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Experimental Analysis of Effect of Mixed Biodiesel Blends on Performance, Combustion, and Emission of Variable Compression Ratio Engine

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ABSTRACT

Indiscriminate use of fossil fuels throughout the world has led to emission, price hike, and destruction of petroleum sources. The environmental concern has encouraged the researcher to seek for an alternative fuel source such as biodiesel for CI engine. The objective of the study is to investigate the effect of mixed biodiesel blends on performance, combustion, and emission of variable compression ratio engine. The three biodiesel Jatropha, Mahua and Neem were selected for the study based on properties. The five samples of biodiesel such as Jatropha, Mahua, Neem with 10 % blend individually (biodiesel 10 % and diesel 90 %) and mixed blends JNM25 (Jatropha + Neem + Mahua of 25 %, diesel 75 %) and JNM30 (Jatropha + Neem + Mahua of 30 %, diesel 70 %) were prepared and the performance, emissions, and combustion of variable compression ratio (VCR) engine were measured. B10 blends of Jatropha, Mahua, and Neem each have properties close to the diesel and it showed lower performance than diesel because of the lower calorific value of biodiesels. The JNM 25 and JNM 30 mixed blends showed a performance close to diesel and emissions are lower than diesel. The NO_x (oxides of nitrogen) emissions were increased, and hydrocarbon, carbon monoxide emissions were decreased.

1. INTRODUCTION

A large amount of energy required worldwide is presently developed from fossil fuels such as petroleum, natural gas, and coal. These energy sources are exiguous, unevenly spread throughout the worldwide and going to exhaust in the nearer future. Also, it has a bad impact on the environment; it degrades the quality of air. So it is necessary to search an alternative source of renewable energy that demotes the emissions. The alternative biofuels are having the potential to address all these issues such as air pollution, price hike, global warming, and sustainability. Nowadays, among the vegetable oil, the biodiesel is one of the alternatives and renewable biofuel prepared from plant oil or animal fats for a diesel engine [1]. Oils obtained from plant species such as neem, soya, sunflower seeds, cottonseed, jatropha curcas (ratanjyot), pongamiapinnata (Karanja), madhucaindica (mahua), calophylluminophyllum (nagchampa), rice bran, algae, etc. are the major resources for the production of biodiesel [2]. Biodiesel has environmental benefits like fewer air pollutants, nontoxic and biodegradables. Energy yield from biodiesel is 40 % to 90 % more than invested in producing it [3].

As per the Indian petroleum and natural gas statistics (2016-2017), the production of crude oil in the year 2016-17 was 36.95 MMT (Million Metric Tonnes) and the consumption of petroleum products in India was 184.674 MMT. The consumption is more than production, which needs to import crude oil from other countries. India is the second-largest country in population. In India, due to the scarcity of food edible oils cannot be used for biodiesel production. Hence, it is beneficial to use the non-edible oils like Mahua, Karajan, Neem, Rubber, Jatropha, Kusum and Cashew shell for biodiesel production which is available in abundant. The biodiesel as a fuel in diesel engines improves the rural farming economy through the production of biodiesel seed, which can lead to the development of the country [4, 5].

Jatropha curcas plant is drought resistant and perennial plant which can live up to 50 years with marginal soil. It does not require a lot of water, hence it is sustainable than any other plant. Jatropha seed contains 25-30 % oil, which contains 21 % saturated and 79% unsaturated fatty acids. After the transesterification process, most of the properties of Jatropha oil methyl ester were found close to diesel [6, 7]. Experiments were carried out on Jatropha biodiesel, the performance characteristics showed that the brake specific fuel consumption (BSFC) increases and brake thermal efficiency (BTE) decreases. Combustion characteristics showed an increase in peak cylinder pressure and a decrease in ignition delay period with the increase in Jatropha biodiesel proportion in the blends [8]. The emission of NO_x and CO_2 increases and smoke emission decreases due to higher carbon-hydrogen ratio and presence of oxygen molecule in the biodiesel [9, 10]. MadhucaIndica (Mahua) is also available in Maharashtra, West Bengal, Orissa and in South Indian forests. It contains 20-25 % oil in seeds. Navindgi et al. [11] have observed the performance of CI engine with different blends of Mahua under varying operating conditions. As the concentration of mahua oil methyl ester in diesel increases power output decreases, but when injection pressure and fuel temperature is increased power output is increased. The blend up to 20 %

concentration of mahua biodiesel was found to be suitable for the short term engine performance. Mahua biodiesel is suitable for higher injection pressures (240 bar) and higher inlet fuel temperatures (70 °C). The blend proportion up to B20 can be a better substitute for a CI engine without any modifications. Puhan et al. [12] have studied the performance of Mahua oil (madhucaindica oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine and resulted that the brake thermal efficiency of mahua biodiesel is comparable with diesel; for diesel, it is 26.36 % whereas for mahua biodiesel it is 26.42 %. The CO, HC, NO_x and Bosch smoke number was reduced around 58, 63, 12 and 70 %, respectively as compared to diesel.

Neem is abundantly grown in varied parts of India. The Neem can be grown on saline soil, clay and alkaline conditions [13]. Seeds of Neem have 30-40 % oil as well as free fatty acids about 5.7 %. [14,15]. Nair et al. [16] have analyzed the performance and emission of CI engine fuelled with blends of Neem biodiesel; it was observed that Neem biodiesel blends have higher BTE as compared to diesel. These blends result in no prominent drop in performance of the engine. The emissions of CO, HC, CO_2, and NO_x of Neem biodiesel are less as compared with diesel. The O_2 emissions of Neem biodiesel are more than diesel. B10 of Neem has higher performance than B20 and B30. It also has lower emissions than blends B20 and B30.

It is observed that research on a single blend of various biodiesels has been carried out. The performance analysis for mixed blends of any biodiesel is scared in literature. Hence, in this paper attempt is made to analyze engine performance for mixed blends of biodiesel with diesel on the VCR engine under different operating conditions.

2. MATERIALS AND METHODS

2.1 Blends preparation

One of the most common method transesterifications is used for the preparation of biodiesel. In the transesterification process plant oils, molecules are broken down into constituent a molecule which forms biodiesel with glycerine as a by-product. The biodiesel produced from the process of transesterification has a much lower viscosity, which enables it to use in the diesel engine. The three oils Jatropha, Mahua, Neem are selected for biodiesel blend preparation on the basis of properties.

Table 1. Experimental matrix of biodiesel blends

Blend	Jatropha	Neem	Mahua	Diesel
J10	10%	-	-	90%
N10	-	10%	-	90%
M10	-	-	10%	90%
JNM25	8.33%	8.33%	8.3%	75%
JNM30	10%	10%	10%	70%

Table 1 shows the experimental matrix of the biodiesel blend. Jatropha, Mahua, and Neem are blended in the percentage of 10 (J10, N10, M10) with Diesel. JNM25 blend is prepared by mixing all three selected biodiesels in the proportion of 8.33 % and JNM30 blend is prepared by mixing all three selected biodiesels in the proportion of 10 %, resulting in 30 % of Jatropha, Neem and Mahua and 70 % of diesel.

2.2 Properties of biodiesel blends

The biodiesel blend characteristics such as viscosity, density, flash and fire point, and calorific value were measured. Table 2 shows the properties of biodiesel blend test fuels. The density, viscosity, flash point and fire point of all blends found higher than diesel. The calorific value of all blends found lower than diesel.

2.3 Experimental setup

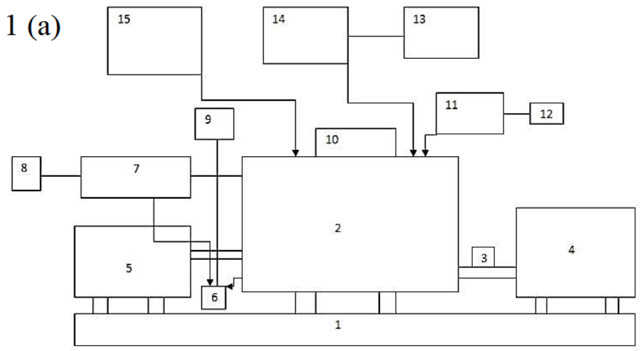
To analyze the performance of biodiesel the experiments are carried out on a Variable Compression Ratio Engine (VCR). The effect of different compression ratios (CR) is compared for various blends. The engine tests are carried out at different loading conditions with constant speed for all blends at 17.5 and 18.5 compression ratios. The experiment is conducted on a single-cylinder, 4 stroke, Spark/Compression Ignition VCR, water-cooled, naturally aspirated test rig. The engine is coupled with eddy current dynamometer having a maximum power of 25 BHP at 4200 to 10000 RPM and with a maximum torque capacity of 41.8 N-m at 2700 to 4200 RPM. Table 3 represents the technical specifications of the VCR engine.

Table 2. Properties of test fuels

Test Description	Diesel	Biodiesel blends				
		J10	N10	M10	JNM25	JNM30
Density (kg/m^3)	830	832.6	837.6	840.9	836.6	840.2
Calorific value (kJ/kg)	42514	37220	36883	39333	35235	34699
Viscosity (cSt)	3	4.18	4.38	4.87	3.6	4.33
Flash point (℃)	64	64	67	71	72	74
Fire point (℃)	70	71	76	78	76	79

Table 3. Engine specifications

Engine Parameters	Specifications
Type of Engine	4-Stroke, CI Engine
No. of cylinders	Single
Bore/Stroke	87.5 mm/110 mm
Rated Power	5 BHP at 1500 RPM at 17.5:1
Capacity (cc)	662
Loading	Eddy Current Dynamometer
Manufacturer	M/S Accurate Test Equipment and Engineers, Shiroli MIDC, Kolhapur



1. Engine bed 2. VCR engine 3. RPM sensor 4. Eddy Current 5. D.C. motor 6. Rota meter 7. Exhaust pipe 8. Exhaust gas analyzer 9. Water tank 10. CR lever 11. Air tank 12. Orifice meter 13. Monitor 14. Control Panel 15. Fuel tank

Figure 1(a). VCR engine layout

Figure 1(b). Experimental setup

The load on the engine is varied by controlling the excitation of current to the eddy current dynamometer. The VCR engine layout and experimental setup are shown in Figure 1 (a) and (b).

3. RESULT AND DISCUSSION

The different performance, combustion and emission parameters like brake thermal efficiency, mechanical efficiency, brake specific fuel consumption, exhaust gas temperature, Air fuel ratio, pressure with respect to crank angle, carbon dioxide emission, carbon monoxide emissions, oxides of nitrogen are analysed at different loading conditions with constant speed for blends of J10, M10 N10, JNM25 and JNM30 at CR 17.5 and CR18.5.

3.1 Performance of engine

3.1.1 Effect of brake power on mechanical efficiency

Figure 2 and Figure 3 shows the variation of mechanical efficiency with respect to brake power at CR 17.5 and CR 18.5 respectively. It is observed that mechanical efficiency increases with an increase in brake power and mechanical efficiency of all the blends found comparative to diesel. The increase in mechanical efficiency at CR 17.5 for J10, M10 and N10 blends compared to diesel at full load is 1.54 %, 2.72 %, and 3.14 % respectively. For JNM 25 and JNM 30 at CR 17.5 mechanical efficiency was increased by 1.44 % and 2.83 % respectively. At full load, the increase in mechanical efficiency at CR 18.5 for J10, M10 and N10 blends was 0.89 %, 3.5 %, and 5.6 % respectively as compared to diesel. For mix blends, JNM25 and JNM 30 at CR 18.5 increase in mechanical efficiency was 3.2 % and 2.1 % respectively.

It is observed that the increase in CR decreases mechanical efficiency. Comparing the results at CR 17.5 and CR 18.5, decrease in mechanical efficiency for blends J10, M10, N10, JNM 25, JNM 30 and diesel at full load is 3.4 %, 1.97 %, 0.45 %, 0.36 %, 1.07 % and 3.67 % respectively.

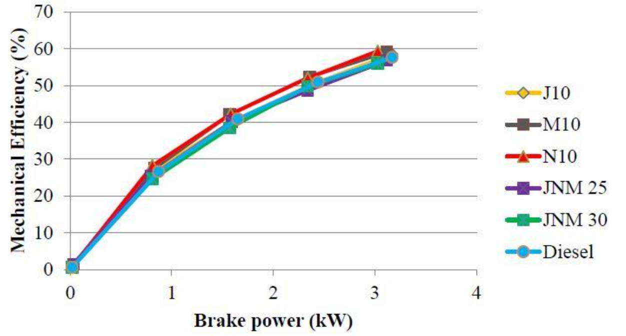


Figure 2. Mechanical efficiency vs brake power at CR 17.5

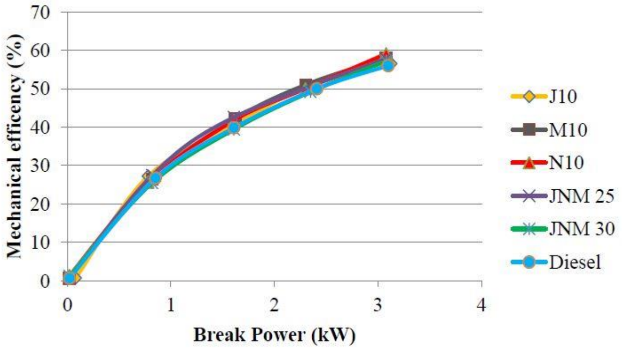


Figure 3. Mechanical efficiency vs brake power at CR 18.5

3.1.2 Effect of brake power on brake thermal efficiency (BTE)

Figure 4 and Figure 5 shows the variation of Brake Thermal Efficiency for all selected blends and diesel at CR 17.5 and CR 18.5. The result showed an increase in brake thermal efficiency with increase in brake power of the engine for all blends. This is due to a reduction in heat loss and increases in power with the increase in load.

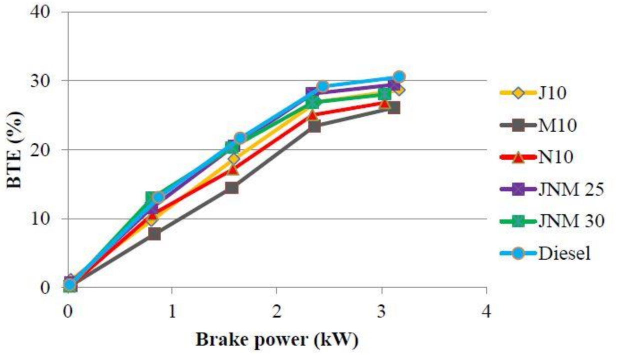


Figure 4. Brake thermal efficiency vs brake power at CR

At CR 17.5 the decrease in brake thermal efficiency for J10, M10, and N10 blends compared to diesel at full load were 6.45 %, 16.39 %, and 18.18 % respectively. For JNM 25 and JNM 30 at CR 17.5 increase in brake thermal efficiency was

7.05 % and 12.88 % respectively. At CR 18.5 the decrease in brake thermal efficiency for J10, M10, and N10 blends compared to diesel at full load is 6.74 %, 13.82 %, and 12.59 % respectively. For blend JNM 25 and JNM 30 at CR 17.5 increase in brake thermal efficiency was 3.97 % and 9.73 % respectively.

It is observed that the increase in CR increases brake thermal efficiency. Comparing the results at CR 17.5 and CR 18.5, increase in brake thermal efficiency for blends J10, M10, N10, JNM 25, JNM 30 and diesel, at full load was 8.65 %, 6.85 %, 5.60 %, 11.80 %, 12.93 %, and 15.27 %, respectively.

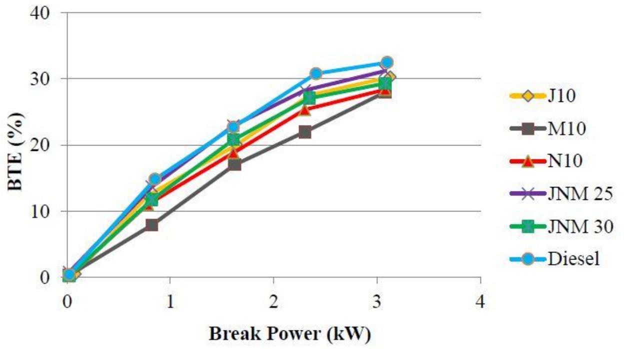


Figure 5. Brake thermal efficiency vs brake power at CR 18.5

3.1.3 Effect of brake power on brake specific fuel consumption

Figure 6 and Figure 7 show the variation of BSFC of blends J10, M10, N10, JNM 25 and JNM 30 at CR17.5 and CR 18.5 respectively. It is observed that the increase in load increases cylinder combustion temperature which improves the evaporation of the fuel. BSFC of biodiesel blends is more than diesel due to lower calorific values.

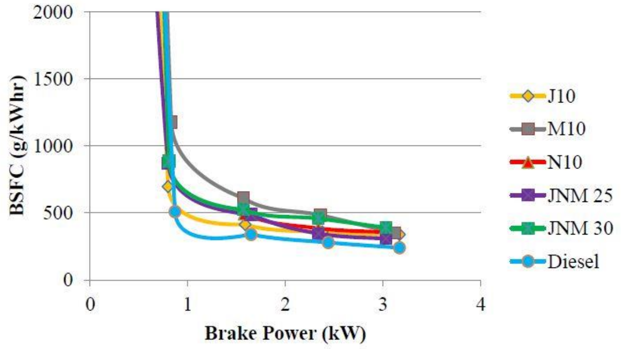


Figure 6. BSFC vs brake power at CR 17.5

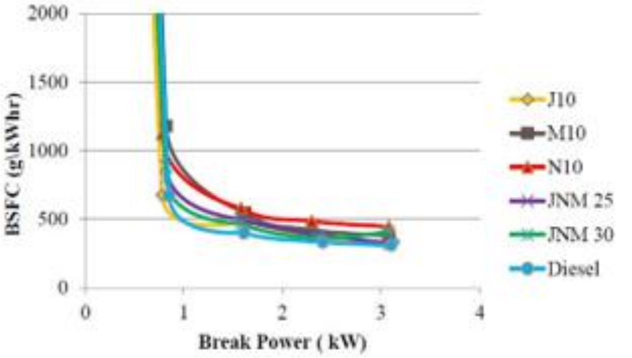


Figure 7. BSFC vs brake power at CR 18.5

The increase in BSFC for blends J10, M10, N10, JNM 25 and JNM 30 compared to diesel at full load was 41.44 %, 46.25 %, 48.49 %, 28.47 % and 62.32 %. respectively at CR17.5. The increase in BSFC for J10, M10, N10, JNM 25 and JNM 30 compared to diesel at full load was 7.77%, 22.81 %, 44.02 %, 13.68 %, and 31.54 %, respectively at CR 18.5.

It is observed that the increase in CR decreases BSFC. Comparing the results at CR 17.5 and CR 18.5, decrease in BSFC for J10, M10, N10, JNM 25, and JNM 30 at full load was 13.98 %, 13.73 %, 19.81 %, 14.76 %, and 16.34 %, respectively. This may be due to complete combustion of the mixture at higher CR.

3.2 Engine combustion

3.2.1 Effect of brake power on exhaust gas temperature

Figure 8 and Figure 9 show the variation of Exhaust Gas Temperature of blends J10, M10, N10, JNM 25 and JNM 30 at CR17.5 and CR 18.5 respectively. It is observed that exhaust gas temperature increases with BP. The diesel fuel has the least exhaust gas temperature than all other blends. It is due to its less viscosity and flash point than all other blends.

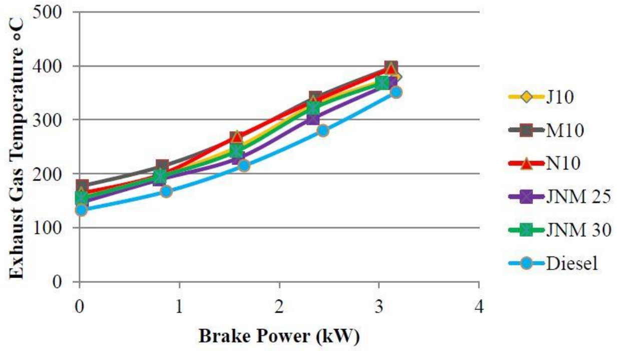


Figure 8. Exhaust gas temperature vs brake power at CR 17.5

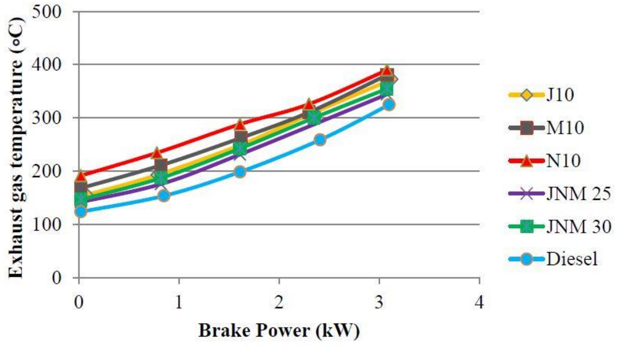


Figure 9. Exhaust gas temperature vs brake power at CR 18.5

At CR 17.5, the increase in exhaust gas temperature for blends J10, M10, N10, JNM 25 and JNM 30 compared to diesel at full loads are 8.81 %, 13.11 %, 12.57 %, 4.81 %, and 4.36 % respectively. At CR 18.5, the increase in exhaust gas temperature for blends J10, M10, N10, JNM 25 and JNM 30 compared to diesel at full loads is 14.69 %, 17.22 %, 20.08 %, 6.03 %, and 4.96 %, respectively.

It is observed that the increase in CR decreases the exhaust gas temperature. Comparing the results at CR 17.5 and CR

18.5, decrease in exhaust gas temperature for blends J10, M10, N10, JNM 25, JNM 30 and diesel, at full load was 1.89 %, 4.10 %, 1.29 %, 6.39 %, 3.66 %, and 7.46 %, respectively.

3.2.2 Effect of brake power on air fuel ratio

Figure 10 and Figure 11 shows the variation in Air fuel ratio with respect to BP at CR 17.5 and CR18.5 respectively. It is seen that the air-fuel ratio for the single blend is slightly lower than diesel fuel. In case of mixed blends JNM 25 and JNM30, it is dropped dawn highly. In mixed blends, the mass of fuel consumed is more due to lower calorific value to produce the same power hence air-fuel ratio decreases. Similar trends are observed for an increased compression ratio of the engine from 17.5 to 18.5.

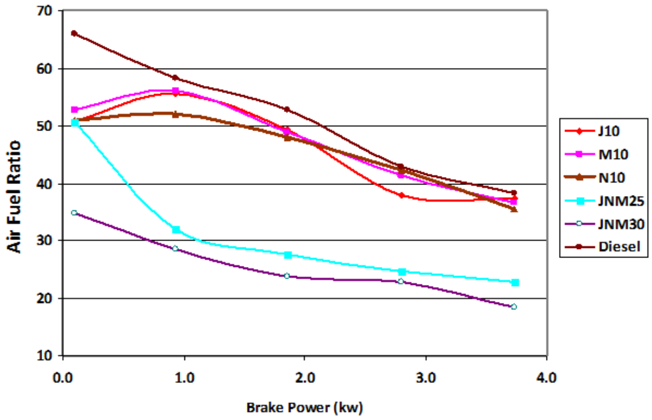


Figure 10. Air fuel ratio vs brake power at CR 17.5

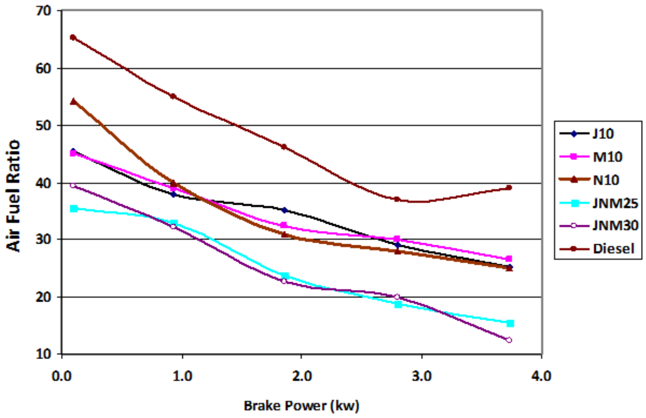


Figure 11. Air fuel ratio vs brake power at CR 18.5

3.2.3 Heat balance sheet

Figure 12 and Figure 13 shows the heat balance sheet at CR 17.5 and CR18.5 respectively at full load conditions. It is observed that for J10 blend and JNM25 mixed blend heat equivalent to brake power is close to diesel fuel. For single blends, M10 and N10 showed lowest heat equivalent to brake power. Also, for single blends exhaust heat is more as compared to mixed blends and diesel fuel. This can be attributed to incomplete combustion due to more BSFC and lower air-fuel ratio.

The increase in CR also leads to an increase in heat equivalent to break power resulting in increased break thermal efficiency. The heat required for cooling is almost equal to all kinds of blends and for increased CR of the engine.

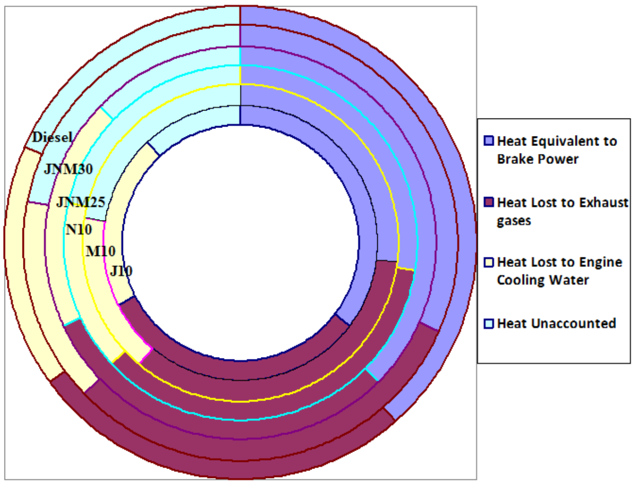


Figure 12. The heat balance sheet at CR 17.5

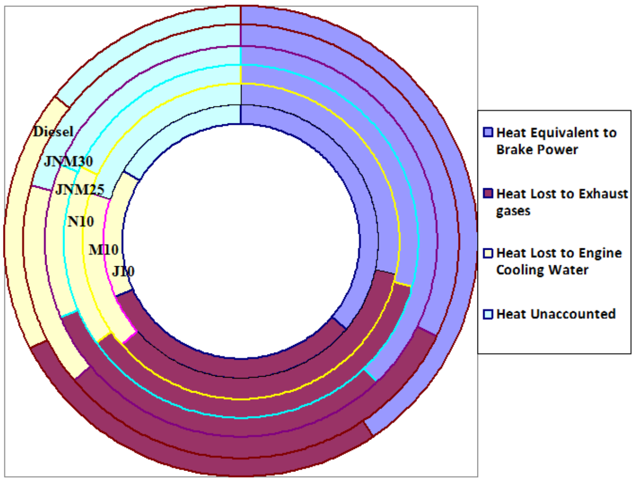


Figure 13. Heat balance sheet at CR 18.5

3.2.4 Effect of pressure on the crank angle

Figure 14 and Figure 15 show variation in-cylinder pressure with respect to the crank angle at CR 17.5 and CR18.5 respectively. It is observed that maximum heat release in the combustion chamber is for diesel fuel as compared to selected blends. The maximum pressure attained is also showing desired trends for all blends. Hence, these blends can be suitable as an alternative to diesel fuel. With the increase in CR similar trends are observed on P-ɵ diagram.

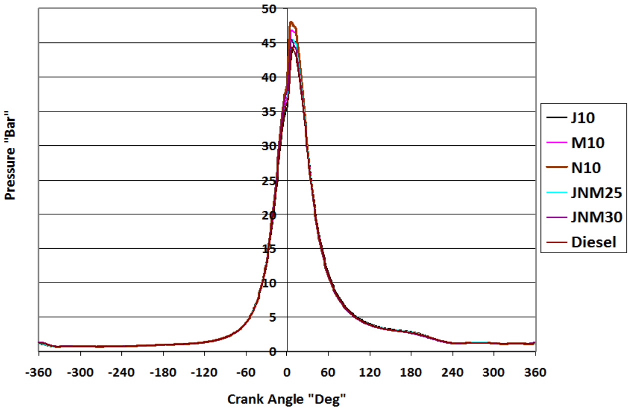


Figure 14. Crank Angle vs pressure at CR 17.5

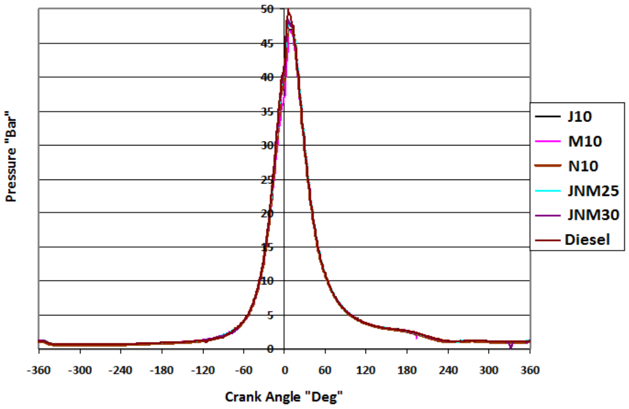


Figure 15. Crank angle vs pressure at CR 18.5

3.3 Engine emission

3.3.1 Effect of brake power on HC emissions

Figure 16 and Figure 17 show the HC (hydrocarbon) emission with respect to break power at CR 17.5 and 18.5 respectively. The HC emission was decreased as CR increases. The unburnt hydrocarbon emission decreases with the increase in load due to the sufficient amount of oxygen in the mixture.

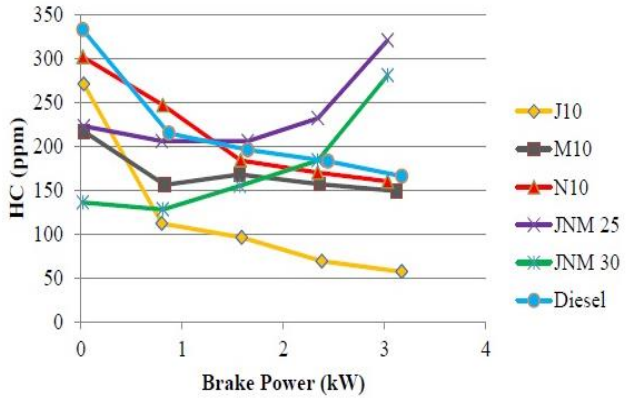


Figure 16. HC emissions at CR 17.5

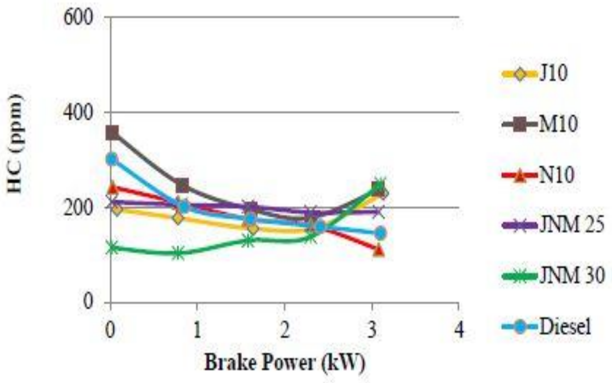


Figure 17. HC emissions at CR 18.5

At 17.5 CR HC emission decreases up to 3.14% and 3.61% for M10 and N10, respectively and JNM25 produces 321ppm maximum HC emission at full load compared to 166 ppm of diesel. At CR17.5 the blend of J10 has least HC emission as compared to other blends and at CR18.5 the blend of N10 has the least HC emission as compared to other blends for a full load.

3.3.2 Effect of brake power on CO emissions

The emissions of CO (carbon monoxide) with respect to break the power at CR 17.5 and 18.5 are shown in Figure 18 and Figure 19 respectively. The main effect of methyl based fuel is oxygen content and the cetane number. As the combination of methyl ester fuel oxygen contains improves, which helps in the combustion of the fuel. Oxygen helps for combustion of fuel, which converts CO into CO_2. Hence CO present in the exhaust reduces drastically. The N10 and J10 have maximum CO emission up to 0.12% volume which is near to diesel at 17.5. JNM25 and JNM30 have less CO emission up to 35 % and 10 % than diesel respectively.

It is observed that the increase in brake power decreases CO emission. The CO emission was reduced up to 25 % as compared with diesel at full load condition. At CR 18.5 the J10 produce more CO emission up to 30 % greater than diesel at full load and blend N10 shows least CO emission.

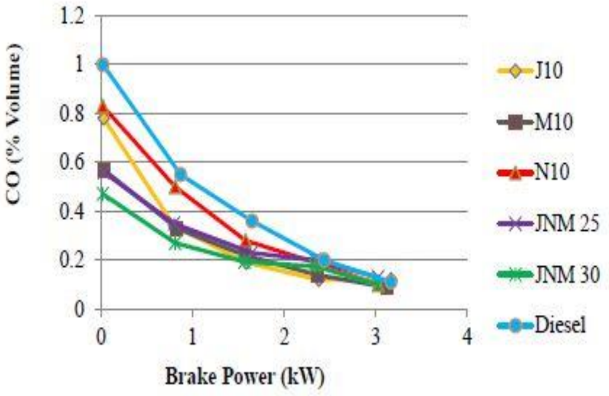


Figure 18. CO emissions at CR 17.5

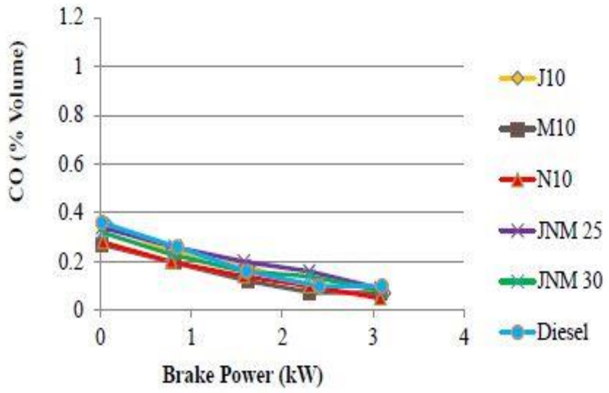


Figure 19. CO emissions at CR 18.5

3.3.3 Effect of brake power on NO_x emissions

The variation of NO_x emission with respect to the break power of the engine at CR 17.5 and CR 18.5 are shown in Figure 20 and Figure 21 respectively. The NO_x emission depends on the maximum combustion temperature. Highest combustion temperature breaks the strong triple bond of nitrogen, which reacts with oxygen and forms the oxide of nitrogen.

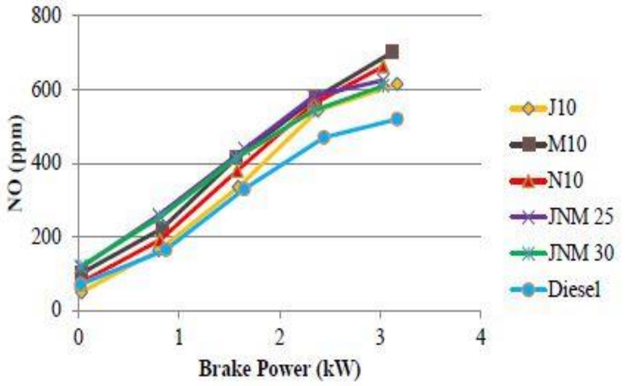


Figure 20. NO_x emissions at CR 17.5

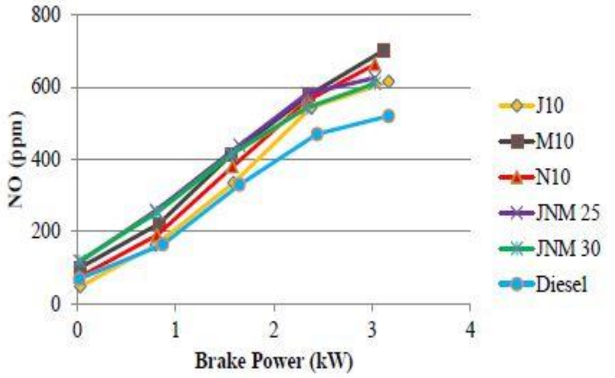


Figure 21. NO_x emissions at CR 18.5

The M10 produces maximum NO_x up to 701 ppm which is 34 % more than diesel. The minimum emission was produced by J10 up to 615 ppm which is 18 % more than diesel at full load. The N10 produces NO_x up to 663 ppm which is 27 % more than diesel at full load. The NO_x emission reduces in JNM 30 compared to JNM 25 as oxygen contains increases.

With the increase in CR the NO_x emission increases because of increase combustion temperature. The M10 produces less NO_x emission at 18.5 CR than other two blends having 3-4 % reduction as compared to diesel. The J10 produces 23 % more NO_x emission at full load than diesel.

4. CONCLUSION

In this paper, investigations of mixed blends of biodiesel are presented. The performance and emission analysis of pure and mix blends are carried out on VCR engine. The results are presented in comparison with diesel fuel, biodiesel and mixed biodiesel blends for CR 17.5 and CR 18.5. From selected pure biodiesel blends J10, N10 and M10 and mixed biodiesel blend JNM25 and JNM 30, results showed that JNM 25 performance is better at CR 18.5 as compared to other blends and it is close to diesel. The brake specific fuel consumption and mechanical efficiencies are higher than diesel by 3.62 % and 4.63 % at full load. For JNM25 brake thermal efficiency is 4.24 % lower than diesel at full load condition. Exhaust gas temperature shows 14.70 % high value at no load and 6.03% high value at full load than diesel. Emission analysis showed that for all blends, NO_x (oxides of nitrogen) emission are increased, and hydrocarbon, carbon monoxide emissions are decreased. The biodiesel blend M10, J10 and N10 have 20 % more emissions of NO_x (oxides of nitrogen) than diesel. The hydrocarbon and carbon monoxide emissions decreased up to 25 % as compared to diesel. The JNM25 gives 30 % less emission of CO than diesel at different loads. The investigation shows that mixed biodiesel blends have the potential to replace conventional diesel fuel.

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