Effect of ternary fuel blends on performance and emission characteristics of single cylinder diesel engine

Vinodkumar V1,2 and Karthikeyan A2

1Research Scholar, Department of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, India
2Professor, Department of Automobile Engineering, Sathyabama Institute of Science and Technology, Chennai, India

*E-mail: v.vinodkumar85@gmail.com

Abstract: The higher alcohol such as hexanol was added at various concentrations with diesel in this current research work while retaining the neem biodiesel at 20% concentration to form the ternary fuel blend. In a single cylinder diesel engine, three distinct ternary blends (B20HB10, B20HB20, B20HB30) were taken and all the blends were tested and the results were contrasted with a binary blend (D80:B20, namely B20) and pure diesel fuel. The experiment showed that when the alcohol concentration rises from 10% to 30% because of the decrease in calorific value, the brake thermal efficiency decreases slightly. In addition, owing to the availability of intrinsic oxygen in it, all the ternary blend contributes to a decrease in HC and CO emissions, which leads to more complete combustion. It was also found that there was a substantial reduction in NOx emissions for all ternary blend due to the high latent heat of vaporization.

1. Introduction

Internal combustion engines running with petroleum fuels such as petrol and diesel are more popular and attractive all over the world, but due to the depletion, greenhouse effect and hike in cost of the petroleum fuels, researchers are concentrated on alternative fuels such as biodiesel derived from vegetable oils. Use of straight vegetable oil in compression ignition engine suffers from lesser performance and higher emissions due to incomplete combustion as it has high kinematic viscosity [1,2]. Transesterification is one of the most successful method which is used to extract biodiesel from vegetable oil with the help of some chemical reaction in the presence of catalyst. When associated to straight diesel fuel, biodiesel emitted greater NOX emissions and inferior hydrocarbon and carbon monoxide emissions in nearly all loads due to its higher oxygen content [3]. Various practices such as retarding injection pressures and timings, EGR, SCR, and variable geometry turbocharging, have been used to minimize NOX emissions [4,5]. The exhaust gas recirculation technique is one such successful method that ensued a greater drop in NOX emissions. The major reason for this is that the exhaust gas is diluted with fresh air, resulting in a lower combustion peak temperature. Antioxidants were also used to lower NOX emissions and improve engine efficiency [6]. It has been observed that at all loads, a mixture of canola and fish oil biodiesel with diesel fuel emits fewer HC and CO than diesel fuel [7,8]. Due to its poorer heating value, biodiesel and its combinations with diesel yield lower brake thermal efficiency than diesel fuel. According to the Environmental Protection Agency Act, a 20 percent biodiesel fuel blend with diesel fuel has better efficiency and emission characteristics than any other mixture. Nowadays the researches are focused on blending alcohol with diesel and biodiesel to reduce the emission and performance characteristics. Generally lower order alcohols emits lesser HC and CO emissions and higher NOX emissions due to its inherent oxygen content that leads to better combustion.
characteristics than diesel fuel, but due to their low cetane number and high resistance to self-ignition, lower alcohols like methanol and ethanol are limited in diesel engines [9,10]. Blending of higher alcohol with diesel and biodiesel is having many advantages due to its superior properties such as higher cetane number and latent heat of vapourisation characteristics than lower order alcohol [11]. It has been observed that the n-butanol, n-decanol and n-octanol blended with diesel resulted in lesser HC, CO and NOₓ emissions compared than diesel fuel due to its higher oxygen content and latent heat of vapourisation [12,13,14].

In this present work, the neem oil biodiesel concentration kept constant at 20 % by volume basis and hexanol was mixed at different ratio such as 10 %, 20 % and 30 %. According to the hexanol concentration, the proportion of diesel has been varied. Three different ternary blends such as D70:B20:H10 named as B20HB10, D60:B20:H20 named as B20HB20, D50:B20:H30 named as B20HB30 were taken for this current experimental study.

2. Experimental setup and methodology

The neem oil and hexanol were collected from local vendor, Chennai, Tamilnadu. The obtained neem oil has been converted into biodiesel with the help of transesterification process. In transesterification, the catalyst sodium hydroxide (NaOH) pellets and methanol were used for the reaction purpose. Initially the raw neem oil of 1litre was poured into a round bottom flask and then 250 ml of methanol and 10g of NaOH were added and this mixture were heated to a temperature of 60 °C for 120 minutes and stirred with the help of magnetic stirrer. After the reaction, the mixture was allowed to settle down under gravity about one day. Now the mixture were taken into the separating funnel where the glycerol and biodiesel have been removed. The obtained biodiesel sample was washed with water twice and it was further heated about 125 °C to remove the moisture content in it.

The test rig used for this experimental study is a single cylinder, water cooled direct injection diesel engine with brake power of 5.2 kW at a constant speed of 1500 rpm. The further details of test rig is shown in table1. For this experiment, ternary fuel blends were prepared by using diesel, biodiesel and hexanol alcohol in different combinations such as B20HB10, B20HB20 and B20HB30. The final results were mapped with diesel and B20 fuel. The properties of test sample is shown in table2.

| Table 1: Engine Specifications |
|--------------------------------|
| Make                          | Kirloskar     |
| No.of Cylinders               | One           |
| Type of Cooling               | Water-cooled  |
| Bore                          | 87.5 mm       |
| Stroke                        | 110 mm        |
| Compression ratio             | 17.5:1        |
| Rated Power                   | 5.2 kW @ 1500 rpm |
| Piston bowl                   | Hemispherical |
| Lubrication oil               | SAE 40        |
Table 2: Test Fuel Properties

| Properties                        | Diesel | B20  | Hexanol | B20HB10 | B20HB20 | B20HB30 |
|-----------------------------------|--------|------|---------|---------|---------|---------|
| Density @ 15 °C (kg/m³)           | 835    | 850  | 821.8   | 852.18  | 850.36  | 848.54  |
| Kinematic Viscosity @ 40 °C (cSt) | 3.6    | 3.72 | 5.32    | 3.89    | 4.06    | 4.24    |
| Cetane Index                      | 50     | 51   | 23      | 48      | 46      | 43      |
| Calorific Value (kJ/kg)           | 42500  | 41964| 39100   | 41624   | 41284   | 40944   |
| Latent heat of Vaporisation (kJ/kg)| 250   | -   | 603     | -       | -       | -       |
| Flash Point (°C)                  | 75     | 96   | 59      | 94.4    | 92.8    | 91.2    |

3. Results and Discussion

3.1 Brake thermal efficiency

The amount of heat energy transferred to useful work is known as brake thermal efficiency. This parameter is solely dependent on the fuel’s calorific value and viscosity. This variation of brake thermal efficiency and brake power is shown in fig1. It is comprehended from the graph that the BTE value at rated load for diesel, B20, B20HB10, B20HB20, B20HB30 are 34.95 %, 32.29 %, 33.1 %, 31.15 % and 30.31 % respectively. It is observed from the above data that the diesel fuel has higher BTE compare than all other tested fuels due to its superior chemical properties such as calorific value and kinematic viscosity. Among all hexanol blending, the B20HB10 yield higher BTE compare than B20 fuel. As the hexanol percentage increased, there was a slight reduction in BTE due to the reduction calorific value and increase in kinematic viscosity.

![Figure 1. Variation of BTE with BP](image-url)
3.2 Brake specific fuel consumption
The quantity of fuel used to generate one unit of power in one unit of time is referred to as brake specific fuel consumption (BSFC). This parameter is solely dependent on fuel’s calorific value. The variation of BSFC and BP is shown in fig1. It is comprehended from the graph that the BSFC value in kg/kWh at rated load for diesel, B20, B20HB10, B20HB20 and B20HB30 are 0.25, 0.32, 0.29, 0.33 and 0.34 respectively. From the above data, it is observed that the diesel has lower BSFC which resulted in higher BTE than all other tested fuels due to its higher heating value. Among hexanol blend, B20HB10 resulted lower BSFC than B20 due to its high calorific value. The BSFC increases for all other hexanol blend due to their reduction in calorific value, but the difference in BSFC for B20 and all hexanol blend are closer due to their excess oxygen availability which promotes the combustion faster.

3.3 Unburnt hydrocarbon emission
The variation of unburnt hydrocarbon emission (UBHC) with BP is shown in fig3. The UBHC indicated the fuel’s ability for complete combustion. It is comprehended from the graph that the UBHC in ppm at rated load for diesel, B20, B20HB10, B20HB20 and B20HB30 are 55, 52, 46, 44 and 36 respectively. Among all other tested fuels, B20HB30 emitted lower HC emission. The readiness of inherent oxygen in hexanol blend leads to more complete combustion that resulted in lower HC emission. It is observed from the above data that there was a reduction in HC emission about 34.5 % and 30.7% for B20HB30, 20 % and 15.38 % for B20HB20 and 16.38 % and 11.5 % for B20HB10 compare than neat diesel fuel and B20 respectively. Among all other tested fuels, the diesel emits higher HC emission.

3.4 Carbon monoxide emission
The variation of carbon monoxide (CO) emission with BP is shown in fig4. Like HC emission, CO also indicated the fuel’s ability for complete combustion. It is comprehended from the graph that CO emission at rated load for diesel, B20, B20HB10, B20HB20 and B20HB30 are 0.195%, 0.19%, 0.187%, 0.168% and 0.133% respectively. Due to improved oxidation for B20 and all other hexanol blend, all the blends have lesser CO emission than diesel fuel. Among all tested fuels, the B20HB30 gave lesser CO emission due to
its inherent oxygen content that leads to more complete combustion. It has been found from the graph that there was a reduction in CO emission about 31.7 % and 30 % for B20HB30, 13.8 % and 11.5 % for B20HB20 and 4.1 % and 1.5 % for B20HB10 compare than the neat diesel fuel and B20 respectively. Only a marginal reduction in CO has been found for B20HB10 since its properties are very nearer to diesel and B20.

Figure 3. Variation of HC Emission with BP

Figure 4. Variation of CO Emission with BP
3.5 Nitrogen oxide (NO\textsubscript{X}) emission
The major toxic emission emitted from the diesel engine is NO\textsubscript{X} emission which is majorly dependent on in-cylinder temperature and ignition delay. The variation of NO\textsubscript{X} emission with BP is shown in fig5. The NO\textsubscript{X} emission at rated load in ppm for diesel, B20, B20HB10, B20HB20 and B20HB30 are 1556, 1601, 1298, 1266 and 1240 respectively. Among all the tested fuels, B20 emits higher NO\textsubscript{X} emission due its excess oxygen availability in it which makes higher in cylinder temperature and shorter ignition delay. Irrespective of the inherent oxygen content, the addition of hexanol resulted in lower NO\textsubscript{X} emission for ternary fuel blend due their higher latent heat of vapourisation. Higher latent heat of hexanol absorbs more heat from the fuel during combustion which resulted in lower in-cylinder temperature. It is observed that among all tested fuel, the B20HB30 resulted in lesser NO\textsubscript{X} emission. From the above date, it has been found that there was a reduction in NO\textsubscript{X} emission about 17.2 % and 18.92 % for B20HB10, 18.6 % and 20.92 % for B20HB20 and 20.3 % and 22.54 % for B20HB30 compare than the diesel and B20 fuel.

![Figure 5. Variation of NO\textsubscript{X} Emission with BP](image)

3.6 Smoke opacity
Fig6 shows the variation of smoke emission with brake power at rated load for all tested fuels. At full load, the smoke emission for diesel, B20HB10, B20HB20 and B20HB30 are 72.7 %, 60.6 %, 67.9 %, 69.2 % and 71.2 % respectively. Among all tested fuels, B20 gave lesser smoke emissions since it has lower kinematic viscosity and density compare than all ternary blends. Also nil sulphur content in the biodiesel leads to reduction in smoke emission. Smoke also reduced to all ternary blend due to its inherent oxygen content in it compare than diesel, but it is in slightly increasing trend as the alcohol proportion increased. This is because of kinematic viscosity increased marginally when the alcohol proportion increased in ternary blend. The trade-off relation of NO\textsubscript{X} and smoke emission has been resolved somewhat in diesel engine by using ternary blend with the help of hexanol. Overall the reduction in NO\textsubscript{X} emission and smoke emission has been observed from the fig5 and fig6 respectively.
4. Conclusion

The effect of ternary blend in different proportions such as B20HB10, B20HB20 and B20HB30 were examined in comparison with B20 and diesel fuel. From the experiments, the following points are concluded:

1. The BTE is higher for diesel fuel than all other tested fuels since it has higher calorific value and lower kinematic viscosity and density. B20HB10 gave higher BTE than B20 and other ternary blend due to its higher calorific value.
2. Lower BSFC has been observed for diesel fuel than other tested fuels. Like BTE, B20HB10 has lower BSFC than other tested fuels except diesel.
3. Both HC and CO emission decreased for all ternary blend compared to B20 and diesel fuel due to its inherent oxygen content in it. Among ternary blends, B20HB30 gave lesser HC and CO emissions.
4. NOX emission drastically reduced for all ternary blend compared to B20 and diesel fuels due to its higher latent heat of vaporization which reduces the in-cylinder temperature effectively.
5. Smoke emission also reduced when ternary blends have been introduced compared to diesel fuel. But they have marginally higher smoke than B20 due to its higher kinematic viscosity.

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