International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(4): 1910-1916

Received: 16-05-2019
Accepted: 18-06-2019

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Performance and emission characteristics of CI engine using biodiesel blend

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Abstract
This study is motivated by the fact that the vegetable oils are being considered as the fuel of the future for the internal combustion engines, especially the compression ignition engines which are working with diesel as fuel. The vegetable oils are characterized by different set of properties than diesel and hence cannot be used as such in the existing engines. Different approaches for using the vegetable oils in CI engines as fuel are either to modify the oils to match with that of diesel or to modify the engines to run successfully with these oils. Transesterification is one of the common methods to bring the properties of these oils within acceptable limits. Still, the performance loss is seen with biodiesel with standard design of the engine. The investigation was to check the feasibility of *Jatropha curcas* L. as an alternate to diesel in terms of engine performance and emission characteristics.
The engine performance and emission characteristics were measured during the short-term test using the bio diesel blends 0, 10 and 20 per cent with diesel at full load. It was observed that brake power of B10 and B20 was 4.16 and 9.4 per cent lower than diesel. The volumetric efficiency measured in percentage was 82.11, 81.36 and 82.50 for B10, B20 and diesel respectively. Both blends had shown 1.65 and 4.40 per cent more specific fuel consumption than diesel. Indicated power was reduced by 2.13 and 3.11 per cent for B10 and B20 respectively than diesel. Brake thermal efficiency of B10 and B20 were 2.91 and 6.84 per cent less than diesel. It was observed that mechanical efficiency of B10 and B20 was 0.23 and 0.24 per cent higher than diesel. The brake mean effective pressure (BMEP) and indicated mean effective pressure (IMEP) measured in bar. BMEP was 19.55, 19.46 and 19.71 bar for B10, B20 and diesel respectively. While IMEP was observed 0.30 per cent for B10 and 0.80 per cent for B20, lower than diesel. Exhaust gas temperature with B10 and B20 were higher than diesel. Nitric oxide was observed for diesel, B10 and B20 were 123.22, 130.74 and 134.70 ppm respectively. Carbon dioxide concentration was reduced by 5.28 and 6.48 per cent for B10 and B20 respectively than diesel. Carbon monoxide concentration of B10 as 0.082 per cent and B20 as 0.080 per cent were observed as compared to 0.10 per cent of diesel.

Keywords: Bio diesel, B10, B20, Trans esterification, CI engine

1. Introduction
The increased industrialization and motorization of the world in recent years has resulted in great demand for petroleum products. Petroleum is the largest single source of energy, which has been consuming by the world's population, exceeding the other energy resources such as natural gas, coal, nuclear and renewable. About 90% of energy consumption of the world is from petroleum fuels. Petroleum based fuels are obtained from limited reserves and estimated to last only for new decades (Velmurugan and Gowthamn, 2012) [12]. However, because of their non-renewable nature, these fossil fuels are projected to be exhausted in the near future. The main consumers of energy are the electricity generation and transportation sectors. The diesel engine forms a vital part of both of these sectors throughout the world.
Increasing fossil oil prices, limited reserves of fossil fuels and environmental concerns have boosted the research on alternative fuel sources such as biodiesels. Moreover, the combustion of these fuels has polluted the environment. Because of increasingly reduction of fossil-based sources and their negative effects on the environment, the importance of alternative energy sources has become more apparent. Biodiesel was found as the best alternate fuel, technically and environmentally acceptable and easily available. Bio-diesel is methyl or ethyl ester of fatty acid from fresh or used vegetable oil and animal fats. For certain reasons, which include its properties, *Jatropha Curcas* oil (Ratanjot) ester are often used, as a synonym for bio-diesel in India, as has been the case with rapeseed oil methyl ester (RME) in Europe (Pathak, 2004) [7]. The usage of straight vegetable oil as fuel causes the coking of injector nozzles,

piston ring sticking, crankcase oil dilution, lubricating oil contamination, and other problems.

The use of clean and renewable fuels may be the key to overcome emission regulations without significant changes in engine efficiency and fuel economy. Pure biodiesel fuel (ester-based oxygenated fuel) and blends of biodiesel/diesel fuel have been used in compression ignition (CI) diesel engines without any engine modification. Biodiesel fuel is produced from renewable resources like vegetable oil or animal fat; it is biodegradable and has beneficial effects on engine exhaust emissions as compared to diesel fuel. It was also reported that besides being a renewable and domestic resource, biodiesel blends reduce most emissions while engine performance and fuel economy are nearly identical when compared to conventional fuels. Regarding exhaust emission, the use of biodiesel results in lower emissions of unburnt hydrocarbons; carbon monoxide, smoke and particulate matter with some increase in emissions of NO_x (Tsolakis and Megaritis, 2004) [9].

2. Materials and methods

The performance of a compression ignition engine was studied using biodiesel blends. The experiment was conducted in the College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

2.1 Experimental set up and Performance measurement

The set up would comprise of one engine testing rig with power measurement device, exhaust gas temperature sensors fitted at different places and one digital exhaust gas analyzer. The engine was installed on the platform. In the foundation, holes were drilled with hand drill so that engine can be fixed with nails/studs. Initially wooden block are to be placed between engine and platform to absorb the socks and vibration. The proper alignment of the engine would be made and nails/studs are to be fixed properly around the engine to minimize vibration. The engine was connected to overhead water supply tank for cooling of the engine.

The setup consisted of single cylinder, four stroke engine connected to water-cooled eddy current type dynamometer for loading. It provided necessary instrument for combustion pressure, crank-angle, airflow, fuel flow, water flow, temperatures and load measurement. These signals are interfaced to computer through high-speed data acquisition device. Data acquisition can be described as the process of sampling signals that measure real world physical conditions, like data signals sent from the sensors of an experimental setup; and then converting the resulting samples into digital numeric values that can be manipulated by an attached computing source based on the relations fed into it or as pre-programmed by the manufacturer. Data acquisition systems (DAS) typically convert analog waveforms into digital values for processing. DAS products centrally connect all the components together, such as sensors that indicate temperature, flow, performance, combustion parameters etc. The average data of the pressure and crank angle values, occurrence of the peak pressure, maximum rate of pressure rise and heat release rate were recorded by the DAS and stored in the computer as HTML files. This data acquisition software is developed by Technical Teaching (D) Equipment's Pvt. Ltd.

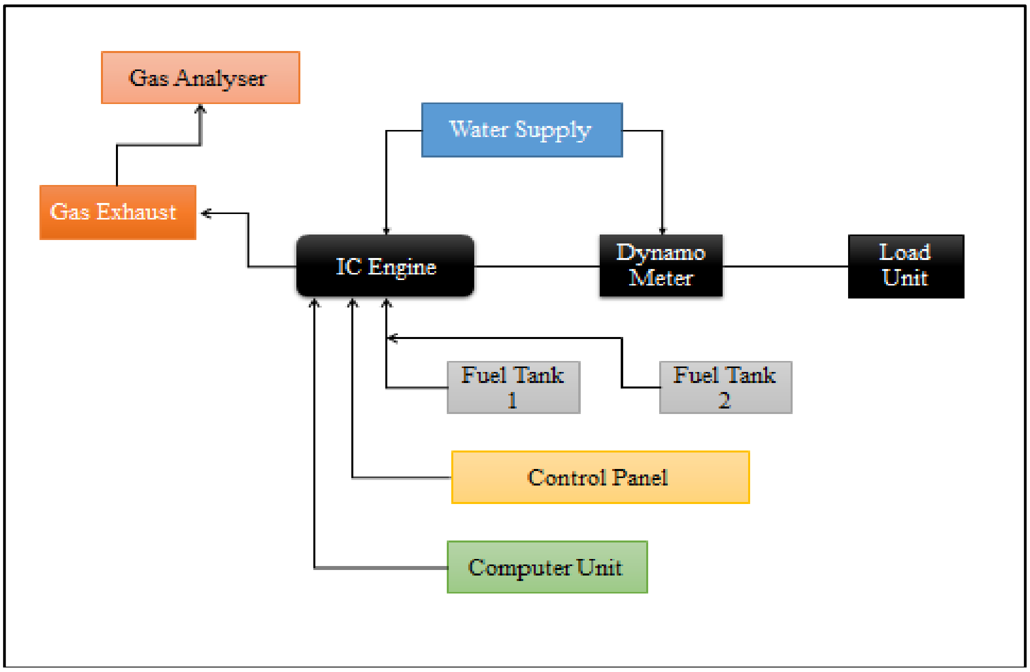

Fig 1: Experimental set up

The engine performance and emission test was conducted using diesel fuel for comparison with blends of methyl and ethyl esters of Jatropha oil. The diesel fuel was allowed to come down to the burette through a valve attached to the tank. The engine was hand cranked and started with a care having that a fixed amount of water was passing through the cooling system of the engine. The engine was allowed to warm up and achieve its operating temperature at no load. The operating temperature would be observed with the help of temperature sensors mounted at the water jacket out let. As the operating temperature is achieved, the engine was loaded with full load. Then again, the warm up time would be given to achieve operating temperature and by the time all the heaters specified for the load were at their full gleam. Thereafter the observations for the dependant parameters for performance and emissions were recorded by means of specified instruments i.e. performance measurement unit, exhaust gas analyser.

Fig 2: Pure bio diesel and petroleum diesel fuel

2.2 Engine performance parameters
2.2.1 Volumetric efficiency (%)
It is the ratio of actual weight of air introduced by the engine on the suction stroke to the theoretical weight of air that should have been introduced by filling the piston displacement volume with air at atmospheric pressure and temperature.

2.2.2 Specific fuel consumption (kg/kW-h)
Specific fuel consumption designated as SFC is the quantity of fuel consumed per kW h in an engine.
Specific fuel consumption = Total fuel consumption / Power output

$$SFC = \frac{TFC}{P}$$

Where,
SFC = Specific fuel consumption (kg/kW-h)
TFC = Total fuel consumption (kg/h)
P = Power output (kW)

2.2.3 Brake power (kW)
Power developed by the engine using the diesel fuel and blend fuels under test was calculated from the observed values of current and voltage developed by the generator attached to the engine.

$$Bp = \frac{V \times I}{1000}$$

Where,
V = Voltage (V) and
I = Current (A)

2.2.4 Brake thermal efficiency (%)

$$\text{Brake thermal efficiency (\%)} = \frac{\text{brake power (kW)}}{\text{power value of fuel (kW)}} \times 100$$

2.2.5 Indicated power (kW)

$$\text{Indicated power (ip)} = \frac{\text{PLAn}}{60 \times 10^{12}} \times \frac{x}{2}$$

Where,
P = Mean effective pressure (Pa)
L = Length of stroke (mm)
A = Cross sectional area of piston (mm^2)
n = Engine speed (rev/min)
x = Number of cylinder

2.2.6 Mechanical efficiency (%)

$$\text{Mechanical efficiency } (\eta_{mech}) = \frac{bp}{ip} \times 100$$

Where,
bp = Brake power (kW)
ip = Indicated power (kW)

2.2.7 Indicated mean effective pressure (IMEP)

$$IMEP = \begin{pmatrix}\text{Avg. pressure during} \\ \text{power stroke } (Pa)\end{pmatrix} - \begin{pmatrix}\text{Avg. pressure during} \\ \text{other stroke } (Pa)\end{pmatrix}$$

2.2.8 Brake mean effective pressure (BMEP)

$$BMEP\ (Pa) = \frac{bp \times 60 \times 10^{12}}{L \times A \times n \times \frac{x}{2}}$$

Where,
bp = Brake power (kW)
L = Length of stroke (mm)
A = Cross sectional area of piston (mm^2)
n = Engine speed (rev/min)
x = Number of cylinder

2.3 Exhaust gas analyser and Emission measurement
Exhaust gas analyser (PRIMA FEM-55), which measures the concentration of the exhaust gases in parts per million (ppm) or percentage and temperature in °C. They are microprocessor based, and can store real time data with which can later be either printed or copied to a computer disk for long time storage. The measurements were made under all the selected load conditions and different biodiesel blends. The heart of the instrument is an electrochemical sensor, which converts the concentration of gas encountered around it into an electrical signal, which was sensed by the instrument, amplified, compensated and displayed in terms of percentage on the LCD. Temperature of exhaust gas was measured by a thermocouple.

2.3.1 Engine emission parameters
The engine emission parameters Exhaust gas component and exhaust gas temperature were measured using exhaust gas analyzer. In which CO_2 and CO ware measured in percent. While NO and exhaust gas temperature was measured in ppm and °C respectively.

3. Results and disscusion
3.1 Performance of CI engine using biodiesel blends
3.1.1 Effect of various blend on volumetric efficiency of CI engine
From Fig. 3 it is clear that as percentage of biodiesel is increased in blend, volumetric efficiency was found to be decreasing successively.

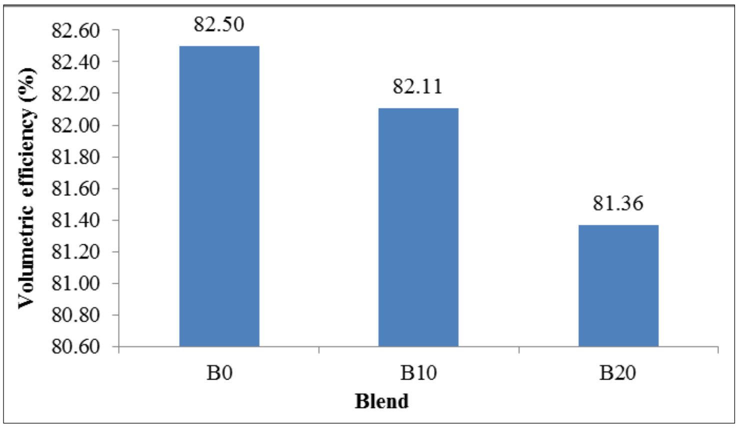

Fig 3: Effect of different blend on volumetric efficiency

3.1.2 Effect of various blends on specific fuel consumption of CI engine

Effects of different fuel blends on specific fuel consumption are shown in Fig. 4. As percentages of biodiesel were increased in blend, specific fuel consumption was found to be increasing as compared to diesel fuel.

Specific fuel consumptions for biodiesel are higher than diesel fuel due to the lower calorific values of Jatropha biodiesel as compared to diesel fuel. In case of biodiesel and its blends with diesel fuel, diesel engine consumes more fuel than diesel fuel to develop the same power (Agarwal and Agarwal, 2007) [1].

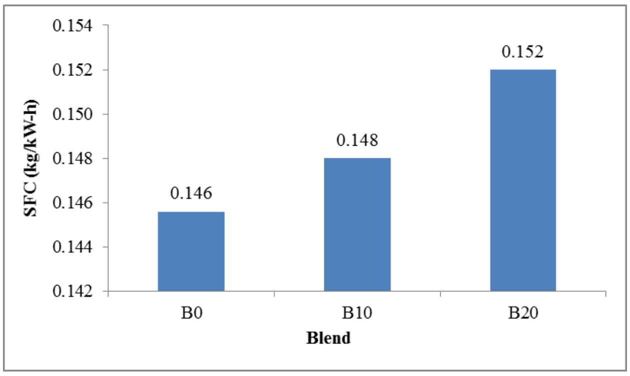

Fig 4: Effect of various blends on specific fuel consumption

3.1.3 Effect of various blends on brake power of CI engine

Fig. 5 reveals effects of variation in biodiesel blends on brake power. As percentage of biodiesel is increased in blend, brake power was found to be lowering than that of pure diesel fuel. This may be due to lower spray characteristics of biodiesel blend, improper mixing of fuel–air and incomplete combustion occurred due to higher density of biodiesel blend as compare to pure diesel (B0) (Nagaraja *et al.*, 2015) [6].

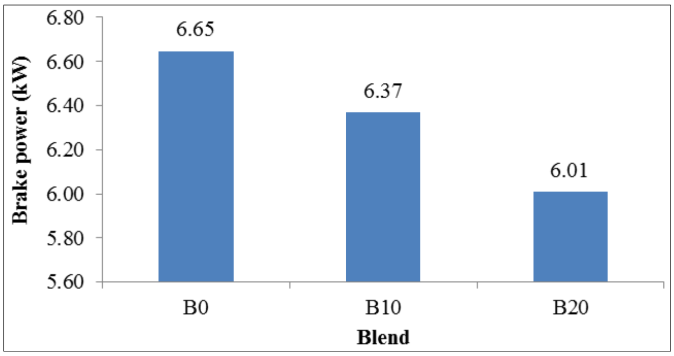

Fig 5: Effect of various blends on brake power

3.1.4 Effect of various blends on brake thermal efficiency of CI engine

Brake thermal efficiency is slightly lower for biodiesel blends B10 and B20 compared to blend B0 (Pure diesel) fuel at full load shown in Fig. 6. This drop in brake thermal efficiency for biodiesel blends was due to the poor combustion characteristics of biodiesel due to lower calorific value, higher density, higher viscosity and poor volatility of biodiesel blends as compared to diesel fuel (Patnaik *et al.*, 2015) [8].

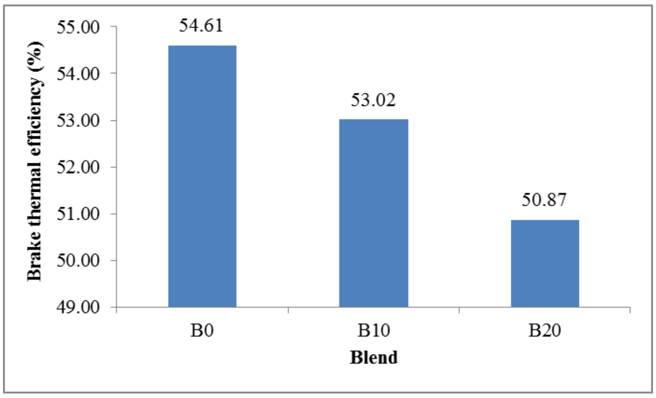

Fig 6: Effect of various blends on brake thermal efficiency

3.1.5 Effect of various blends on indicated power of CI engine

Fig. 7 shows as percentage of biodiesel is increased in blend, indicated power was found to be lowering than that of pure diesel fuel. This may be due to lower spray characteristics of fuel, improper mixing of fuel–air and incomplete combustion occurred due to higher density of biodiesel blend as compare to pure diesel (Nagaraja *et al.*, 2015) [6].

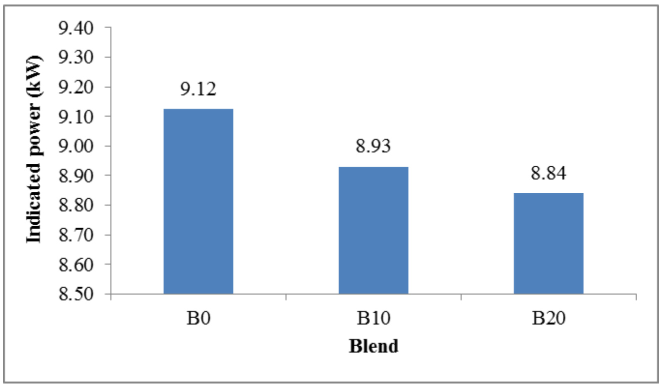

Fig 7: Effect of various blends on indicated power

3.1.6 Effect of various blends on mechanical efficiency of CI engine

As percentage of biodiesel is increased in blend, mechanical efficiency was found to be increasing successively which is represent in Fig. 8. Reason behind the increment of mechanical efficiency was lubrication effect due to higher glycerol content into biodiesel than that of diesel fuel.

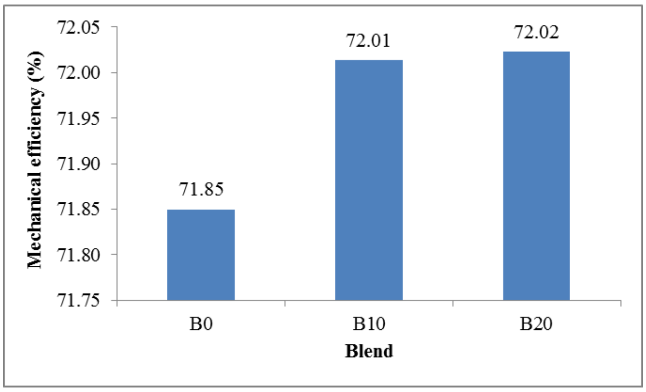

Fig 8: Effect of various blends on mechanical efficiency

3.1.7 Effect of various blends on indicated mean effective pressure (IMEP) of CI engine

As a percentage of biodiesel is increased in blends, indicated mean effective pressure was decreased continuously due to lower volatility of biodiesel than that of pure diesel (Attard *et al.*, 2007) [2].

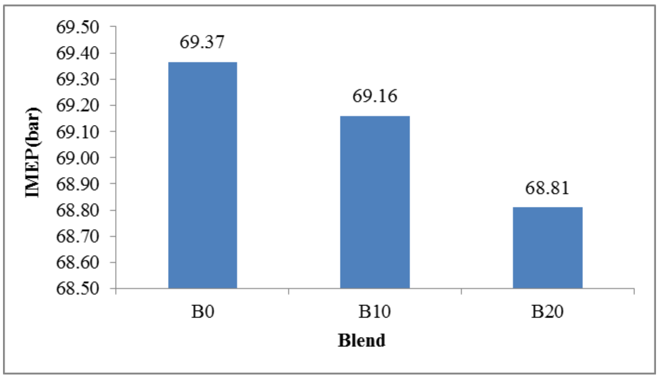

Fig 9: Effect of various blends on IMEP

3.1.8 Effect of various blends on brake mean effective pressure (BMEP) of CI engine

Brake mean effective pressure (BMEP) of diesel fuel is higher than biodiesel blend (Fig. 10) due to higher combustion characteristics and higher volatility of diesel fuel (Attard *et al.*, 2007) [2].

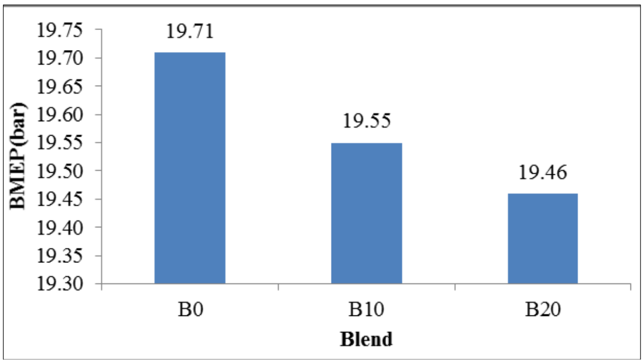

Fig 10: Effect of various blends on BMEP

3.2 Emission characteristics of CI engine using biodiesel blends

3.2.1 Effect of various blends on carbon dioxide (CO_2) emission of CI engine

From Fig. 11, as percentage of biodiesel is increased in blend, carbon dioxide (CO_2) emission was found to be decreasing successively. CO_2 emission indicates that how efficiently fuel is burnt in the combustion chamber of a diesel engine. Since the biodiesel blend fuel burns more efficiently than diesel due to higher oxygen content in biodiesel (Hulwan and Joshi, 2011) [5].

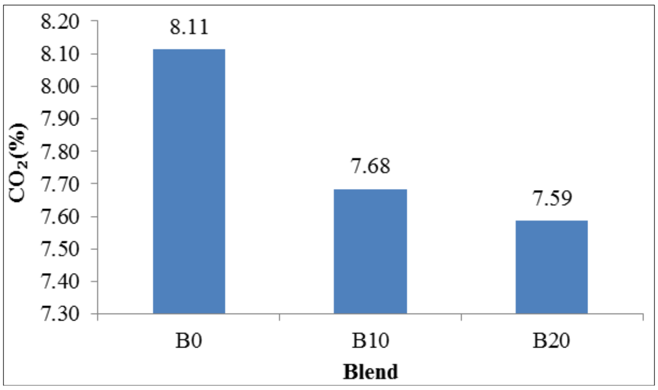

Fig 11: Effect of various blends on CO_2 emission

3.2.2 Effect of different blend on carbon monoxide (CO) emission of CI engine

Lower carbon monoxide emissions of biodiesel blends may be due to more availability of oxygen leads to complete oxidation as compared to diesel. Carbon monoxide produced during combustion of biodiesel blends might have converted into CO_2 by taking up the extra oxygen molecule present, thus reduced carbon monoxide formation (Ganapathy *et al.*, 2011) [4].

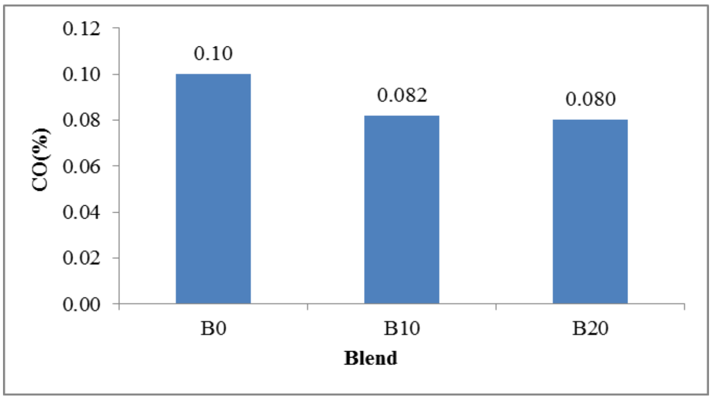

Fig 12: Effect of various blends on CO emission

3.2.3 Effect of various blends on nitric oxide (NO) emission of CI engine

Fig. 13 shows the effect of different fuel blends on nitric oxide (NO) emission. As percentage of biodiesel increased as fuel in blend, nitric oxide (NO) emission was found to be increasing as compare diesel fuel.

The higher temperatures of combustion and the presence of fuel oxygen with the blend combustion caused higher NO emissions, especially at medium engine speed (around engine speed of 1500 rpm) (Ganapathy *et al.*, 2011) [4].

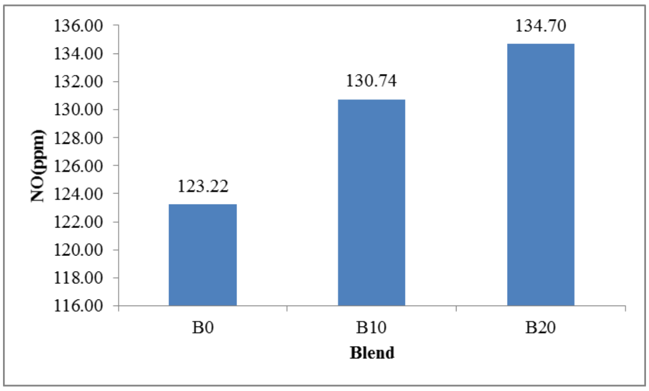

Fig 13: Effect of various blends on NO emission

3.2.4 Effect of various blends on exhaust gas temperature of CI engine

From Fig. 14 it is clear that, as percentage of biodiesel increased as fuel in blend, resultant exhaust gas temperature was found to be increasing as compare diesel fuel.

Because of the poor combustion characteristics, a higher exhaust gas temperature was recorded for biodiesel blends compared to fossil diesel for the entire engine load. This may be due to higher temperature inside the engine cylinder as more fuel is burnt to meet the higher load demand (Buyukkaya, 2010) [3].

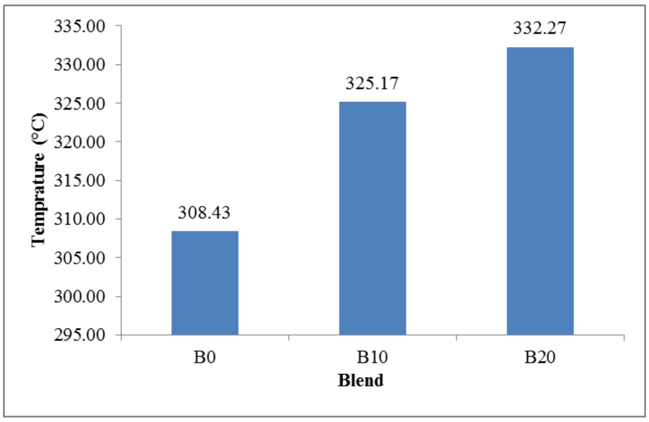

Fig 14: Effect of various blends on exhaust gas temperature

4. Conclusions

The major conclusions drawn from this experiment were;

1. Diesel as a fuel gave maximum volumetric efficiency of 82.5%, While B10 fuel gave minimum volumetric efficiency of 82.11%.
2. B20 blend as a fuel gave maximum specific fuel consumption of 0.152 kg/kW-h. Biodiesel blend B0 containing only diesel as fuel gave minimum *i.e.* 0.146 kg/kW-h specific fuel consumption.
3. B20 blend as a fuel gave least brake power of 6.01 kW. Biodiesel blend B0, means pure diesel as a fuel gave maximum 6.65 kW brake power.
4. Diesel as a fuel gave maximum brake thermal efficiency of 54.61%, while biodiesel blend B20, gave minimum *i.e.*, 50.87% brake thermal efficiency.
5. B20 blend as a fuel gave minimum indicated power of 8.84 kW. Biodiesel blend B0, means diesel as a fuel gave maximum indicated power of 9.12 kW.
6. Diesel as a fuel gave minimum mechanical efficiency of 71.85%. Biodiesel blend B20 gave maximum *i.e.*, 72.02% mechanical efficiency.
7. Biodiesel blend B0 gave maximum indicated mean effective pressure (IMEP) of 69.37 bar. Biodiesel blend B20 as a fuel gave minimum *i.e.*, 68.81 bar indicated mean effective pressure (IMEP).
8. Blend B0 as a fuel gave maximum brake mean effective pressure (BMEP) of 19.71 bar, while B10 as a fuel gave minimum *i.e.*, 19.55 bar.
9. Diesel as a fuel gave maximum carbon dioxide (CO_2) emission of 8.11%, while B20 was gave 7.59%.
10. Diesel as a fuel gave maximum carbon monoxide (CO) emission of 0.10%. Biodiesel blend B20 as a fuel gave minimum of 0.080% carbon monoxide (CO) emission.
11. Diesel as a fuel gave minimum nitric oxide (NO) emission of 123.22 ppm, while B20 gave maximum *i.e.*, 134.70 ppm.
12. Diesel as a fuel gave minimum exhaust gas temperature of 308.43 °C. B20 blend as a fuel gave maximum *i.e.*, 332.27 °C.

5. Acknowledgement

Junagadh Agricultural University, Junagadh and Department of Farm Machinery and Power Engineering are gratefully acknowledged.

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