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Effect of the Addition of 1-Pentanol on Engine Performance and Emission Characteristics of Diesel and Biodiesel fuelled Single Cylinder Diesel Engine

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ABSTRACT:
Bioalcohols have recently become one of the promising alternate fuels. Lower alcohols exhibit some problems like phase separation, stability issues, storage problems, corrosion etc. Hence, the addition of higher alcohols is regarded least-problematic and the concept of using higher alcohols as fuel blends is relatively new. In this article, the effects of the addition of higher alcohol (1-pentanol) on engine performance and emission characteristics are discussed. Two reference fuels (diesel and biodiesel derived from waste cooking oil) and two test fuels (blends of 20% of 1-pentanol and 80% of either diesel or biodiesel) are tested in a single cylinder compression ignition diesel engine for six load conditions (0, 4, 8, 12, 16, and 20 kg) at a constant speed of 1200 rpm. The engine performance and emission characteristics are determined and discussed.

Keywords: biodiesel, pentanol, higher alcohol, engine performance, emissions, biofuel.

1. INTRODUCTION:

Bioalcohols, derived from renewable sources, have high potential to be used as the promising alternative fuels in automobile applications. Since they can be derived from biomass, agricultural wastes and other wastes, production of alcohols do not increase the food prices and eliminate the need of extra land for cultivation. The term "lower alcohols" refers to alcohols containing less than four carbon atoms, such as methanol, ethanol, propanol an butanol, while the term "higher alcohols" refers to alcohols containing four or more carbon atoms, such as, butanol, pentanol, hexanol, octanol, etc. [1-3]. Lower alcohols have some disadvantages. Due to lower densities, they require a large fuel tank. They are not stable when blended with diesel. Methanol is toxic, corrosive is completely miscible. Ethanol exhibits phase separation problems and cold starting problems. Ethanol is miscible with water and is flammable polar solvents. The lower flash points require extra care in its storage and handling. Lower alcohols are not miscible with the diesel fuel which may require an emulsifying agent for preparing the miscible fuel blends [4-6]. The use of higher alcohols has recently gained much attention as one of the next generation alternative fuel sources. Higher alcohols have many advantages over lower alcohols. Higher alcohols dissolve in diesel with no phase separation that eliminates the need of co-solvents or emulsifying agents for improving the blending stability. Higher alcohols, when blended with diesel, show better cold flow properties and stable on all blends, while lower alcohols are not. Higher alcohols have high density, calorific value and cetane number without compromising on the self-ignition properties. High water content causes alcohols more corrosive. Higher alcohols are, however, less hygroscopic and are considered as less corrosive. As the flash points of higher alcohols are higher than that of lower alcohols, they are safe in terms of storage, handling and delivery [7-8]. They burn cleaner producing lower emissions of carbon monoxide, hydrocarbons and oxides of nitrogen as compared to that of gasoline. The heat of vaporization of alcohols decreases the peak flame temperature produced inside the combustion chamber of IC engine leading to lower NOx emissions [9]. Higher alcohols were not largely used earlier due to their limited yield from fossil resources and high production costs. With the advancements in bio-technology, many modern processing techniques have been developed for deriving higher alcohols from renewable sources and to increase the yield of higher alcohols. This has increased the potential of being used as an alternative fuel source [10]. However, higher alcohols are not suitable as a direct fuel in diesel engines due to their low cetane numbers, low calorific value and high latent heat of evaporation as compared to that of the conventional diesel fuel. However, they can be used as blends of diesel and alcohols which can reduce the dependency of fossil fuel [11].

The effects of higher alcohols have been investigated by some researchers. In the work of Kumar et al. [12], the effects of n-octanol/diesel blends (10%, 20% and 30% of n-octanol) on combustion, performance and emissions characteristics were investigated in a single-cylinder diesel engine. The resutls showed that n-octanol improved efficiency, reduced fuel consumption, and reduced emissions of smoke, NOx, HC and CO. Campos-Fernandez et al. [13] prepared the pentanol/diesel blends (10%, 15%, 20% and 25% pentanol) and tested the engine performance in a three cylinder diesel engine and found that the addition of pentanol had increased brake thermal efficiency while slight increase of specific fuel consumption was observed. Wei et al. [14] investigated the effects of diesel and n-pentanol blends (10, 20 and 30% of n-pentanol) on combustion, performance and emissions in a four cylinder diesel engine. The results showed increased fuel consumption with no significant difference in brake thermal efficiency. Emissions of CO, HC and NOx increased with the increase of n-pentanol in diesel, as compared to that of diesel fuel. Kerschgens et al. [15] investigated the effects of di-n-buthylether, n-octanol, and n-octane on engine combustion characteristics and found that the emissions of CO, HC and NOx of n-octanol were found to be higher than di-n-buthylether and n-octane.Yilmaz and Atmanli [16] prepared the diesel-1-pentanol blends (5%, 10%, 20%, 25% and 35% of 1-pentanol) and studied their effects on the engine performance and emissions of a diesel engine. The results showed that the diesel/1-pentanol blends increased the brake specific fuel consumption, reduced the combustion efficiency and the brake thermal effieciency, while increasing the emissions of CO, HC and NOx. Yilmaz et al. [17] investigated the effects of butanol-biodiesel blends (5%, 10%, and 20% butanol by volume) on engine performance and emissions of an indirect injection diesel engine and compared the results with diesel and neat biodiesel. While butanol-biodiesel blends showed lower NOx emissions, higher CO and HC emissions as compared to biodiesel, they showed lower CO and HC emissions and higher NOx emissions as compared to diesel fuel. Deep et al. [18] assessed the effects of 1-Octanol/Diesel Fuel Blends (10%, 20%, 30% and 40%) on engine performance and emissions of a water cooled diesel engine. The results showed that the increase of 1-octanol reduced brake thermal efficiency and increased specific fuel consumption with reduced emissions of NOx, CO and smoke and increased HC emissions. Yang et al. [19] prepared the effects of n-pentanol (15% and 30% by volume) blended with biodiesel (produced from waste cooking oil) and the effect on particulate emissions was tested on a 4-cylinder diesel engine. The results showed that biodiesel reduced emissions of particulates (elemental carbon and toxic polycyclic aromatic hydrocarbons) when compared to diesel. The addition of pentanol further reduced these emissions as compared to pure biodiesel. Atmanli [20] studied the effects of propanol, n-butanol and 1-pentanol on engine performance and emissions by preparing 20% of alcohol content blended in the mixture of 40%-40% biodiesel-diesel fuels. The results showed that lower NOx and higher CO emissions were reduced in the order of 1-pentanol, n-butanol and propanol, respectively. Subramanian et al. [21] investigated the effects of 20% of either methanol or pentanol blended with biodiesel (extracted from karanja oil and orange oil) on engine performance, emissions, and combustion characteristics. The results showed that the addition of 1-pentanol produced lower emissions of NOx, smoke, and CO2 simultaneously as compared to that of methanol blends.

Pentanol is one of the promising candidates as an alternative fuel source due to its similar properties to that of the diesel fuel. Few works are available on the effects of 1-pentanol blended with diesel. However, only limited research is performed on pentanol, and there is a need to explore its effects on engine performance and emission characteristics. In this article, the effects of 1-pentanol/biodiesel blends on engine performance and emission characteristics are presented and discussed. 20% of 1-pentanol was added with diesel and biodiesel separately to prepare the test fuels and the characteristics are compared with neat diesel and biodiesel fuels.

2. PREPARATION OF FUEL MIXTURES:

Waste cooking oil was collected from the local restaurants near Avadi, Chennai, India. Diesel, methanol, 1-pentanol, and catalyst (sodium hydroxide) were purchased from the local market near Rich Street, Chennai, India. The collected waste oil was filtered for removing solid particles and heated for removing moisture. In the preparation of biodiesel, the molar ratio of methanol to waste cooking oil was taken as 1:3 and the quantity of catalyst was about 1% of waste cooking oil. Biodiesel was then produced by using alkaline transesterification process at International Research Centre, Sathyabama Institute of Science and Technology, Chennai. The prepared biodiesel is stored after purification process. The test fuels were then prepared by adding 20% of 1-pentanol by volume with 80% diesel (D80P20) and biodiesel (B80P20) separately. Neat diesel (D100) and neat biodiesel (B100) were considered to be the reference fuels. The fuel properties are shown in the table 1.

Table 1: Fuel Properties

Fuel Properties	Diesel (D100)	Biodiesel (B100)	1-Pentanol	D80P20	B80P20
Density at 17 ºC(kg/m^3)	817	868	814	816	858
Kinematic Viscosity at 40C (mm/s^2)	2.95	4.62	2.89	2.94	4.12
Lower Heating Value (MJ/kg)	44.8	20.8	27.7	41.4	24.3
Latent Heat of Vaporization (kJ/kg)	250	238	308	261	251
Cetane Number	46	52	20	41	46
Oxygen Content (%)	0	11	15	4	12

3. EXPERIMENTAL SETUP & PROCEDURE:

Figure 1 shows the experimental setup used for engine performance and emissions characteristics. A single cylinder and four stroke diesel engine with the power rating and maximum speed of 5.2KW and 2000 rpm respectively. The cylinder bore diameter, stoke length and the length of connecting rod are 87.5 mm, 110 mm and 234 mm respectively. The engine is connected to eddy current dynamometer where the load could be varied. Six load conditions (0 kg, 4 kg, 8 kg, 12 kg, 16 kg and 20 kg) were considered in the experiment. Different types of sensors wer used for taking measurements of various parameters. The parameters can be adjusted with the help of the control panel attached. The display unit attached to the control panel can show the values of those parameters. The exhaust pipe is connected to a secondary pipeline which is connected to an AVL Digas 444 gas analyzer for measuring the emissions of various gases.

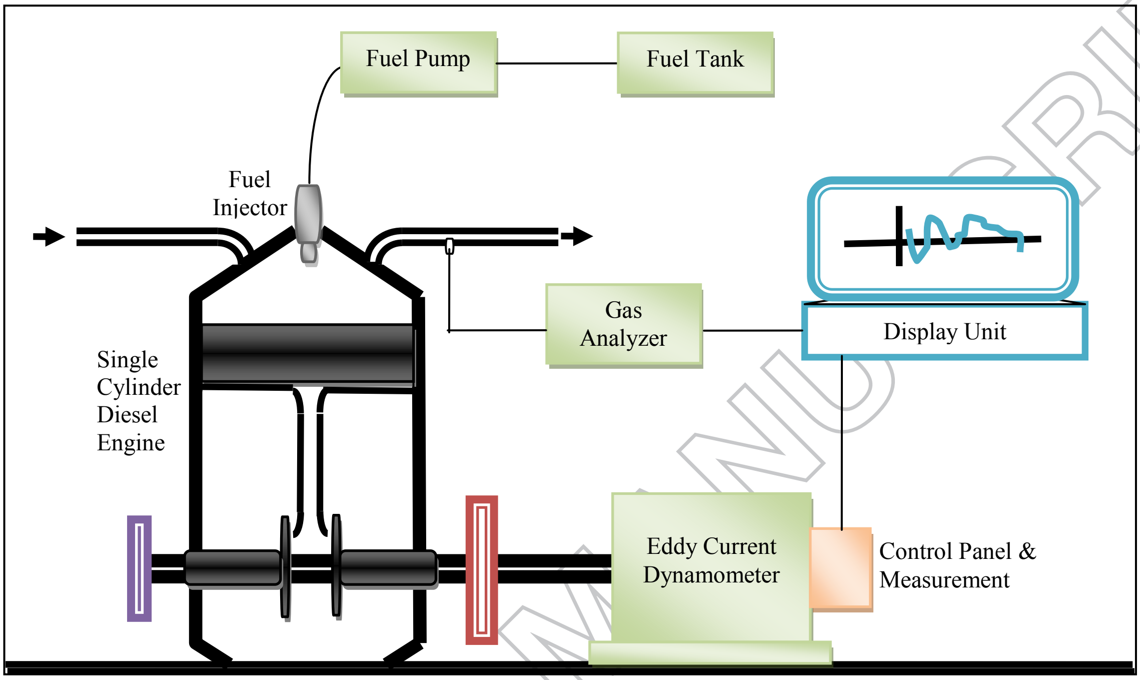

Figure 1: Experimental Setup

The test fuels can premixed and poured in a burette or can be poured in separate burette and mixed in the tank. The speed of the engine was kept constant at 1200 rpm under varying load conditions (0, 4, 8, 12 and 16 kg). Experiments are conducted and the engine performance (brake thermal efficiency, specific fuel consumption and exhaust gas temperature) and emissions characteristics (CO, HC and NOx) were determined.

4. RESULTS & DISCUSSION:

4.1 BRAKE THERMAL EFFICIENCY

Figure 2 shows the brake thermal efficiency of test fuels and reference fuels at all load conditions. The brake thermal efficiency of diesel fuel is higher than that of biodiesel and the fuel blends. The addition of 1-pentanol reduced the brake thermal efficiency slightly. The oxygen content increases with the addition of 1-pentanol and higher heat is expected to be released during combustion. However, due the higher heat of vaporization of 1-pentanol/diesel blend, more heat is absorbed during vaporization of 1-pentanol.

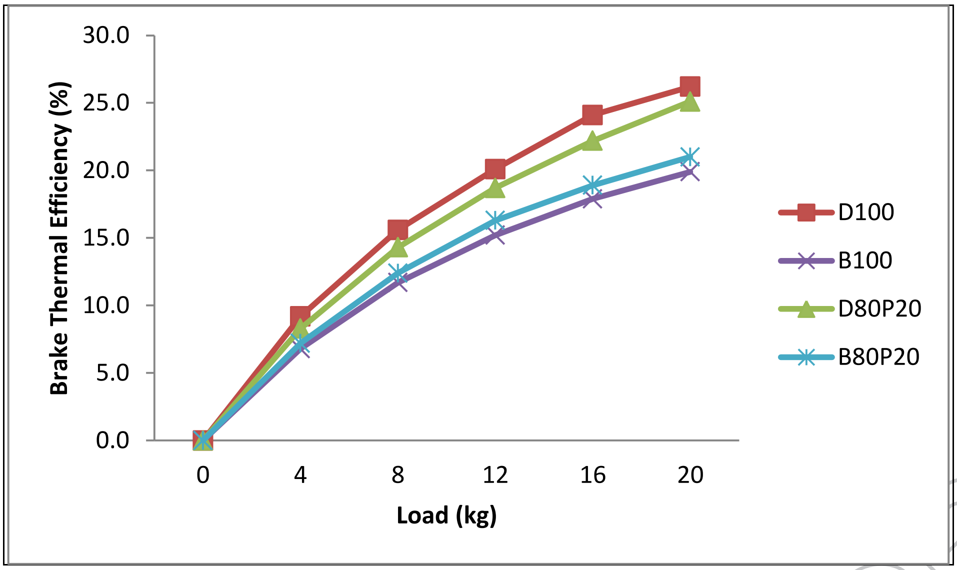

Figure 2: Brake Thermal Efficiency

Neat biodiesel produces lower brake thermal among the remaining test fuels at all load conditions. Higher density and higher viscosity and less heating values could be the reasons for the reduced brake thermal efficiencies. Due to higher viscosity, the fuel particles are not atomized properly and the spray characteristics are affected. This leads to incomplete combustion reducing the combustion efficiency. This, in turn, can cause reduced brake thermal efficiency. 1-pentanol/biodiesel blends, on the other hand, shows increase in the brake thermal efficiency than that of the neat biodiesel. The addition of 1-pentanol reduced the viscosity but increased the heating value of the biodiesel. This causes increase in combustion efficiency and the brake thermal efficiency increases.

4.2 EXHAUST GAS TEMPERATURE

Figure 3 shows exhaust gas temperature of test fuels and reference fuels. The exhaust gas temperature of diesel is higher than that of other fuels, followed by neat biodiesel. The alcohol blended test fuels showed even higher exhaust temperatures than the reference fuels. The exhaust gas temperatures are explained by the heat of vaporization, oxygen content and viscosity (poor atomization). Diesel contains no oxygen content and produces relatively lower exhaust gas temperatures at all load conditions. 1-pentanol/diesel blends have higher latent heat of vaporization that absorbs more heat and the exhaust gas temperatures. Due to the presence of more oxygen content, more combustion is expected and could increase the flame temperatures inside the cylinder. However, the more heat is absorbed by heat of vaporization. Cetane number is reduced with the addition of 1-pentanol resulting in poor combustion. Thus the exhaust gas temperature of 1-pentanol/diesel blends is lower than the diesel fuel.

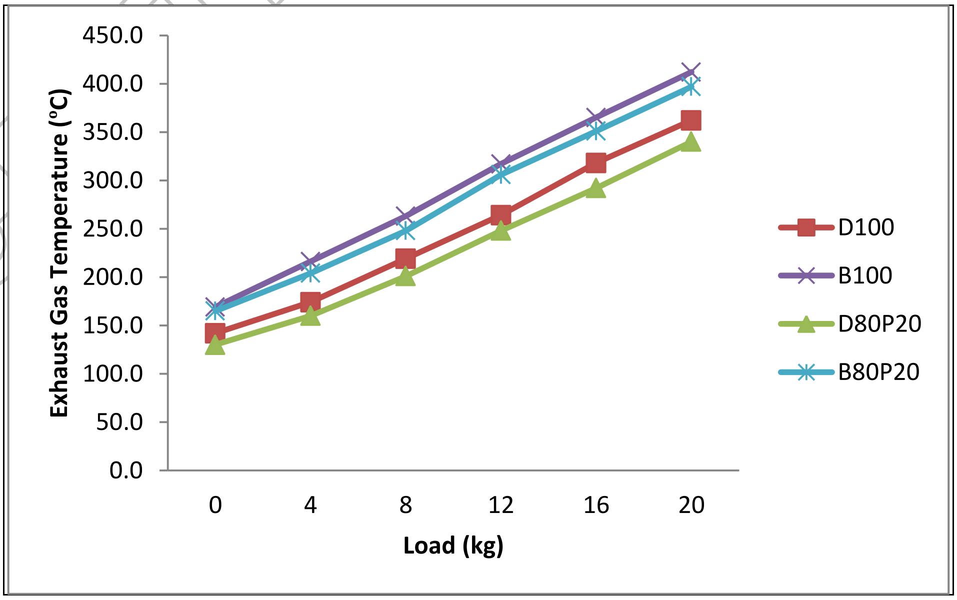

Figure 3: Exhaust Gas Temperature

Biodiesel shows the highest exhaust gas temperatures at all load conditions. This may be due to the higher oxygen content in biodiesel. Due to higher oxygen content, the combustion is enhanced and the flame temperature increases during combustion. Due to poor atomization, there could be burning even after combustion and can be a reason for higher exhaust gas temperatures. The exhaust gas temperature of 1-pentanol/biodiesel blends is found to be lower than that of biodiesel. This may be due to increased heat of vaporization and reduced viscosity. Increase in viscosity improves the combustion quality of 1-pentanol/biodiesel blends and the possibility of burning after combustion is reduced. High heat of vaporization absorbs more heat during combustion and the reduction in exhaust gas temperature is thus obvious in 1-pentanol/biodiesel blends.

4.3 SPECIFIC FUEL CONSUMPTION:

Figure 4 shows the specific fuel consumption of test fuels and reference fuels. Specific fuel consumption of biodiesel is higher than that of diesel and the test fuels. Diesel showed the least specific fuel consumption. This is due to the higher calorific value of diesel as compared to all other fuels. For the remaining fuels, more fuel is needed to produce the same amount of output power, due to lower calorific values. When 1-pentanol is added to diesel, the heat of vaporization increases. Hence, 1-pentanol/diesel blends absorb more heat than that of diesel, which increases the fuel consumption.

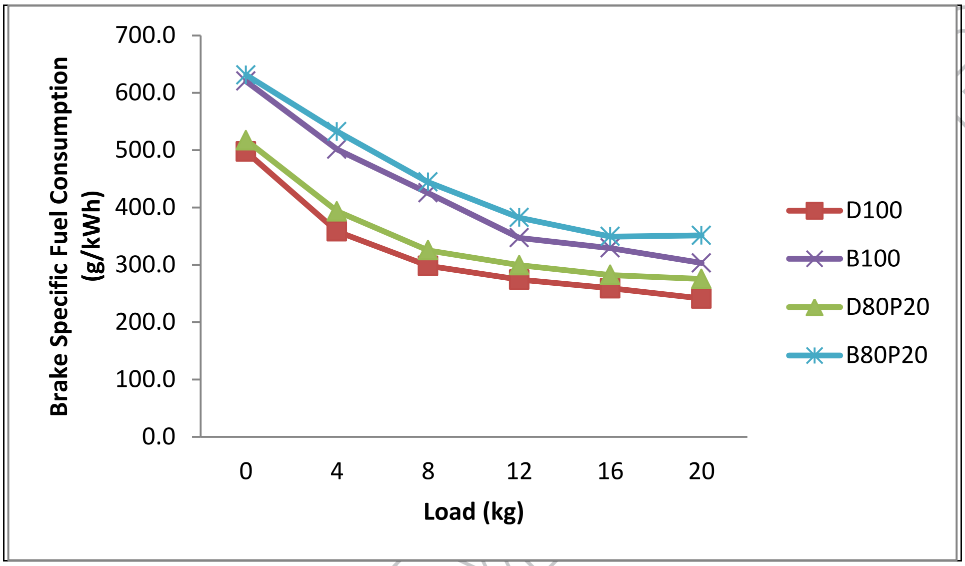

Figure 4: Specific Fuel Consumption

The calorific value of biodiesel is lesser than that of diesel. Biodiesel, therefore, requires more fuel for producing a particular engine output. High viscosity of biodiesel causes poor spray characteristics and leads to poor atomization. The combustion efficiency of biodiesel is thus reduced, which in turn increases the specific fuel consumption. In the case of 1-pentanol/biodiesel blends, the addition of 1-pentanol increases the heat of vaporization and calorific value, but reduces viscosity and cetane number. Higher calorific value increases the power output and reduces the specific fuel consumption for a particular engine output. Furthermore, the increase in viscosity improves, combustion efficiency could be improved. However, due to increased heat of vaporization, more heat would be absorbed during combustion and specific fuel consumption of 1-pentanol/biodiesel blends is found to be slightly higher than that of neat biodiesel. Lower cetane number could also have reduced the combustion quality.

4.4 NOx EMISSIONS:

Figure 5 shows the emissions of NOx of test fuels and reference fuels. NOx emission of biodiesel is usually higher than that of diesel due to high flame temperatures of biodiesel produced during combustion. As expected, diesel produced lower NOx emissions than that of biodiesel. This can be explained by exhaust gas temperatures and heat of vaporization. NOx emissions are higher when the combustion temperature is high. As the combustion temperature increases, NOx emissions increase. Exhaust gas temperatures of diesel is lower than that of biodiesel, and the combustion temperature is expected to be lower, which produced lower NOx compared to that of biodiesel. However, NOx emissions of 1-pentanol/diesel blends show the lowest NOx emissions than that of diesel fuel, due to increased heat of vaporization of 1-pentanol/diesel blends. Higher heat of vaporization reduced the combustion temperature resulting in lower NOx emissions.

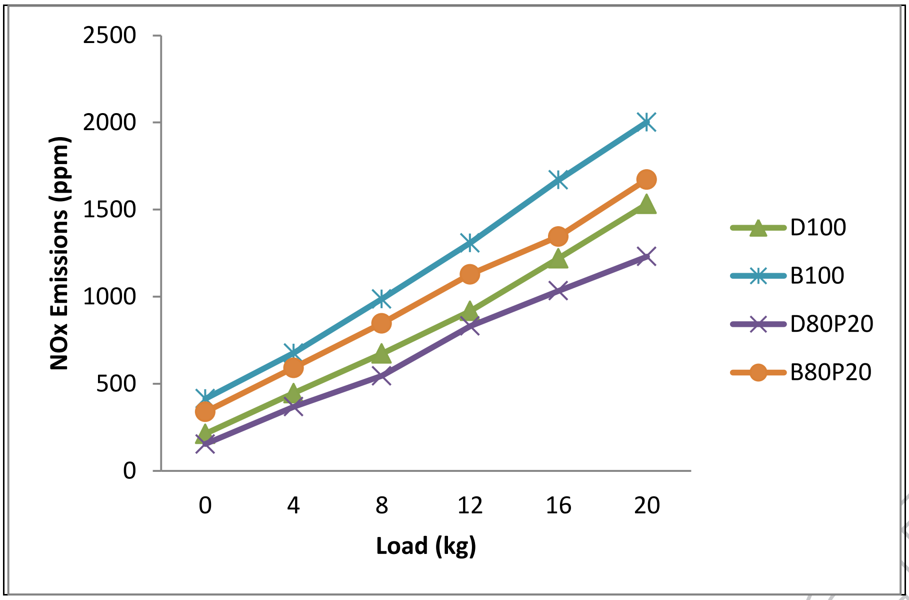

Figure 5: NOx Emissions

Neat biodiesel produced higher NOx emissions due to more oxygen content which increases the combustion temperature. The viscosity of biodiesel is higher than that of diesel, which results in poor atomization of biodiesel particles and non-uniform combustion inside the cylinder. This can increase the flame temperature in certain regions, which cause higher NOx emissions. Higher oxygen presence in biodiesel favours combustion and higher temperature is produced. Also, the heat of vaporization of biodiesel is lesser than diesel and therefore lesser heat is absorbed during combustion. All these conditions make NOx emissions higher than diesel fuel. Addition of 1-pentanol increases the oxygen concentration and the calorific value of 1-pentanol/biodiesel blends, and the heat produced is expected to be higher than that of neat biodiesel. However, increase in viscosity and heat of vaporization make the temperature lower than that of neat biodiesel and lower NOx is produced as compared to neat biodiesel. Increased viscosity produces efficient atomization and uniform combustion resulting uniform temperature distribution and thus reducing high temperature spots. Increased heat of vaporization absorbs more heat during combustion, reducing the effective combustion temperature and producing unfavourable conditions for NOx formation.

4.5 HC EMISSIONS:
Figure 6 shows the emissions of unburnt HC of test fuels and reference fuels. Hydrocarbon emissions are higher if combustion is incomplete. The oxygen content in diesel is lesser than biodiesel, and more unburnt diesel particles escape from the cylinder producing higher HC emissions as compared to that of biodiesel. Addition of 1-pentanol increases the oxygen content, which enhances more complete combustion leading to lower HC emissions.

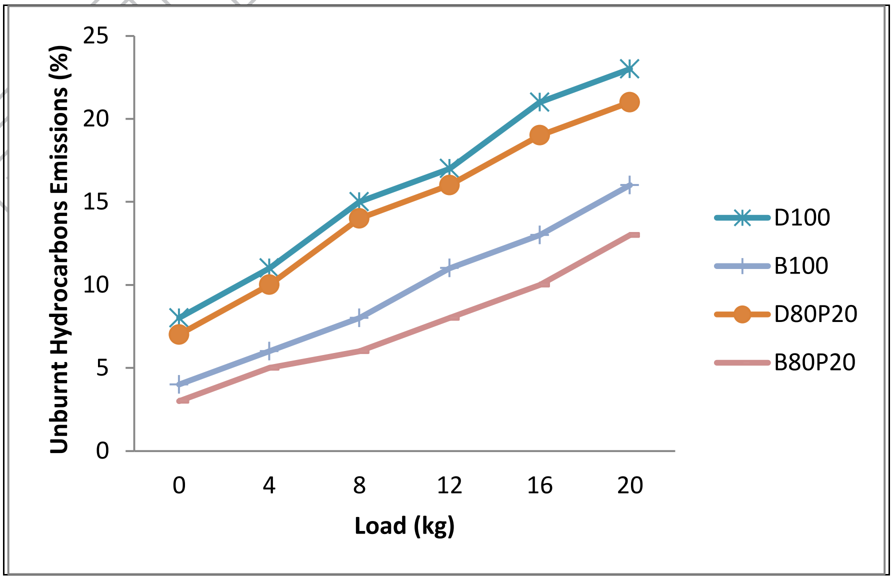

Figure 6: HC Emissions

Higher oxygen content in biodiesel favours more complete combustion resulting lower HC emissions at all load conditions as compared to that of diesel fuel. 1-pentanol/biodiesel blends further reduces HC emissions, mainly due to reduced viscosity and slight increase in oxygen content due to the addition of 1-pentanol. It can therefore be said that 1-pentanol blends produced lower HC emissions as compared to reference fuels.

4.6 CO EMISSIONS:

Figure 7 shows the emissions of CO of test fuels and reference fuels. CO emissions are mainly caused by incomplete combustion. As diesel has no or very low oxygen content, the amount of CO emissions is expected to be higher than that of biodiesel (biodiesel has more than 10% oxygen content). However, the results show that CO emissions of diesel fuel are lower than that of biodiesel. This can be explained by viscosity and poor atomization due to higher viscosity of biodiesel. Poor atomization causes poor spray characteristics and poor combustion efficiency. Due to poor combustion, particles are not completely burnt inside the cylinder and more CO emissions occur.

1-pentanol/diesel blends have higher oxygen content and lower viscosity than diesel fuel, enhancing more complete combustion. Hence, CO emissions of 1-pentanol/diesel are lower than that of diesel fuel. Similarly, 1-pentanol/biodiesel blends reduce HC emissions as compared to neat biodiesel due to reduced viscosity and slight higher oxygen content.

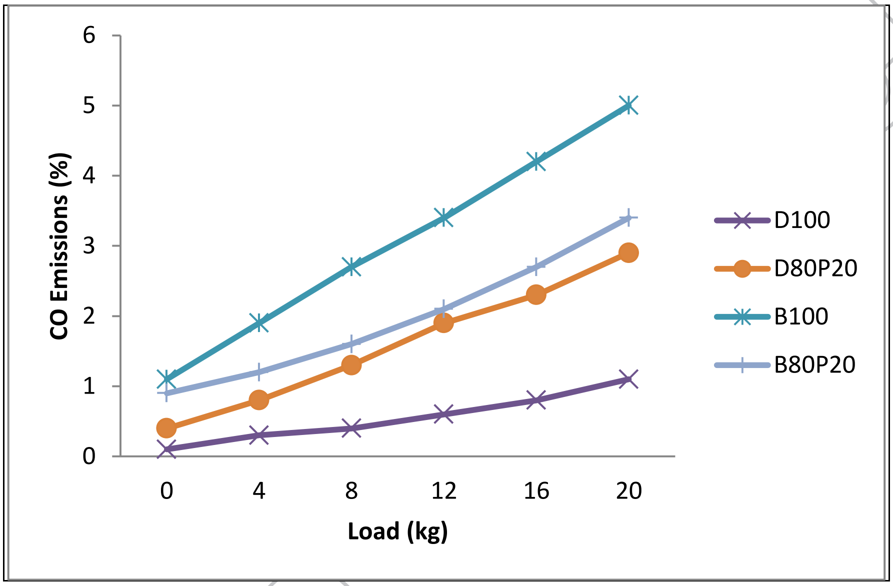

Figure 7: CO Emissions

CONCLUSION:

In this article, the effects of 1-pentanol on the engine performance and emission characteristics of 1-pentanol/diesel and 1-pentanol/biodiesel blends were analyzed. Two reference fuels (diesel and biodiesel) and two test fuels (blends of 20% of 1-pentanol and 80% of either diesel or biodiesel) were tested in a single cylinder compression ignition diesel engine for six load conditions (0, 4, 8, 12, 16, and 20 kg) at a constant speed of 1200 rpm. The engine performance and emission characteristics were determined and discussed. From the results it is observed that 1-pentanol/diesel blends reduced the emissions of NOx, HC and CO simultaneously as compared to diesel fuel, while there was a slight reduction of BTE observed in 1-pentanol/diesel blends. 1-pentanol/biodiesel blends also lowered the emissions of NOx, HC and CO simultaneously as compared to neat biodiesel, with a slight penalty of BTE. On the whole, the addition of 1-pentanol can be regarded as one of the promising fuel additives that can be used with both diesel as well as biodiesel fuels. The investigation was carried out only for 20% of 1-pentanol addition. Further investigation is required to determine the effects of other blend proportions of 1-pentanol as well as neat 1-pentanol on engine performance and emissions.

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