India. The yield of irrigated crop may be up to 1200 to 1500 kg per ha and occupies third rank among the flaxseed-producing countries after Australia and Canada. Flaxseed oil is the most used carrier in oil paint. It is available in Asian countries. It is an important oilseed in the world. Flaxseeds are a source of high-quality proteins, soluble fibre, and a high content of polyunsaturated fatty acids. The chemical composition of flaxseed oil alters with geographical location and variety. Oils from various sources have different fatty acid compositions. Flaxseed oil consists chiefly of three glycosides, linoleic, linolenic, and olein. A small amount of free fatty acids, such as palmitic and arachidic is also present.[6] They present values of 30–40% lipids, 20–25% proteins, 4–8% moisture, 3–4% ash and 20–25% dietary fiber.

Also Savita Dixit et al. (2012) studied the possibility of flaxseed oil to produce the biodiesel. They found that flaxseed is a high source of oil which can be converted into biodiesel and supply a major source of renewable energy both locally and internationally. The viscosity and flash point values of flaxseed oil methyl and ethyl esters highly decrease after transesterification process. So, there is need to investigate a suitable method for the transesterification of flaxseed oil based on its properties because flaxseed oil esters have better oxidative stability. Suyash Mandal et al. (2019) studied the process variables i.e., Methanol to Oil molecular ratio, concentration of catalyst KOH% to analyze the transesterification process based on methyl ester yield. They explained that free fatty acid content of the pure flaxseed oil was 1.8%, making it practical for single-stage alkali-catalyzed analysis to produce biodiesel. The kinematic viscosity of all the reactions was within biodiesel fuel standards. Fuel properties such as API gravity, flash point, calorific value, acid number and carbon residue of the flaxseed methyl ester were all within the IS 15607, EN 14214, ASTM D6751 and Australian biodiesel fuel standards. The results showed that the highest yield is produced when methanol to oil molar ratio is 6:1. KOH concentration is 1%, and reaction time is 45 minutes produced. The yield was 94%. V A Markov et al. (2018) found that Physical and chemical properties of diesel fuel and pure linseed oil mixtures with low content (10%) are close to diesel fuels characteristics. They studied the effects of these blend on the emission parameters such as NO, HC, and CO. Experiments showed that diesel fuel mixture of 91%-diesel fuel and 9%- linseed oil reduced NOx emission from 7.018 to 6.441 g/(kWh), carbon monoxide emissions CO reduced from 1.723 to 1.511 g/(kWh), unburned hydrocarbons emissions HC reduced from 0.788 to 0.664 g/(kWh**).** K. Thaniyarasu et al (2018) studied the performance and emission characteristic of direct injection diesel engine fuelled with diesel, flaxseed oil and cottonseed oil as fuel. The results showed that specific fuel consumption and smoke intensity were lowest for pure diesel. There is 18% smoke increment with increased content of biodiesel in the fuel while increment in SFC is 12%. BTE is almost same for diesel and blend of 95% diesel + 2.5% of both flaxseed oil and cottonseed oil. HC emissions were reduced around 30% for biodiesel. Lowest HC emissions were found for the blend of 90% diesel + 5% of both flaxseed oil and cottonseed oil. There is 35 % reduction in NOx emission for the biodiesel compared to pure diesel.

It has been observed from various studies that biodiesel of required properties can be generated from the flaxseed by controlling the transesterification process parameters. Biodiesel blends generated from the flaxseed have few properties that are remarkably close to the pure diesel, when flaxseed is added in small proportion. Noise intensity and vibration of diesel engine is reduced for lower percentage of flaxseed oil biodiesel in blends. Flaxseed oil biodiesel has better lubricating properties compared to diesel. The performance and emission characteristic of diesel engine can be improved by using flaxseed biodiesel as a fuel can be considered for study.

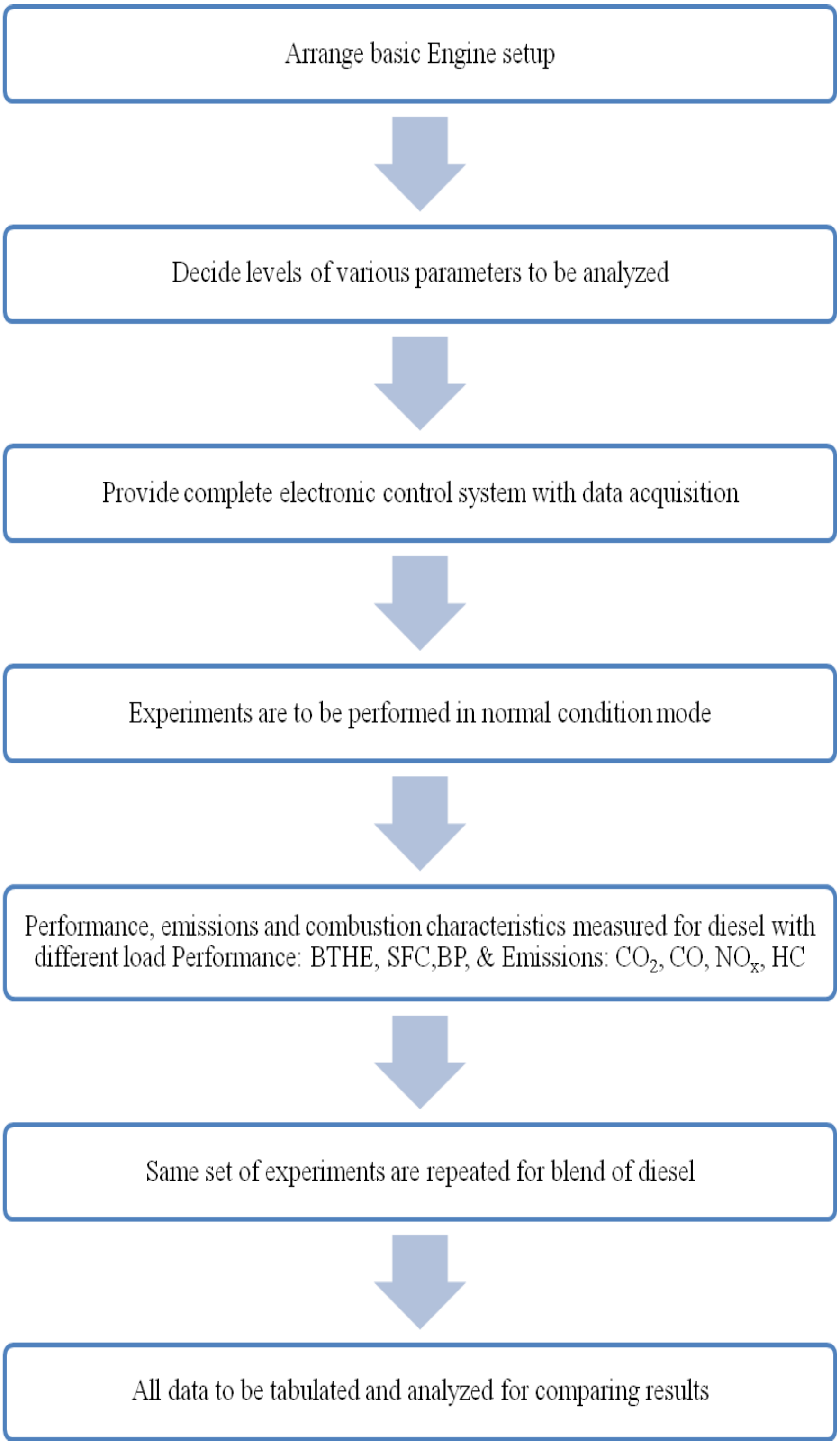
Effect of flaxseed biodiesel on performance and emission parameters has also been studied by the researchers. While there is reduction in HC and CO emission using flaxseed biodiesel-diesel blends [19] the effect on NOx emission is not justified. Along with flaxseed other fuel such as soyabean oil biodiesel, cottonseed biodiesel, di-ethyl carbonate and methanol has also been blended to find their effect on other parameters. Butanol which is a good alternative fuel has not been blended with flaxseed oil biodiesel to determine its effect on engine parameters. Hence, research objectives are as follows

II Research methodology

The detail research methodology adopted for the research work is shown in Figure 1

Figure 1: Research Methodology

II.1 Engine Setup description and experimental process



The set up consists of single cylinder, four stroke, water cooled computerized research engine in which loading has been provided by eddy current dynamometer. Various instruments for airflow, fuel flow, temperatures and load measurements are also provided. As shown in figure 2 experimental set-up consisting of air box, fuel tank for fuel test, transmitters for air and fuel flow measurements, fuel measuring unit, manometer, process indicator and hardware interface. Rota meter is used for calorimeter water and cooling water flow measurement. Various sensors and instruments are integrated with data acquisition system for online measurement of load, air and fuel flow and different temperatures.

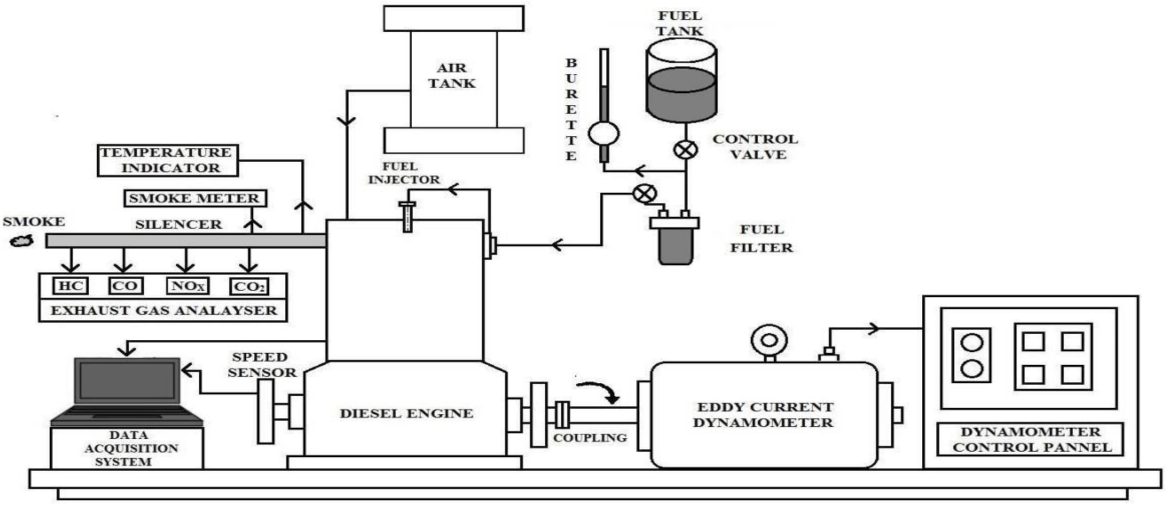


Figure 2 Schematic Diagram of Experimental Set up

The setup enables the evaluation of thermal performance and emission constituents of an engine. Thermal performance parameters include brake power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance etc. The constituents of the exhaust gas like CO, HC and NO_x are measured with exhaust gas analyser.

Diesel engine technical specifications

The prepared fuels were tested in a single-cylinder four-stroke air-cooled DI diesel engine having a rated power of 3.7 kW at an engine speed of 1500 rpm. The specification details of the diesel engine used for experimental investigation are given in Table 2. In all cases it is necessary to ensure that throughout the speed range and engine torque output cannot exceed the capacity of dynamometer to with it coupled. If this condition does occur, the engine speed will increase uncontrollably until a point is reached where the falling torque value again comes within the capacity of the brake. Under such conditions, test work would be impossible, and the engine might be dangerously over speed.

Table 2 Engine specification

Make and Model	**Kirloskar Model AV1**
Number of cylinders	1
Type	4 Stroke, Water Cooled
Swept volume	552.64 cc
Bore	80 mm
Stroke	110 mm
Power	3.7 kW
Speed	1500 rpm
Compression ratio range	12 to 18
Loading	Eddy current dynamometer, Water cooling

II. 2 Experimental Procedure

In this research, single cylinder water cooled diesel engine coupled with eddy current dynamometer is used. The setup is fully computerized and provided with all types of sensors to note readings. Gas analyser is used to find the emission characteristic of exhaust gas. Engine performance such as break power, indicated power, break specific fuel consumption etc. are found from the experiments.

Fuel tank was filled with required blend than engine was run on different load. For all load readings were taken after the stabilization is achieved. After completion of readings fuel tank was emptied and filled with diesel and ran for 15 to 20 minutes to remove any traces of biodiesel. Again, fuel tank is emptied and filled with other blend and ran for 15 to 20 minutes to remove any traces of diesel in the engine. The readings were taken after the stabilization is achieved. As this engine is integrated with data acquisition system all the readings are noted and recorded with the help of data acquisition system as shown in Figure 3.

Figure 3: Data acquisition system

Figure 4: Exhaust gas analyser

III Experiment Variables

For this research different parameters among their respective blend range can be varied. The variable parameters are alternative fuels, engine load, blend ratio etc. Blending of diesel with flaxseed biodiesel can be on weight basis or volume basis. Blending means simple mixing and final product should be homogeneous mixture. Being almost similar properties, it will get mixed very easily. It should be such that the blended fuel must fulfil a rigorous set of standards to avoid damages to the engine and the fuel system. In this experiment also two fuels are mixed on volume basis in a jar of 1000 ml. 500 ml of diesel and 500 ml of diesel are mixed at ambient condition with low mixing speed til miscible with each other. The main parameter used in this experimental work is achieved by varying engine load with change in respective blending proportions. The blend prepared were FB5, FB10, FB20 and FB15+B5 (15%Flaxseed Biodiesel + 5% Butanol + 80% Diesel). The measuring parameters are mainly in two categories, performance, and emission. In performance parameters BTHE, mechanical efficiency, SFC, FC and in emission parameters CO, HC, CO_2, and NOx are being found out and analysed. Researchers have proposed that flaxseed oil which is used for the industrial purpose has the potential to be used as alternative fuel in IC engines. The blending with different proportions has different effects on engine performance, emission, and combustion characteristics.

IV Results and Discussion

Result Table for Various Blend shoeing brake power, brake thermal efficiency and brake specific fuel consumption

<u>100% Diesel</u>

Sr. No.	Load (Kg)	RPM	FC (Kg/hr)	BP (kW)	BTHE (%)	BSFC (kg/kWh)
1	1.56	1475	0.519652	0.543403	8.42178373	0.956293
2	2.03	1468	0.533571	0.703764	10.62257343	0.758168
3	2.97	1458	0.558505	1.022632	14.7464464	0.546145
4	4.21	1444	0.656703	1.43567	17.60679497	0.457419
5	5.72	1423	0.807568	1.922234	19.17000712	0.420119
6	7.02	1400	0.996	2.320975	18.76748268	0.42913

90% diesel + 10% FB

Sr. No.	Load (Kg)	RPM	FC (Kg/hr)	BP (kW)	BTHE (%)	BSFC (kg/kWh)
1	1.56	1480	0.42742	0.545245	10.42084923	0.78391
2	2.03	1476	0.46387	0.7076	12.46122876	0.655554
3	2.97	1462	0.53428	1.025437	15.67872012	0.521025
4	4.21	1444	0.65757	1.43567	17.83525998	0.458026
5	5.72	1422	0.79786	1.920883	19.66734117	0.415359
6	7.02	1392	1.03171	2.307712	18.27229525	0.447071

80% Diesel + 20% FB

Sr. No.	Load (Kg)	RPM	FC (Kg/hr)	BP (kW)	BTHE (%)	BSFC (kg/kWh)
1	1.56	1472	0.42747	0.542298	10.51381497	0.788265
2	2.03	1467	0.44005	0.703285	13.24539596	0.625702
3	2.97	1456	0.52961	1.021229	15.98071305	0.518605
4	4.21	1443	0.61068	1.434675	19.47037823	0.425656
5	5.72	1427	0.72983	1.927637	21.88939407	0.378616
6	7.02	1401	0.96526	2.322632	19.94191324	0.415591

80% Diesel + 15% FB + 5% Butanol

Sr. No.	Load (Kg)	RPM		FC (Kg/hr)	BP (kW)	BTHE (%)	BSFC (kg/kWh)
1	1.56	1480		0.42634	0.545245	10.44724704	0.781929
2	2.03	1478		0.43888	0.708558	13.18854529	0.619402
3	2.97	1473		0.52821	1.033153	15.97810072	0.511263
4	4.21	1458		0.60906	1.449589	19.44254936	0.420161
5	5.72	1448		0.7279	1.956004	21.95158875	0.372137
6	7.02	1416		0.96271	2.3475	19.91955214	0.4101

The emission characteristics against the load are discussed individually as below.

Load Vs CO2 emission: The emissions against the load are observed as Fig 5 shows the variation of carbon dioxide (CO2) emission with variable load and for different blend. It has been found that with an increase in load, CO2 increases, the higher combustion temperature and pressure at load mounting leads to oxidize the CO to produce the CO2. Biodiesel has higher content of oxygen which increases the CO2 emissions. Hence, CO2 emission for the FB20 and FB15+B5 is slightly higher than the diesel fuel. Though, there is a huge reduction of 29% in CO_2 emission for the FB10 blend. Addition of Butanol in the Blend reduces the CO2 emission.

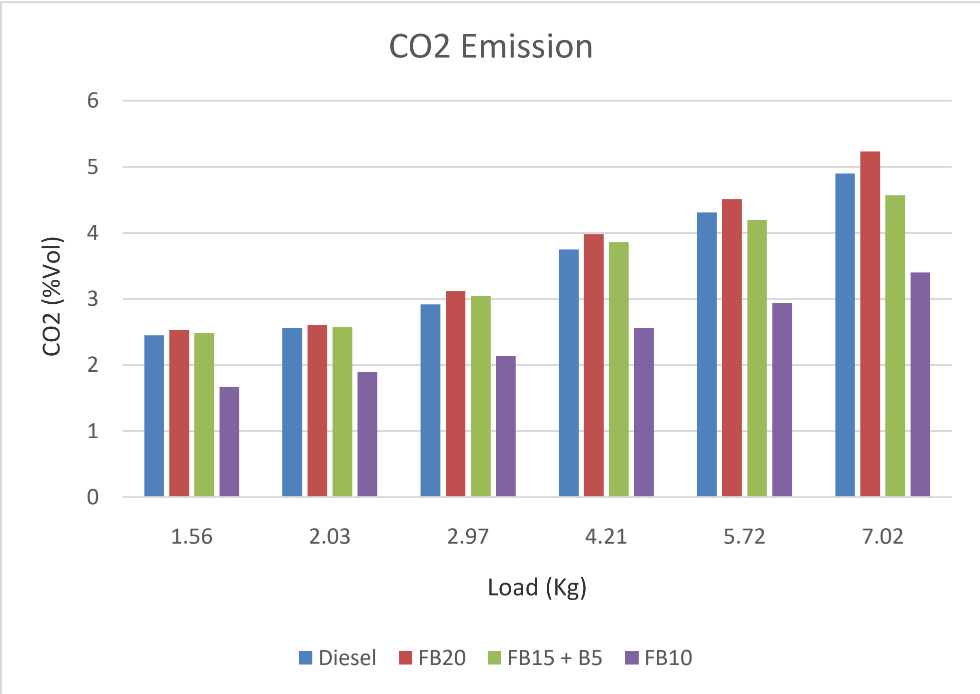


Figure 5 Load Vs CO_2 emssion

Load Vs CO emission: Figure 6 show the variation of carbon monoxide (CO) emission with variable load and for different blend. Poor combustion and insufficient oxygen are the main reason for CO emissions. For Biodiesel blends CO emission is lower than the pure diesel as they have higher content of oxygen.

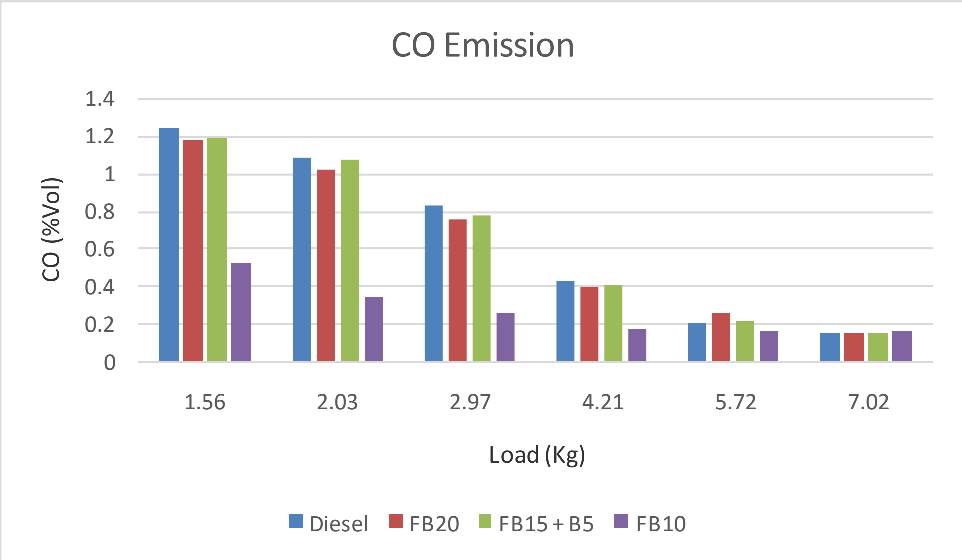


Figure 6 Load Vs CO emission

With increase in load CO emissions decreased for each of the blends. For higher loads CO emission from biodiesel blend same to the pure diesel. Lowest CO emissions were recorded for B10 blend. There is 44.44% reduction in emission using FB10 blend compared to pure diesel. At 7 kg load CO emissions for Diesel, FB20, FB15+ B5, and FB10 were 0.145, 0.153, 0.149, and 0.158 percentage respectively. Addition of Butanol does not help in reducing the CO emission. It slightly increases the emission as compared to FB20 blend.

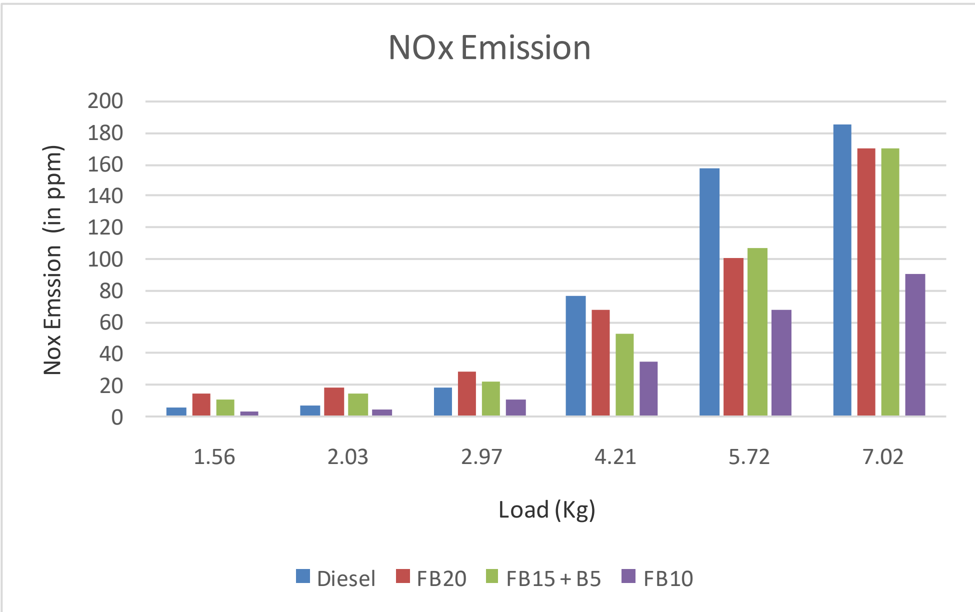


Figure 7 Load Vs NOx emission

Load Vs NOx emission: Fig 7 shows the variation of Nitrogen oxide (NOx) emission with variable load and for different blend. As shown in the graph for lower load NOx emission is higher for biodiesel blend compared to pure diesel.

This is due to higher oxygen content present in the biodiesel. Due to higher oxygen content complete combustion is achieved. Hence, the exhaust temperature increases which increases NOx emission. As for the load greater than 4 kg NOx emission is lower for biodiesel compared to pure diesel. At higher load there is incomplete combustion which reduces the exhaust gas temperature. Hence, NOx emission is reduced. While FB10 shows significant reduction of an average 50% compared to pure diesel. For 7 kg load NOx emission for Diesel, FB20, FB15+ B5, and FB10 were 184.69, 169.158, 170.03, and 89.63 ppm respectively. Butanol reduces NOx at lower load compared to FB20 blend, but it increases NOx at higher load.

Load Vs HC Emission: Fig 8 shows the variation of Hydrocarbon (HC) emission with variable load and for different blend. With increase in load HC emission decreases for the diesel and all the other blends. HC emission is mainly produced by the unburned fuel left inside the engine.

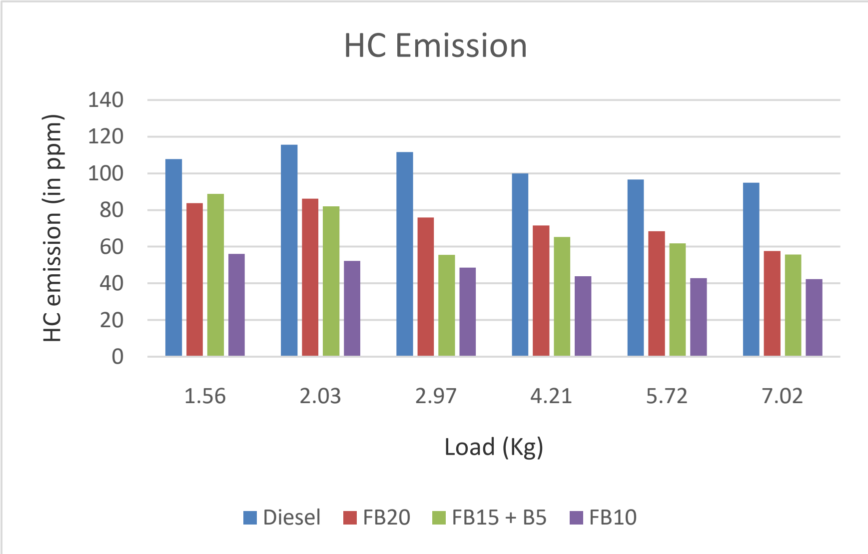


Figure 8 Load Vs HC emission

As biodiesel have extra amount of oxygen there is complete combustion inside the engine which reduced the HC emissions. FB10 blend shows far better emission characteristics than other blend it reduces HC emission up to 54% compared to diesel. FB15 + B5 has lower HC emission than the FB20 blend. Butanol reduces 7.94 % of HC compared to FB20 blend.

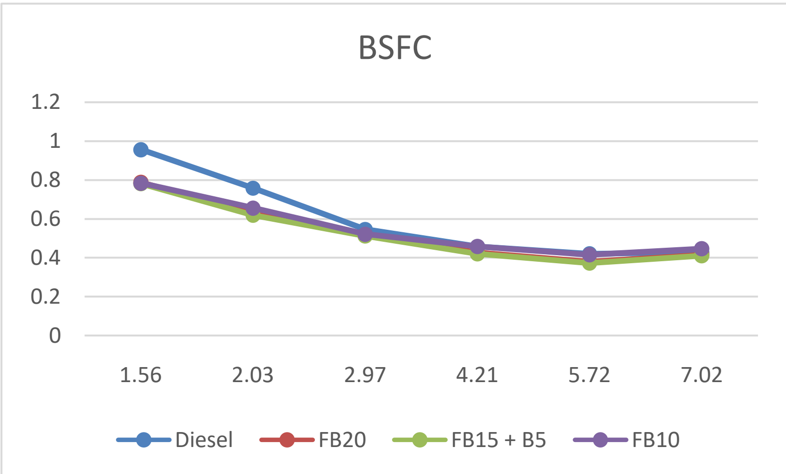


Figure 9 Load Vs BSFC

Load Vs BSFC*:* Figure 9 shows variation in the BSFC at various load and for different blend. For low load BSFC of biodiesel blend is lower than the diesel.

As the load increase, difference between BSFC of diesel and different blend decreases. For 7 Kg load BSFC is almost same for all the fuel which is approximately 0.41 kg/kWh. Addition of butanol slightly reduces the BSFC compared to FB20 blend.

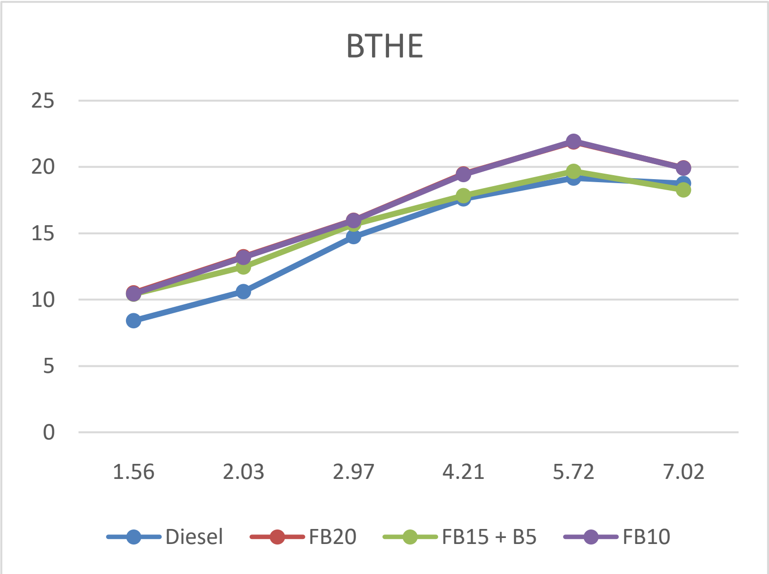


Figure 10 Load Vs BTHE

Load Vs BTHE: Figure 10 showcase variation in BTHE at various load and for different blend. As load increases BTHE increases for all the fuel. BTHE of biodiesel blend is higher than the diesel for all the loads.

It is clearly seen that as load increases difference between the BSFC of diesel and different blend decreases. Addition of butanol reduces BTHE compared to FB20 blend, but it increases BTHE compared to diesel. At higher load BTHE of diesel and FB15 + B5 is almost same.

V Conclusion

Flaxseed biodiesel produced from the flaxseed oil using methanol to oil molar ratio 6:1 and reaction time of 45 minutes and reaction temperature of 60°C has 84% yield. Performance and emission characteristics of CI engine fuelled with diesel and flaxseed biodiesel were investigated in this research work. Tests were carried out for diesel, FB10, FB20 and FB15 + B5 fuels. Various conclusions from this obtained from this research can be summarized as:

- With increase in load CO and HC emission decreases while NOx and CO_2 emission increases.
- CO_2 emissions for the biodiesel blend having flaxseed % 15 and 20 is higher than the pure diesel. While FB10 blend shows 29% reduction in CO2 emission. CO emissions for biodiesel blends are lower than diesel. However, at higher load CO emission is almost same for all the blends. FB10 shows a reduction of 44.44% in CO emission compared to diesel.
- NOx emissions for biodiesel blends are higher than diesel at low load. At high load NOx emission is lower than the diesel fuel. FB10 shows a reduction of 50% in NOx emission compared to diesel. HC emissions for biodiesel blends are lower compared to pure diesel. FB10 shows a reduction of 54 % in HC emission compared to pure diesel.
- Brake thermal efficiency (BTHE) increases as the load increases. BTHE for biodiesel blends is higher compared to pure diesel. However, at higher load BTHE is almost same (20%) for all the blends. Brake specific fuel consumption (BSFC) decreases as the load decreases. It is lower for biodiesel blends compared to diesel at low load. At high load BSFC of all the fuel has same value which is approximately around 0.41 kg/kWh.

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