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Research Article

The Effect of Cyclo- Alkane Additives in Waste Cooking Oil (WCO) B20 fuel on a Single Cylinder DI Diesel Engine

George Varghese[Ȧ*] and P. Mohanan[Ḃ]

[Ȧ]Manipal Institute of Technology, Manipal, Karnataka, India
[Ḃ] National Institute of Technology Karnataka, Surathkal, Karnataka, India

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Abstract

Diesel engine combustion generates large amounts of oxides of nitrogen due to the presence of oxygen and nitrogen in the combustion chambers at high flame-temperatures. The main component of total cost of producing bio-diesel comprises the cost of raw materials. The use of a low cost feedstock such as Waste Cooking Oil (WCO) can help make biodiesel much cheaper than diesel derived from petroleum sources. Waste cooking oil, which is otherwise wasted, is one of the most economical choices to produce biodiesel (Menga, 2008). In this investigation, Cyclo- Pentane and Cyclo-Hexane were used as blend-components. The scope of this work also includes studies on various fuel-blends of B20 with varying percentages of blend-components, and comparisons to fossil-based diesel. The studies performed also include investigations on the emission characteristics of B20 with blend-components at different loading conditions. The tests performed indicate that the use of B20 with 1.5% cyclo-hexane as a blend-component, resulted in a significant reduction in NOx emissions by 4% when compared to fossil-based diesel, at a normal injection timing of 27.5º before-top dead-center (BTDC), at full-load conditions. It was also observed that the B20 blend with 1% cyclo-pentane possessed the lowest smoke opacity of/by 36% at full-load conditions.

Keywords: *Biodiesel, blend component, cyclo- alkane, emission, WCO, trans-esterification.*

1. Introduction

The world today, is witnessing an increased interest in the use of bio-diesel, and researchers are examining the possibility of using rapeseed oil, sunflower oil, coconut oil, peanut oil, soybean oil, honge (or karanja), Jatropha and sesame oil, and methyl esters (Prakash, 2010).

Diesel engines generally operate with an excess air-fuel ratio on full-load, generating large amounts of NOx in presence of abundant oxygen and nitrogen in the combustion chambers at high flame-temperatures. Increased environmental concerns and tougher emission norms require the development of advanced engine technologies to reduce NOx and particulate matter (PM) emissions.The scope and objectives of this study include:

- Selection of cyclo- alkane as additives
- Testing of fuel-properties of B20 blend produced using WCO, with the addition of various percentages of cyclo-pentane and cyclo-hexane.
- Investigation of the engine emission characteristics using data acquisition software, exhaust-gas analyzer and smoke-meter at various loads, and at three different injection timings.

Biodiesel can be prepared from WCO through the transesterification process. Transesterification is a process of transforming one form of ester into another ester. The reaction breaks the triglyceride vegetable oil molecule into three molecules of esters and one molecule of glycerin. The molecules of esters bond with alcohol to form three molecules of alkyl esters. When methanol is used as alcohol, the resulting alkyl esters after transesterification are called as methyl esters (Reliance, 2010). Further steps including distillation, remove the remaining water content and poorly water-soluble impurities such as unreacted feedstock, and mono and diglycerides (Steinbach, 2007). It is found that the smoke density and BSFC are slightly higher for vegetable oil blends compared to diesel. Vegetable oil blends show performance characteristics similar to diesel. Therefore, vegetable oil blends can be used in compression ignition engines. The performance and emission parameters for different fuel-blends are found to be very close to that of diesel (Yaun, 2008).

The bio-diesel prepared based on the trans-esterification process can be blended with fossil diesel to obtain B20 blend. Yuan et al (Shailendra, 2008) report that the calorific value of bio-diesel thus made, is lower than that of fossil diesel, and hence, the BSFC is greater by about 12%. (Davis, 2007) observes that as bio-diesel contains 11% oxygen, it has a lower heating-value than fossil-based diesel. If 100% biodiesel is used, then it is required to burn 5-6% more fuel volumetrically, in order to maintain the same level of power and performance in an engine (Chemical book, 2010). Murugesan observes that the use of biodiesel in a conventional diesel engine results

*Corresponding author: **George Varghese**

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in substantial reduction in un-burnt hydrocarbon (UBHC), carbon monoxide (CO), particulate matter (PM) emission, and oxides of nitrogen (NOx) (Murugesan, 2009).

It is also found that the use of iso- butanol based diesel fuel-blends result in decreased CO and NOX emissions. However, the hydrocarbon (HC) emissions were found to increase with the use of blended diesel (Indiane, 2010). In the present study, blends of bio-diesel with fossil-based diesel were investigated for flash and ignition points, kinematic viscosity, greater-calorific-value and emission characteristics.

Nomenclature

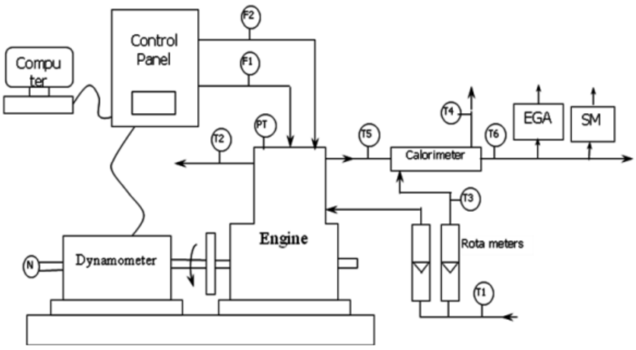
CV	Calorific Value
Inj. tim.	Injection timing
BTDC	Before top dead center
Deg.	degree
B20CPEN1	B20 + 1% Cyclo- Pentane
B20CPEN1.5	B20 + 1.5% Cyclo- Pentane
B20CHEX1	B20 + 1% Cyclo- Hexane
B20CHEX1.5	B20 + 1.5% Cyclo- Hexane

2. Experimental Setup

In this study, bio-diesel obtained by the trans-esterification of waste cooking oil (WCO), was blended volumetrically with petroleum-based diesel to get B20 diesel comprising 80% diesel and 20% bio-diesel. The fuel properties of the bio-diesel thus prepared were studied. The calorific value (CV) of the fuel-blend was found using the bomb-calorimeter. Subsequently, blend-components using various percentages of cyclo-hexane, and cyclo-pentane were prepared, and the fuel properties were tested. The fuel-properties recorded were then compared to those of fossil-based diesel.

The performance and emission tests were then conducted at the normal injection timing (inj. tim.) of 27.5º BTDC, at a constant speed of 1500 rpm, a normal injection pressure of 180bar, and a compression-ratio of 17.5. The data was monitored and recorded on-line, and was retrieved for further analysis. The experiments were conducted at no-load, 25%, 50%, 75% and full-load conditions.

In a similar manner, fuel samples of petroleum-based diesel, B20 diesel blended with 1% cyclo-pentane, (B20CPEN1), B20 diesel blended with 1.5% cyclo-pentane (B20CPEN1.5), B20 diesel blended with 1% cyclo-hexane (B20CHEX1), and B20 diesel blended with 1.5% cyclo-hexane (B20CHEX1.5) were tested.
Data such as, fuel flow, exhaust temperature, brake thermal efficiency, brake specific fuel consumption, exhaust-smoke opacity, NOx, CO, CO2, and UBHC emissions were recorded at the above mentioned load conditions. Steady state emission readings were taken for five trials, and the average of the recorded data was tabulated. Using this data, the emission characteristics of the diesel engine for different loads were compared and analyzed for various fuel samples.
The schematic diagram of the complete experimental setup for the diesel engine test rig is shown in Fig. 1. The tests were conducted on a computerized single cylinder four-stroke, naturally aspirated, direct-injection, constant-speed and water-cooled diesel engine test rig. It was directly coupled to an eddy current dynamometer. The engine and the dynamometer were then interfaced to a control-panel connected to a computer.



T1, T3 Inlet Water Temperature
T2 Outlet Engine Jacket Water Temperature
T4 Outlet Calorimeter Water Temperature
T5 Exhaust Gas Temperature before Calorimeter
T6 Exhaust Gas Temperature after Calorimeter
F1 Fuel Flow DP (Differential Pressure) unit
F2 Air Intake DP unit, PT Pressure Transducer
W Load, N RPM Decoder,
SM Smoke meter
EGA Exhaust Gas Analyzer (5 gas)

Fig. 1 Schematic Diagram of the Experimental Setup Parts of Fig. 1

2.1 Selection of Cyclo Alkanes as blend components

The oil-industry specifies an aromatic content of up to 48% in petrol, in order to check harmful emissions. However, petrol manufactured has an aromatic content greater than 50%, which is later moderated by using additional blend-components. Diesel in contrast, has a lower aromatic content of 30% and an aliphatic content of 70% (Fischer- tropch, 2010).

Generally, aromatic compounds like benzene are used as blend-components to petrol in order to improve fuel properties like calorific value, lubricity as well as the emission-characteristics. Similarly, it can be surmised that petroleum-based diesel fuels can be blended using aliphatic compounds with a chemical structure similar to that of benzene (C_6H_{12}). This led to the choice of an aliphatic compound such as cyclo-alkanes that have ring structure. Cyclo- Pentane occurs as a colorless liquid with a petrol-like odor. It is the most stable of all the cyclo-alkanes. Cyclo-hexane is a colorless and volatile liquid with a slightly pungent odor.

The engine was run at 1500 rpm, and was tested for one injection timing, and five loading-conditions. Five trials were conducted for each fuel sample.

3. Results and Discussions

Tests were performed for B20 blends with various percentages of cyclo-alkanes, for flash and ignition points, viscosity, and calorific value. The results are tabulated in Table1.

On comparing calorific value (CV) of B20CPEN1 to B20, it can be seen that the addition of 1% in volume of the blend-component cyclo-pentane (C5H10) to B20, resulted in a minor increase in the calorific value. This is associated with an increase in the kinematic viscosity (ν), and a significant reduction in the flash and ignition points.

Similarly, on comparing B20CPEN1.5 to B20, it can be seen that with the addition of 1.5% of C5H10, resulted in an increase in the calorific value by 4.29%, coupled with a considerable decrease in the flash and ignition points. This indicates that the flash and ignition points are likely to reduce to ambient temperature conditions with further addition of C5H10. But since this trend can cause catastrophic accidents, it was decided to limit the C5H10 content to 1.5%.

On the other hand, comparing B20CHEX1 to B20, the addition of 1% in volume of the blend-component cyclo-hexane (C_6H_{12}) to B20, resulted in a minor increase in the calorific value (CV), associated with an increase in the kinematic viscosity, and a significant reduction in the flash and ignition point's. Comparing B20CHEX1.5 to B20, it is seen that the addition of 1.5% C6H12 increased the CV by 2.61%. As the calorific value of the fuel is increased, the heat released during combustion also increases.

Considering the properties of B20CPEN1 and B20CPEN1.5, with respect to fossil-based diesel in Table1, it is observed that the flash point reduced by 3.57% and 14.29% respectively for the two blend-components. Similarly, considering the fuel properties of B20CHEX1 and B20CHEX1.5, with respect to fossil-based diesel, it is seen that the flash point increased by 3.45%, and reduced by 3.57% respectively for the two blend-components.

It may be interesting to note that the ignition point of B20 is 24.14% higher than that of fossil-based diesel. The reduction in the flash and ignition points is mainly due to the volatility of the blend-components used. Since the flash and ignition point of B20CPEN1.5 was very low, and almost close to that of room temperature, it was considered safe to limit the tests to only B20CHEX1, B20CHEX1.5, B20CPEN1 and B20CPEN1.5.

From the above discussions, it can be surmised that the use of cyclo-pentane (which is more volatile than cyclo-hexane), will assist in the reduction of flash and ignition points, and this in turn will help reduce the peak pressure and temperature in the combustion chamber, resulting in a reduction in the NO_X emissions.

Table1 Properties of Various Biodiesel Blends

Blends	CV kJ/kg	Kinematic Viscosityν (St)	Flash Point (°C)	Ignition Point (°C)
Diesel	43,068	0.03150	56	58
B20	40,664	0.03200	68	72
B20CPEN 1	40,957	0.03366	54	62
B20CPEN 1.5	42,665	0.03155	48	56
B20CHEX 1	40,895	0.03255	58	61
B20CHEX 1.5	41,727	0.03366	54	58

It is felt that the reduction in the peak temperature will facilitate further research possibilities on investigations using higher compression ratios in a variable compression engine.

The data collected was analyzed and plotted in order to understand the behavior of various parameters with respect to change in load. The parameters such as the carbon monoxide, carbon dioxide, un-burnt hydrocarbons (UBHC), exhaust gas temperatures, NO_X emissions and the smoke opacity were studied under varying loads and injection timings. These parameters were also analyzed for different injection timings.

3.1 Brake Thermal Efficiency

it is seen that as the load increases Bth eff increases. At the normal inj. tim. of 27.5 deg. at loads greater than 50%, B20CPEN1.5 and B20CHEX1.5 gives lesser Bth eff than fossil diesel. However B20CHEX1.5 gives the greatest Bth eff almost through the entire range of varying loads. B20CHET1.5 gives the next greatest Bth eff through the entire range of varying loads. The Bth eff of B20CPEN1 was greater at 50% load marginally and at full load it was greater by 5% compared to fossil diesel. The Bth eff of B20CPEN1.5 was greater at quarter load by 3%, lesser at 50% load by 6.7% and at full load it was greater by 5.5% compared to fossil diesel. At 27.5 BTDC. inj. tim. the Bth eff of B20CHEX1 was greater by 3.46% at half load and greater by 10.5% at full load compared to fossil diesel. At 27.5 deg. BTDC. inj. tim. the Bth eff of B20CHEX1.5 was 2.86% greater at half load and 5.72% greater at full load compared to fossil diesel. It is very clear that at lower loads the Bth eff of B20 fuels with C_5H_{10} components is lesser compared to B20 fuels with C_6H_{12} components.

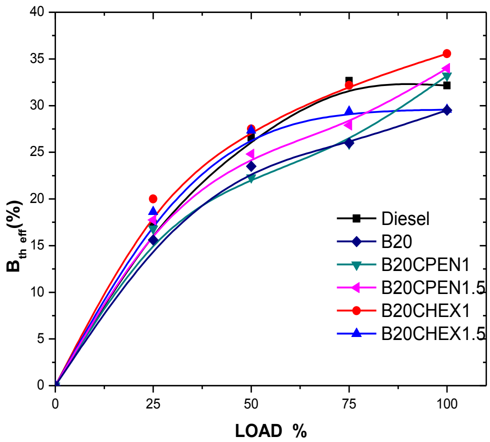


Fig.2 Brake Thermal Efficiency of various Blends for different loads at 27.5 deg. Injection Timing

3.2 Brake Specific Fuel Consumption

For lower loads, blends of biodiesel gives lower BSFC than fossil diesel except B20CHET1.5. However at greater loads fossil diesel gives the least BSFC and all the B20 blends gives lower BSFC. This was due to the lower calorifc value of B20 blends compared to fossil diesel. At 27.5 deg. BTDC. inj. tim. the brake specific fuel consumption of blend B20CPEN1 was 5.7% greater at half load and 1.2% lower at full load compared to fossil diesel. The brake specific fuel consumption of B20CPEN1.5 was 3% greater at half load and 2.75% lower at full load compared to fossil diesel. The BSFC of B20CHEX1 was lower by 1.4% at half load and by 5% at full load compared to fossil diesel. The BSFC of the blend B20CHEX1.5 was almost the same at half load and lower by 2.8% at full load when compared to fossil diesel.

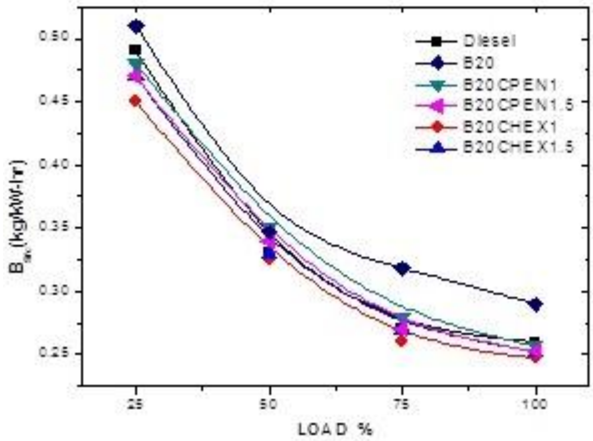


Fig.3 BSFC of various blends for different Loads at 27.5 deg. Injection Timing

3.3 Carbon Monoxide (CO) Emissions

The blend B20CPEN1.5 at 27.5 deg. BTDC. showed 16.6% greater CO emissions by at half load and was lower by 36.8% at full load compared to fossil diesel. For B20CHEX1 at 27.5 deg. BTDC. CO emissions were 33.33% greater at half load and lower by 16% at full load compared to fossil diesel. For B20CHEX1.5 at 27.5 deg. BTDC. CO emissions were greater by 16% at half load and lower by 13.16% at full load compared to fossil diesel. The blend component aided in reducing the CO emissions by lowering the flash and ignition points just enough to have the optimum combustion temperature and pressure. The decrease in CO emission of B20 blend was found to be 5.5% and 16.67% compared to the fossil diesel at half and full load respectively.

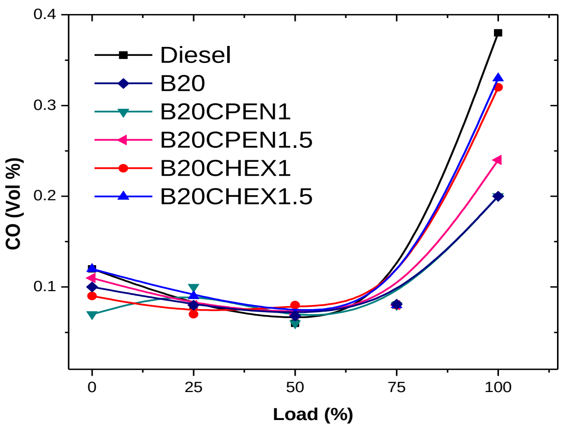


Fig.4 CO Emissions of various blends at different loads at 27.5 deg. Injection Timing

3.4 Un-burnt Hydrocarbon emissions (UBHC)

In Fig. 3 it is seen that at the normal inj. tim. of 27.5 deg BTDC. set by the engine manufacturer, fossil diesel gives the least UBHC emissions and among the biodiesel blends the B20CPEN1.5 gives the least emissions at half and full load conditions. For B20CPEN1 UBHC emission increased by 10% at half load and by 6% at full load compared to fossil diesel. For B20CPEN1.5 the UBHC reduced by 7.4% at half load and there was no change in emission levels at full load compared to fossil diesel. At 27.5 deg. BTDC. inj. tim. for B20CHEX1 the UBHC reduced by 3.7% at half load and by 4.25% at full load. At 27.5 deg. BTDC. inj. tim. the UBHC for B20CHEX1.5 increased by 23% at half load and by 4% at full load compared to fossil diesel. The B20 blend gives 15.2% and 9.33% lower UBHC at 50% and 100% loads respectively compared to fossil diesel. By comparison the B20 blend gives least UBHC due to high peak pressures raising the peak temperature resulting in better combustion. and inclusion of blend components has increased the UBHC emission because of lower peak pressures.

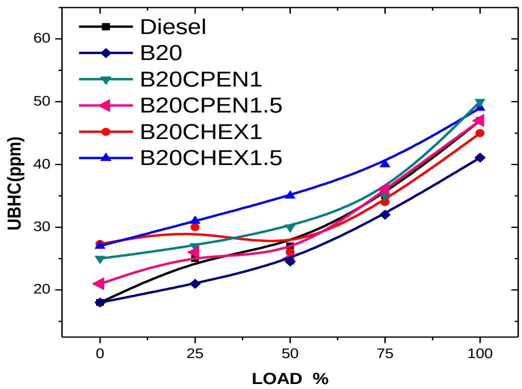


Fig.5 UBHC Emissions of various Blends at different loads at 27.5 deg. BTDC. Injection Timing

3.5 NO_X emissions

From Fig.4 showing the NO_X emissions for various fuel blends at different loads and at normal inj. tim of 27.5 deg. BTDC. it is seen that the biodiesel blend with C5H10 blend component showed the greatest NO_X emissions.

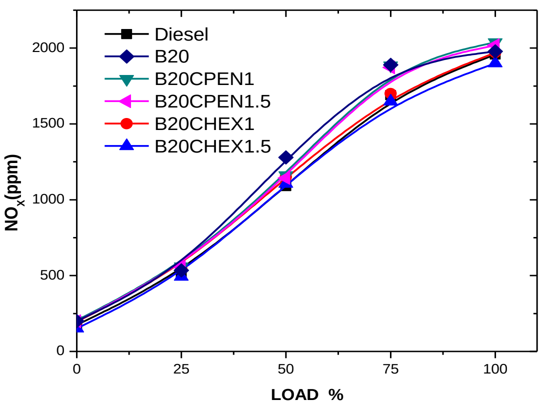


Fig.6 NO_X Emission of various Blends for different loads at 27.5 deg. BTDC. Injection Timing

The blends with cyclo- hexane blend component gave lower NO_X emissions than fossil diesel. The NO_X emissions for B20CPEN1 increased by 6.1% at half load and by 4% at full load compared to fossil diesel. For B20CPEN1.5 the NO_X emission increased by 4.6% at half load and by 3% at full load. The NO_X emissions for B20CHEX1 increased by 11% at half load and was almost the same at full load. For B20CHEX1.5 at 27.5 deg. the NO_X emissions increased by 15% at half load and reduced by 3% at full load compared to fossil diesel. B20 blend gives 22.18% and 11.26% greater NO_X at 50% and 100% load compared to fossil diesel. This is because B20 gives the greatest peak pressures during combustion. With blend component, NO_X emissions were reduced significantly for B20 compared to fossil diesel.

Conclusions

The following conclusions have been obtained:

- B20CPEN1 gave the lowest CO emission among all the blends with additives.
- B20CHEX1 gave the lowest UBHC emissions among all the blends with additives.
- B20CHEX1.5 gave the lowest NO_X emissions among all the blends with additives.
- Use of additives has helped us reduce the NO_X emissions compared to B20 and fossil diesel, but the CO and UBHC emissions are still higher than B20 blend and fossil diesel.
- Cyclo- Hexane blend component was found to be the least expensive for producing blend.

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