International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal
ISSN No: 2456 - 6470 | www.ijtsrd.com | Volume - 2 | Issue – 4

Performance and Emissions Analysis of VCR Engine Using Waste Mustard Cooking Oil

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ABSTRACT

Biodiesel is an alternative to conventional petro diesel fuel. It can be produced by vegetable oils and animal fats. In addition, it can also be produced by waste cooking oils. The main limitation of biodiesel production is that it can cause food shortage and can lead to heavy use of fertilizers and water which deplete the natural resources, soil and water. Using waste cooking oil as a raw material for biodiesel would overcome these limitations and would also avoid the problem of disposal of these waste oils.

In this study, transesterification process is performed on waste cooking oil (mustard oil), to produce biodiesel as a product. Following this, biodiesel is blended with normal diesel fuel to produce blends having biodiesel concentration of 6%, 12% and 18%, hereby referred as B6, B12 and B18. These blends are tested on performance and emissions parameters at different loads on a VCR diesel engine. B12 gave the best suitable outcomes on brake thermal efficiency, specific fuel consumption and mechanical efficiency while B18 gave better volumetric efficiency. NOx, unburnt hydrocarbons, CO and CO2 emissions were the most optimal in case of B12.

Keywords: *Biodiesel, transesterification, VCR diesel engine*

1.0 INTRODUCTION

India is the seventh largest country in the world and a home to a rapidly growing population of 132.42 crores (Census 2016). According to Ministry of Road Transport and Highways, the number of registered motor vehicles per 1000 people was 53 in 2001 and within a decade it rose past 100 in the year 2010. This value rose to 157 per 1000 people in 2015. This clearly implies that there is an increase in the vehicles which has posed an increasing need for petrol and diesel fuels. Also, India is the world's 4th largest energy consumer; oil and gas account for 35.61 per cent of total energy consumption in India. Demand for primary energy in India is to increase 3-fold by 2035 to 1,516 million tonnes of oil. This data has been published by IBEF (Indian Brand Equity Foundation). Thus it is clear that there is a need for an economical alternative energy resource for engines owing to the depletion of fossil fuels at an alarming rate. Many developed countries have started using biofuels as an alternative to conventional fuels as they resolve the crucial problem of fast depleting conventional resources and are also economical.[1] As per the data obtained from US Department of Agriculture, India produced 1.596 MT of mustard oil in 2014-15, 1.862 MT in 2015-16 and 2.166 MT in 2016-17. Consumption of mustard oil in India has grown about 5% per year for the past 40 years and stands at a current value of 2.3 MT per year. Consumption data across various classes suggests that mustard oil is a major part of Indian households and is also used commercially for cooking [2]. After use in cooking around 5-15% of this oil becomes a waste and in the absence of proper disposal media, it is thrown away in drains or open grounds, causing various environmental problems. This waste cooking oil (WCO) can be used to produce biodiesel by using the process of transesterification. According to Sudhir, Sharma and P. Mohanan [3] the biodiesel derived from a WCO is the greenest liquid fuel available because the feedstock is a post consumption waste product. Moreover, biodiesel produces lower HC and NOx emissions owing to high oxygen content and lower flame temperature, thus are ideal to use in India which is the world's third largest greenhouse gas emitter.[4][5]

In India, most of the work pertaining to biodiesel has been done using Jatropha oil, Soyabean oil and other vegetable oils as the feedstock. This work uses waste cooking oil (mustard). Also the blend percentages used are 6%, 12% and 18% rather than conventional 10%, 20% and 30%.

2. BIODIESEL PRODUCTION AND BLENDING

This work employed the process of transesterification using KOH and methanol to produce biodiesel from waste mustard oil leaving glycerol as the by-product of the reaction.

2.1 Properties of mustard oil used:

Chemical name - Mustard Oil Tributyltin
Molecular formula – $C_{13}H_{29}NSSn$
Molecular weight – 350.152 g/mol

2.2 Calculations for experiment (per 100 g of mustard oil):

Ratio of triglyceride to ethanol used here is 1:6.
Molecular mass of mustard oil = 350.152 g/mole
Mass of mustard oil used = 100 g
Molecular mass of methanol = 32 g/mole
Mass of ethanol required = 78.823 g

2.3 Comparison of properties of biodiesel obtained from WCO (mustard) with diesel

Properties	Diesel	Biodiesel
Calorific value (kcal/kg)	11,185	7,385
Density at 15°C (kg/m^3)	832	880
Viscosity at 40°C (cSt)	4	4.7

Table 1. Properties of diesel and biodiesel (comparison)

2.4 Blending of Biodiesel

Biodiesel obtained was blended with diesel, keeping biodiesel concentration at 6%, 12% and 18% by volume. The properties of blends thus obtained are discussed below. (Table 2)

Blend	Density (kg/m^3)	Calorific value (kcal/kg)
B6	834.88	10944.655
B12	837.76	10706.008
B18	840.64	10468.974

Table 2. Properties of blends of biodiesel

3. PERFORMANCE OF BIODIESEL BLENDS

The biodiesel blends B6, B12 and B18 were tested for performance on Brake Power (BP), Specific Fuel Consumption (SFC), Brake Thermal Efficiency (BTE), Exhaust Gas Temperature (EGT), Volumetric Efficiency and Mechanical Efficiency. The specifications of the engine on which these processes were carried out are discussed in Table 3.

Type of engine	Variable Compression Ratio
Number of cylinders	1
Number of strokes	4
Cylinder diameter	87.5mm
Stroke length	110mm
Connecting rod length	234mm
Orifice diameter	20mm
Dynamometer arm length	185mm
Strokes	4

Table 3. Testing engine specifications

3.1 BRAKE POWER (BP)

Change in Brake Power is plotted for diesel and all three blends of biodiesel B6, B12 and B18. At no load condition all three blends and diesel give same brake power and at higher loads diesel attains a higher value of BP. At full load B6 is closest to diesel when BP is considered. Figure 3.1 illustrates the change in brake power w.r.t. brake mean effective pressure. The percent difference in value of BP of diesel and B6 at full load is 2.285% being the least among all three blends. B6 is the most optimum blend pertaining to brake power.

3.2 BRAKE THERMAL EFFICIENCY (BTE)

A graph is plotted for brake thermal efficiency versus brake mean effective pressure (Figure 3.2). This plot shows that the brake thermal efficiency increases with increase in load. At low load, diesel has least mechanical efficiency and all the three blends have almost same value of mechanical efficiency. B18 is closest to diesel when BTE is considered. The percent difference in value of BTE of diesel and B18 at full load is 0.93% being the least among all three blends.

3.3 SPECIFIC FUEL CONSUMPTION (SFC)

We tested the blends obtaining a graph between SFC and BMEP (Figure 3.3). This lot showed that at lower BMEP diesel has the highest SFC however, there is a decrease in SFC with an increase in BMEP. At full load B12 is closest to diesel when SFC is considered. The percent difference in value of SFC of diesel and B12 at full load is 3.448%, being the least among all three blends.

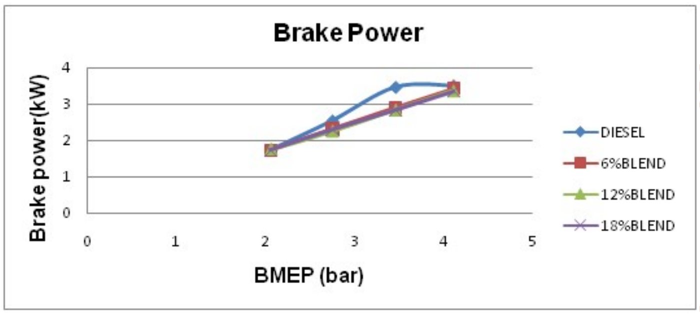

Figure 3.1 Brake power vs. Brake mean effective pressure

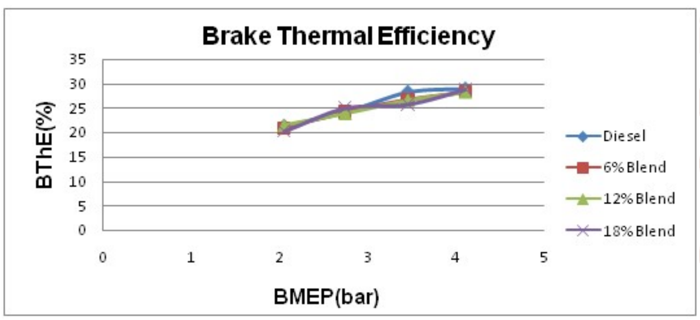

Figure 3.2 Brake thermal efficiency vs. Brake mean effective pressure

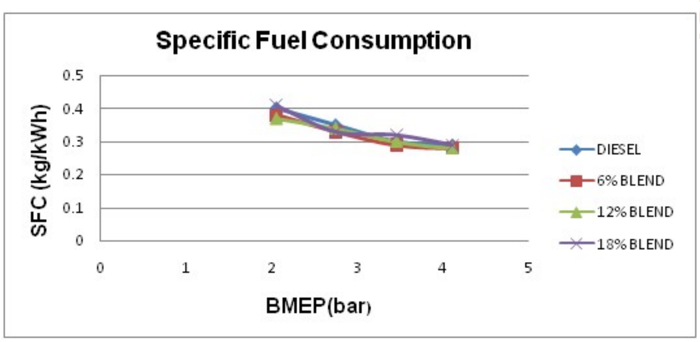

Figure 3.3 Specific fuel consumption vs. Brake mean effective pressure

3.4 MECHANICAL EFFICIENCY

Upon testing of the blends on the VCR engine, a graph was plotted between mechanical efficiency and brake mean effective pressure (Figure 3.4). As BMEP increases mechanical efficiency increases for all the blends as well as for diesel. At low load, diesel has least mechanical efficiency and all the three blends have almost same value of mechanical efficiency. At full load B12 is closest to diesel when mechanical efficiency is considered. The percent difference in value of mechanical efficiency of diesel and B12 at full load is 1.083% being the least among all three blends.

3.5 EXHAUST GAS TEMPERATURE

A plot was made between the values of exhaust gas temperature obtained for the three blends B6, B12 and B18 as well as diesel at different loads (Figure 3.5). EGT is decreasing with increase in quantity of biodiesel in the mixture. With increase in BMEP, EGT increases for all blends as well as for diesel. As the load on the engine increases, more fuel is burnt. So, EGT increases continuously with rise in load. At full load B18 is giving highest positive difference of 7.0923% at full load when compared to diesel. Thus, B18 is optimum among all three blends.

3.6 VOLUMETRIC EFFICIENCY

A graph is plotted between Mechanical efficiency versus Brake mean effective pressure, for all three blends and diesel. It is almost same for all 3 blends and is slightly greater for diesel at different loads. As BMEP increases, volumetric efficiency decreases. At higher loads diesel has least and B18 has highest value of volumetric efficiency. At full load B18 is giving highest negative difference of 0.634% at full load when compared to diesel. Thus, B18 is optimum among all three blends. (Figure 3.6)

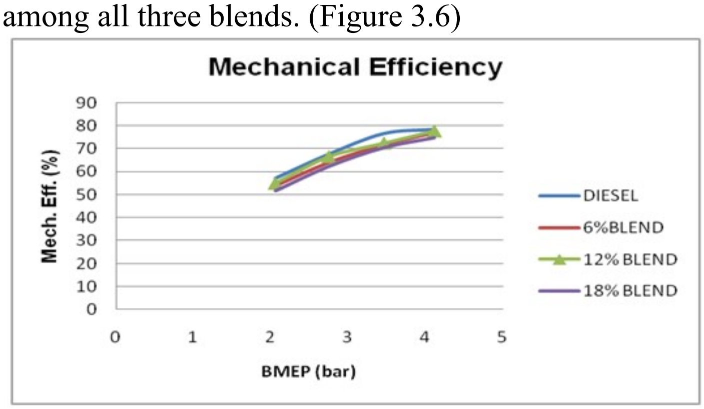

Figure 3.4 Mechanical efficiency vs. Brake mean effective pressure

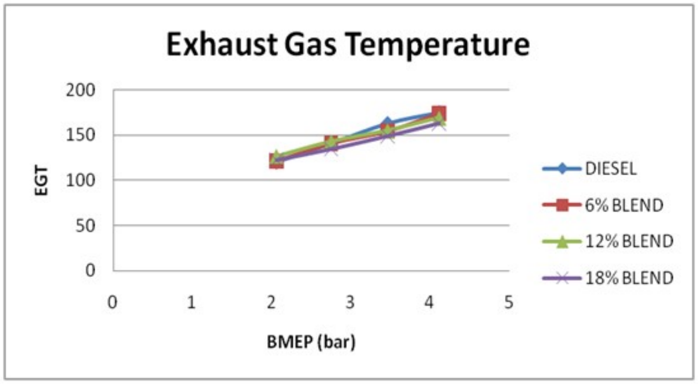

Figure 3.5 Exhaust gas temperature vs. Brake mean effective pressure

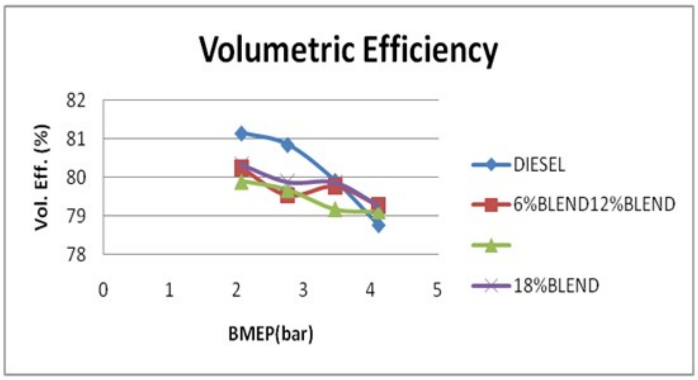

Figure 3.6 Volumetric efficiency vs. Brake mean effective pressure

4. EMISSIONS OF BIODIESEL BLENDS

Emissions analysis was done taking into account Carbon Monoxide (CO), Nitrogen Oxides (NOx), Unburnt Hydrocarbons (HC) and Carbon Dioxide (CO_2) emissions from the testing engine. Single cylinder 4- stroke VCR diesel engine with 3.5kW power and 1500rpm speed is used.

4.1 CARBON MONOXIDE

Diesel has higher CO emissions as compared to all three bends, at all loads. The main reason for this is that due to extra oxygen present in the biodiesel than normal diesel fuel. At no load, B12 having the minimum CO emissions, being 26.351% less than that of diesel. At full load also, B12 is having least CO emissions, being 12.979% less than that of diesel. A plot of CO emissions by biodiesel and diesel at various loads is illustrated in Figure 4.1.

4.2 UNBURNT HYDROCARBONS

Biodiesel blends show a reduction in the amount of unburnt hydrocarbons owing to extra amount of oxygen content present in biodiesel as compared to diesel fuel. A plot of unburnt hydrocarbons present in the emissions of biodiesel blends and diesel, at different loads, is shown in Figure 4.2. At no load B18 and diesel are having almost same emissions. As load increases, HC emissions also increase. For unburnt HC at full load B12 is giving highest positive difference of 21.739% when compared to diesel.

4.3 NITROGEN OXIDES

There is a reduction in the values of nitrogen oxide emissions on using biodiesel fuels, the reason being the low flame temperature of biodiesel and its blends. A graph showing the NOx emissions of various blends and diesel, at different loads, is shown in Figure 4.3. As load increases, NOx emissions increase. At all load B12 is giving least Nox emissions. At full load, for Nox B12 is giving highest percent difference of 5.984% when compared to diesel.

4.4 CARBON DIOXIDE

At full load for CO, B12 is giving highest positive difference of 5.0147% when compared to diesel at full load. At no load B12 is giving highest positive difference of 26.351% (among all three blends) when compared to diesel. A graph showing the change in CO_2 emissions w.r.t different blends at different loads is shown in Figure 4.4.

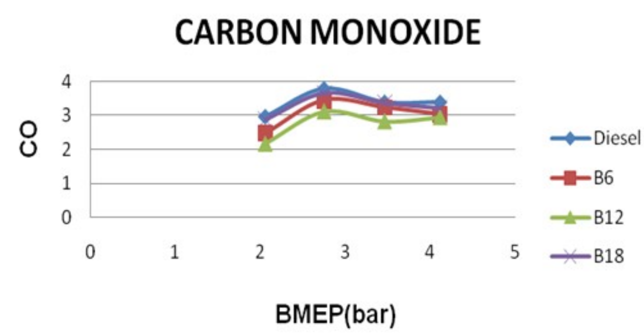

Figure 4.1 Carbon monoxide emissions vs. Brake mean effective pressure

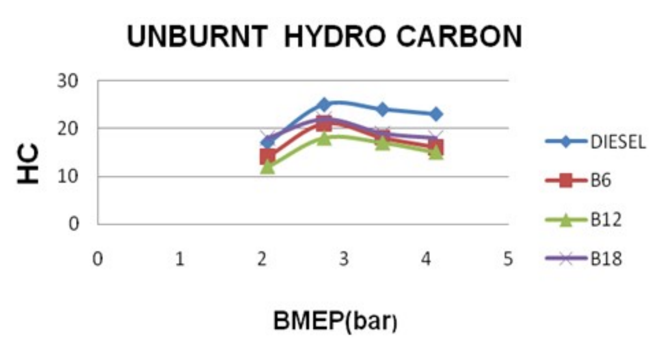

Figure 4.2 Unburnt HC emissions vs Brake mean effective pressure

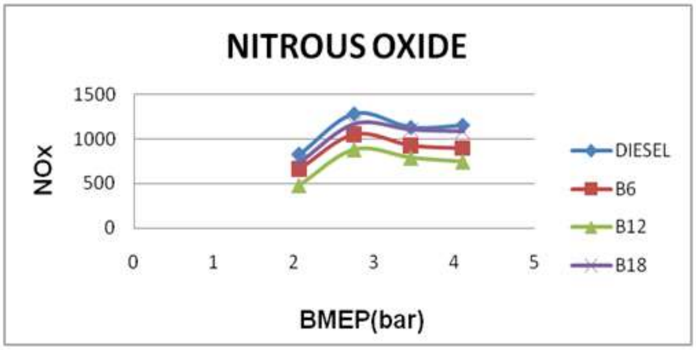

Figure 4.3 Nitrous oxide emissions vs. Brake mean effective pressure

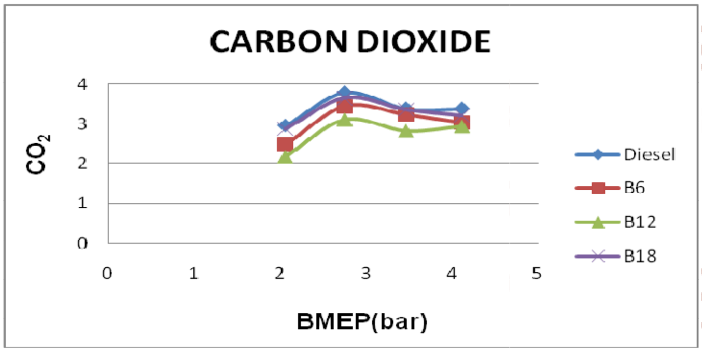

Figure 4.4 Carbon Dioxide emissions vs. Brake mean effective pressure

5. CONCLUSION

The overall studies based on the production, engine performance and exhaust emission of waste mustard biodiesel were carried out. The following conclusions can be drawn:

- The kinematic viscosity of diesel is 4cSt and that of waste mustard oil biodiesel is 4.7 cSt at 40 degree Celsius. The results indicated that the waste mustard biodiesel had the kinematic viscosity 17.5 percent more than that of diesel.
- The calorific value of diesel & waste mustard biodiesel were found as 11,185 & 7,385 kCal/kg respectively. The calorific value of waste mustard biodiesel is lesser by 33.974% than that of diesel.
- The waste mustard biodiesel was found to have higher flash and fire point than those of diesel.
- Waste mustard biodiesel is found to be non-toxic, biodegradable, environment-friendly, renewable and does not add as much to global warming as diesel.
- At full load B18 is closest to diesel when BTE is considered. The percent difference in value of BTE of diesel and B18 at full load is 0.93% being the least among all three blends.
- At full load B6 is closest to diesel when BP is considered. The percent difference in value of BP of diesel and B6 at full load is 2.285% being the least among all three blends.
- At full load B12 is closest to diesel when SFC is considered. The percent difference in value of SFC of diesel and B12 at full load is 3.448% being the least among all three blends.
- At low load, diesel has least mechanical efficiency and all the three blends have almost same value of mechanical efficiency. At full load B12 is closest to diesel when mechanical efficiency is considered.
- The percent difference in value of mechanical efficiency of diesel and B12 at full load is 1.083% being the least among all three blends.
- For exhaust gas temperature at full load B18 is giving highest positive difference of 7.0923% at full load when compared to diesel. Thus, B18 is optimum among all three blends.
- For volumetric efficiency at full load B18 is giving highest negative difference of 0.634% at full load when compared to diesel. Thus, B18 is optimum among all three blends.
- At no load, B12 having the minimum CO emissions, being 26.351% less than that of diesel. At full load also, B12 is having least CO emissions, being 12.979% less than that of diesel.
- For unburnt HC at full load B12 is giving highest positive difference of 21.739% when compared to diesel.
- At loads B12 is giving least NOx emissions. For NOx B12 is giving highest percent difference of 5.984% when compared to diesel.
- For CO, B12 is giving highest positive difference of 5.0147% when compared to diesel at full load. At no load B12 is giving highest positive difference of 26.351% (among all three blends) when compared to diesel.
- At all load B12 is giving least NOx emissions. At full load, for NOx B12 is giving highest percent difference of 5.984% when compared to diesel.
- At full load for CO, B12 is giving highest positive difference of 5.0147% when compared to diesel at full load. At no load B12 is giving highest positive difference of 26.351% (among all three blends) when compared to diesel.
- Use of 12% blends of waste mustard biodiesel as partial diesel substitutes can go a long way in conservation measure, reducing uncertainty of fuel

availability, reducing pollution and global warming and making more self-reliant.

- Legal framework should be there to enforce regulations on biodiesel-diesel blends fuel use.
- Energy education on biodiesel use and storage information and database for wider information dissemination among the public at large should be taken up.

6. REFERENCES

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