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Analysis of The Influences of Biodiesel On Performance and Emissions of a Diesel Engine

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Abstract: Biodiesel remains an alternative fuel of interest for use in diesel engines. A common characteristic of biodiesel relative to petroleum diesel, is a lowered heating value (or energy content of the fuel). This review paper discusses the characteristics of biodiesel that has a great influence on the performance and emission of diesel engine. A lower heating value of the fuel, assuming all other parameters are equal would result in decreased engine torque. Since engine torque is often user-demanded, the lower heating value of the fuel generally translates into increased brake specific fuel consumption. The biodiesel from edible oils is non-toxic, biodegradable and renewable alternate fuel that can be used as a substitute for diesel in diesel engines. There is some indication that the use of biodiesel fuel can degrade diesel engine oil performance to such an extent that shortening of oil drain intervals is required. Oil, which is fuel-diluted with biodiesel, which is also known to contain unsaturated hydrocarbon bonds would be expected to be more prone to oxidation. Besides, the use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOx emission on conventional diesel engines with no or fewer modification. Plus, it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel, with small content in place of petroleum diesel, can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However, many further researches on optimization and modification of engine, low temperature performances of engine, new instrumentation, methodology for measurements and etc., should be performed when petroleum diesel is substituted completely by biodiesel. In this study, reports about biodiesel engine performances and emissions, published by highly rated journals in scientific indexes were cited preferentially since the year 2000. From these reports, the effect of biodiesel on engine power, economy, durability, emissions including regulated and non-regulated emissions and the corresponding effect factors are surveyed and analyzed in detail.

Keywords: Performance, emissions, biodiesel, engine

1. Introduction

In the 1920's, diesel engine manufacturers alter their engines in such a way as to only use petroleum diesel and not vegetable oil. This is due to the lower viscosity of petroleum diesel when compared to straight vegetable oil. During the 1920's and 30's there was a growing interest in the use of vegetable oils as fuel, even though Petroleum diesels was accepted and in use everywhere [1-5]. A solution was found to some of the problems associated with the use of straight vegetable oil, like the choking of injectors and valves due to its higher viscosity. 1937 was a landmark year in the history

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of biodiesel. In this year a patent was granted to G. Chavannes from the University of Brussels for the: “Procedure for the transformation of vegetable oils for their uses as fuels”. The patent describes the process of alcoholises (also called transesterification) of vegetable oils using ethanol in order to separate the fatty acids from the glycerol by replacing the glycerol with short linear alcohols. In 1977 a Brazilian scientist named Expeditor Parented produced biodiesel using transesterification with ethanol and filed a patent for the process. This process is classified as biodiesel by international norms and set the standard for identity and quality [6-10].

Biodiesel remains an alternative fuel of interest for use in diesel engines. A common characteristic of biodiesel, relative to petroleum diesel, is a lowered heating value (or energy content of the fuel). A lower heating value of the fuel, assuming all other parameters are equal, would result in decreased engine torque. Since engine torque is often user-demanded, the lower heating value of the fuel generally translates into increased brake specific fuel consumption [11-15].

There is some other indication that the use of biodiesel fuel can degrade diesel engine oil performance to such an extent that shortening of oil drain intervals is required. Oil, which is fuel-diluted with biodiesel, which is known to contain unsaturated hydrocarbon bonds, would be expected to be more prone to oxidation. Besides, the use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOx emission on conventional diesel engines with no or fewer modification. Additionally, it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy [6-20]. The objective of this study is to find out the effect of biodiesel on engine performance (power, economy, durability) and emissions of a diesel engine experimentally.

2. Engine Performance

2.1 Effect of Biodiesel on Engine Power

Figure 1 shows the variation in engine power at full-load for different fuels. It is seen that there are no noticeable differences in the measured engine power output between diesel and B5 fuels. However, the measured engine power for other blends are lower than that of the diesel fuel. Maximum reduction in engine power for B20, B70 and B100 fuels is 6, 8 and 10 kW respectively. Lower heating value of the rapeseed oil is responsible for this reduction [11-13].

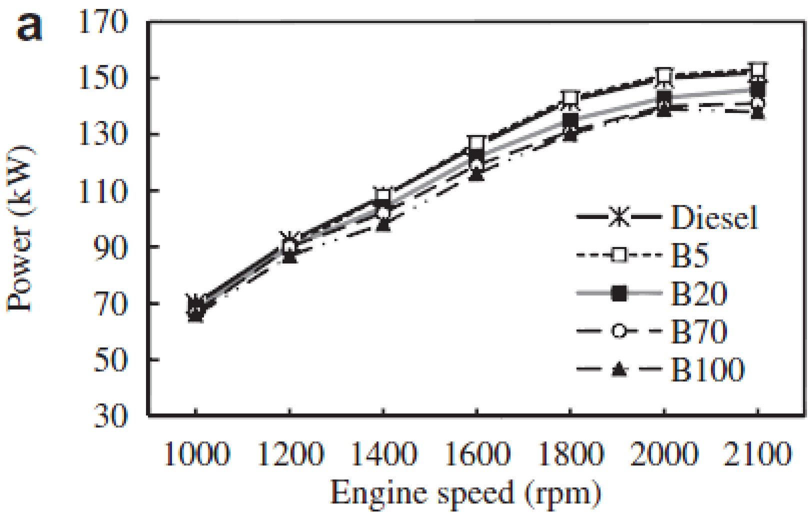

Fig. 1 - Variations of the power output with engine speed at full-load [11]

Figure 2 shows the variation in engine torque at full-load for different fuels. Maximum torque was obtained at 1600 rpm for each kind of fuel. At 1600 rpm, power and torque of the diesel and B5 fuels were almost imperceptible. At higher speeds, the torque delivered with B5 fuel was higher approximately 2 Nm on average than the torque delivered by diesel fuel. But, a more pronounced torque drop was observed for B20, B70 and B100 fuels, and the average torque drop between diesel and B20, B70 and B100 fuels is 19.7, 32 and 38.7 Nm respectively. At the speed of 1800 rpm, the maximum difference of the measured torques between diesel and B20, B70 and B100 fuels were found to be 2.2%, 4% and 5% respectively [11-13].

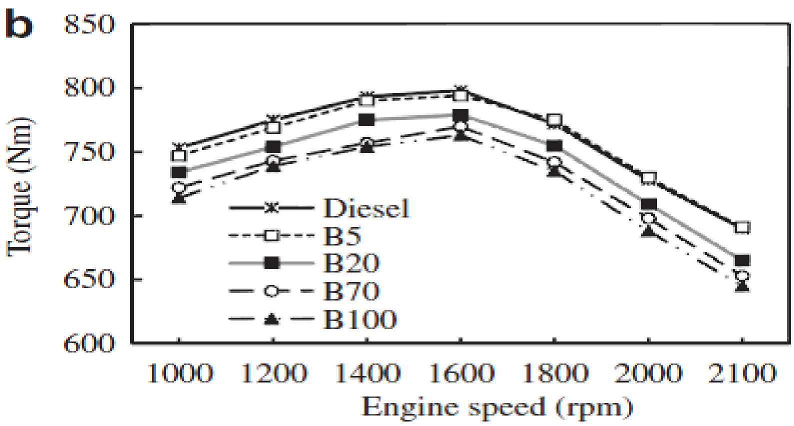

Fig. 2 - The engine torque with engine speed at full-load [11]

2.2 Brake-Specific Fuel Consumption

Brake-specific fuel consumption (BSFC) is the ratio between mass fuel consumption and brake effective power, and for a given fuel, it is inversely proportional to thermal efficiency as indicated in Figure 3. If the latter is unchanged for a fixed engine operation mode, the specific fuel consumption when using a biodiesel fuel is expected to increase by around 14% in relation to the consumption with diesel fuel, corresponding to the increase in heating value in mass basis. In other words, the loss of heating value of biodiesel must be compensated with higher fuel consumption. An indicator of the loss of heating value, and thus of the expected fuel consumption is the oxygen content in the fuel. Based on studies that mentioned the main reason for power loss is based the reduced heating value of biodiesel compared to diesel. The high viscosity and high lubricity of biodiesel also have certain effects on engine power. In addition, an additive used to improve ignition and combustion performances of biodiesel is advantageous for the power recovery of biodiesel engine. [21-22].

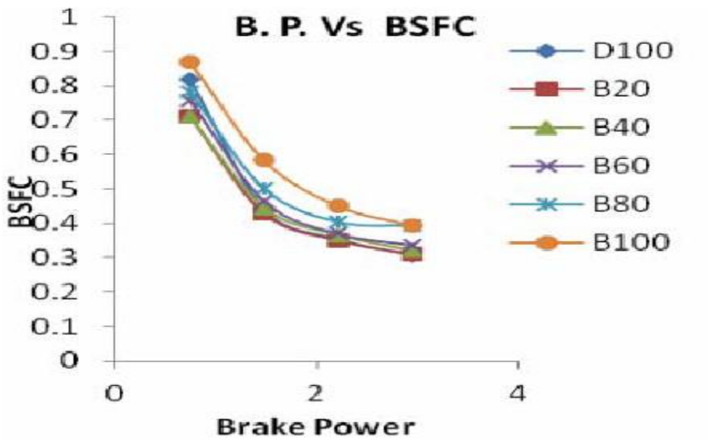

Fig. 3 - BSFC versus brake power [21-22]

2.3 Effect of Biodiesel on Engine Economy

Biodiesel engine economy is affected by engine type and its operating conditions, such as load, speed, and injection timing and injection pressure. The fuel consumption of an engine fueled with biodiesel becomes higher because it is needed to compensate the loss of heating value of biodiesel. Ekrem Buyukkaya [2] also reported in Figure 4, the variations in the BSFC with engine speed at full-load condition. At 1400 rpm, the BSFC of diesel and B100 fuels were 232 and 251 g/kWh respectively. BSFC of the B5, B20, B70 and B100 fuels were observed to be higher by 2.5%, 3%, 5.5% and 7.5% than that of the diesel fuel respectively. The higher fuel consumption of the B100 and their blends could be primarily related to lower heating value of the B100. The fuel consumption increase when using biodiesel, but this trend will be weakened as the proportion of biodiesel reduces in the blend fuel with diesel. The increase in biodiesel fuel consumption is mainly due to its low heating value, as well as its high density and high viscosity. The different feedstock of biodiesel with different heating value and carbon chain length, or different production processes and quality also have an impact on engine economy. The use of a turbocharged engine or a low heat release engine, will improve biodiesel engine economy. Engine operating conditions such as load, speed, injection timing, injection pressure and etc., are also influential to biodiesel engine economy, and although these influences are not essential, further study on these conditions should be executed to improve engine and its control systems in order to obtain the optimal match [23-24].

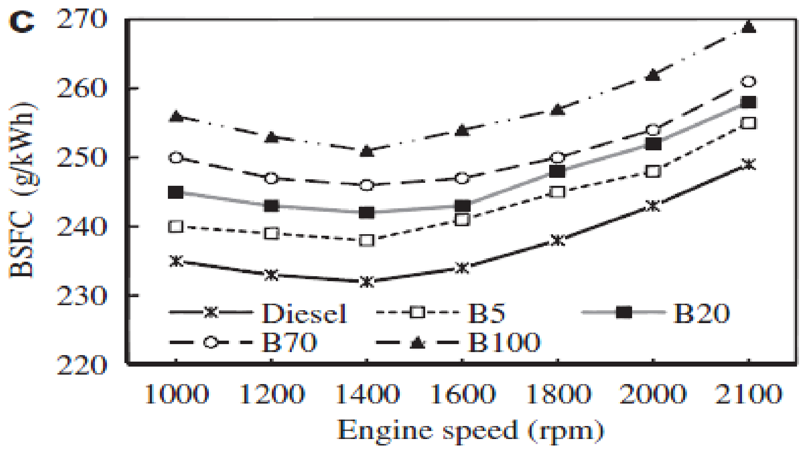

Fig. 4 - The BSFC with engine speed at full-load [23-24]

3. Emissions

3.1 PM Emissions of Biodiesel

Ekrem Buyukkaya [11] shows in Figure 5 that the smoke opacity variation of the engine for all the fuels. The smoke opacity for pure biodiesel and their blends are lower than that of the diesel fuel. Higher BTE indicates better and complete combustion of fuel, that is lesser amount of unburned hydrocarbons present in the engine exhausts gases. So, lower smoke opacity values are achieved with biodiesel blends as compared to that of the diesel fuel. The smoke opacity reduction was 45% with B70 while it was 60% with pre biodiesel. As the oxygen content increases, larger fractions of the fuel carbon are converted to CO in the rich premixed region, rather than soot formation. It is dominating argument that PM emissions of biodiesel are significantly reduced compared to diesel. This reduction will become smaller with the reduction of biodiesel proportion in the blended fuel, and abnormal variation may appear in the case of a certain content of biodiesel. The trend which PM emissions of biodiesel will be reduced is due to lower aromatic and sulfur compounds and higher cetane number for biodiesel, but the more important factor is the higher oxygen content. It should be noted that the advantage of no Sulphur characteristics for biodiesel will disappear as the sulfur content in diesel is becoming fewer and fewer. The larger the engine load, the greater the PM emissions of biodiesel. Additionally, the higher the engine speed, the lower the PM emissions Oxygenates can improve PM emissions of biodiesel, but it would not be useful for power recovery. The metal-based additives may be effective to reduce PM emissions of biodiesel due to catalyst effect. [2,16,17].

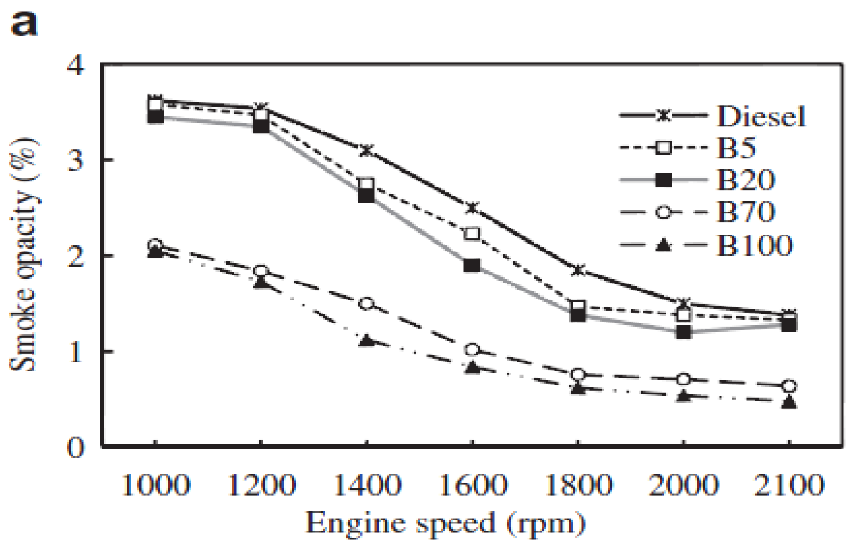

Fig. 5 - Variations of the smoke opacity with engine speed at full load [11]

3.2 NOx Emissions of Biodiesel

It is found in Table 1, that 65.2% literatures believe that the use of pure biodiesel causes the increase in NOx emissions. For example, a maximum of 15% increase in NOx emissions for B100 as shown in Figure 6 was observed at high load condition as the results of 12% oxygen content of the B100 and higher gas temperature in combustion chamber. [1]

Based on Figure 6, it is known that NOx formation is dependent upon volumetric efficiency, combustion duration and especially temperature arising from high activation energy needed for the reactions involved. Although the exhaust gas temperatures increased, the NOx emissions were observed to decrease with the increase in engine speed. This is primarily due to the increase in volumetric efficiency and gas flow motion within the engine cylinder under higher engine speeds, leading faster mixing between fuel and air, and shorter ignition delay. The reaction time of each engine cycle was thereafter reduces so that the residence time of the gas temperature within the cylinder was shortened. This led to lower NOx emissions under higher engine speeds. The increase in NOx emissions was proportional to the amount of biodiesel. In the case of pure biodiesel, the increase in NOx emission was 12% compared to the diesel fuel. There were also 6% and 9% increase in NOx emissions for B20 and B70 respectively. Similar conclusions were drawn by other authors. However, Dorado et al. indicated a decrease in NOx emissions using waste olive oil methyl ester instead of diesel fuelNOx emissions will increase when using biodiesel. This increase is mainly due to higher oxygen content for biodiesel. Moreover, cetane number and different injection characteristics also have an impact on NOx emissions for biodiesel. The content of unsaturated compounds in biodiesel could have a greater impact on NOx emissions. The larger the content of unsaturated compounds, the greater the amount of NOx emissions will be reduced, which is a matter of concern. The larger the engine load, the higher the level of NOx emissions for biodiesel, which is in line with the mechanism of NOx formation. [11, 26-27].

Table 1 - Statistics of effects of pure biodiesel on engine performances and emissions [1]

Total number of references	Increase Number %		Similar Number %		Decrease Number %		
Power performance	27 70.4	2	7.4	6	22.2	19	
Economy performance	62	54	87.1	2	3.2	6	9.7
PM emissions	73	7	9.6	2	2.7	64	87.7
NOx emissions	69	45	65.2	4	5.8	20	29.0
CO emissions	66	7	10.6	2	3.0	57	84.4
HC emissions	57	8	5.3	3	5.3	51	89.5
CO2 emissions	13	6	46.2	2	15.4	5	38.5
Aromatic compounds	13	-	-	2	15.4	11	84.6
Carbonyl compounds	10	8	80.0	-	-	2	20.0

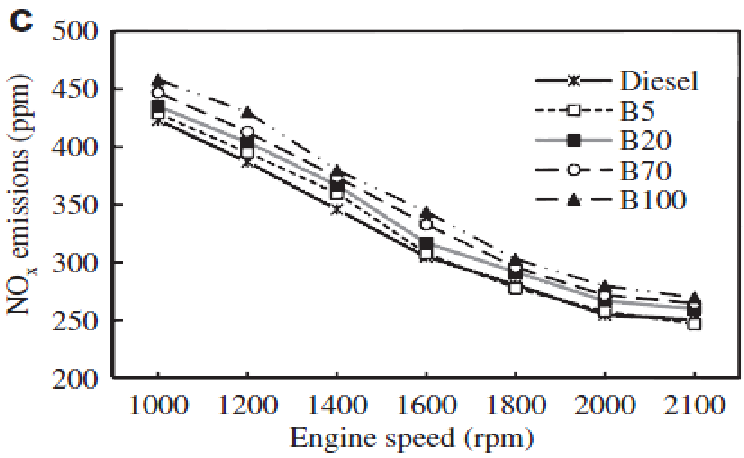

Fig. 6 - The NOx emissions with engine speed at full load [11]

3.3 CO Emissions of Biodiesel

Figure 7 shows the CO traces for different fuels. Ekrem Buyukkaya [11] observed that the CO emission decreased with the increase in engine speed. At low engine speeds, the CO emissions of the B5, B20, B70 and B100 are 12%, 25%, 31% and 35% lower than that of diesel fuel respectively. This decrease may be due to the oxygen content of the blends and pure biodiesel. Poor atomization and uneven distribution of small portions of fuel across the combustion chamber, along with a low gas temperature, may cause local oxygen deficiency and incomplete combustion [12]. The highest CO emission of 900 ppm was measured for diesel fuel at 1000 rpm. The CO emissions are shown to decrease more rapidly for all fuels from 1000 rpm to 1400 rpm. Reduced CO emissions were maintained, probably, thanks to the oxygen inherently present in the biofuel, which makes it easier to be burnt at higher temperature in the cylinder. Similar results can be found in other studies. CO emissions reduced when using biodiesel due to higher oxygen content and lower carbon to hydrogen ratio in biodiesel compared to diesel. With content of pure biodiesel increasing in the blends fuel, CO emissions of blends reduce. CO emissions for biodiesel are affected by its feedstock and other properties of biodiesel such as cetane number and advance in combustion. Engine load has been proven to have a significant impact on CO emissions. CO emissions of biodiesel reduce with metal based additives, and methanol and ethanol also further improve CO emissions [11-13].

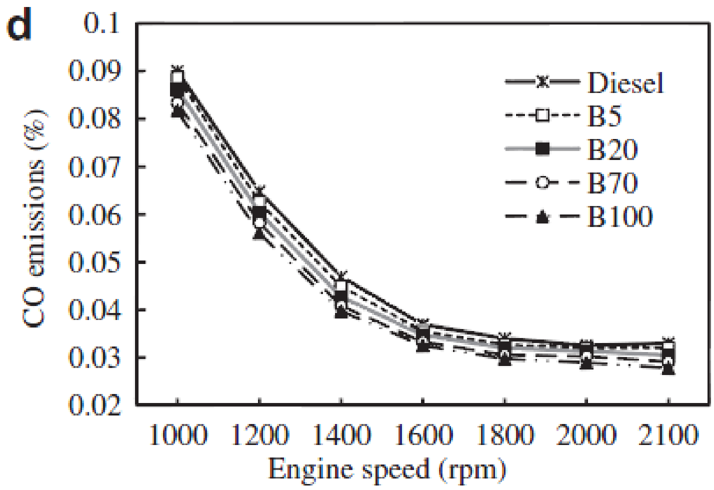

Fig. 7 - The CO emissions with engine speed at full load [11]

3.4 HC Emissions of Biodiesel

The variations of HC emissions for diesel and biofuels are shown in Figure 8. The emission of unburned HC is negligibly small for all the fuels. The HC emissions of B20, B70 and B100 fuels were lower than that of diesel fuel. The increased gas temperature and the higher cetane number as responsible for this decrease may be explained. Because higher temperature of the burned gases prevented condensation of the heaviest hydrocarbons in the sampling line, suggesting proper conditions for HC emission analysis. The higher cetane number of biodiesel causes a decrease in HC emissions due to the decrease in combustion delay. It is a predominant viewpoint that HC emissions reduce when pure biodiesel is fueled instead of diesel. HC emissions for biodiesel reduce with the increase of biodiesel content. The feedstock of biodiesel and its properties have an effect on HC emissions, especially for the different chain length or saturation level of biodiesels. The advance in injection and combustion of biodiesel favors the lower HC emissions. [11-12].

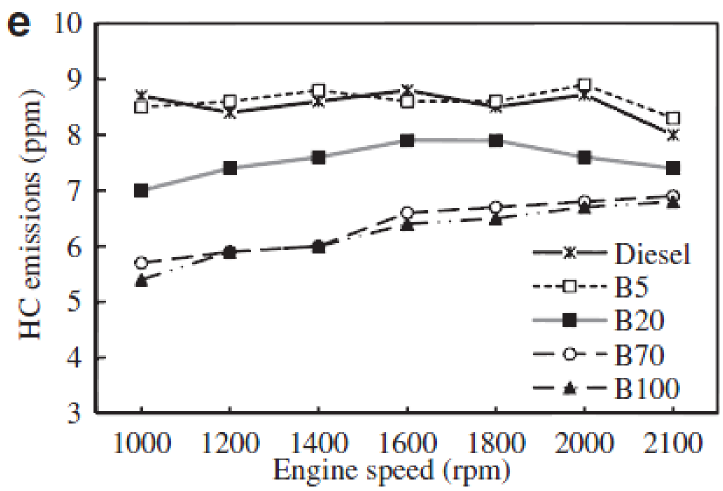

Fig. 8 - The HC emissions with engine speed at full load [11]

3.5 CO2 Emissions of Biodiesel

Since the contribution rate of traffic on CO2 emissions is as high as 23%, it was reported that, biodiesel resulted in fewer CO2 emissions than diesel during complete combustion due to the lower carbon to hydrogen ratio. This is attributed to the fact that biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. But, it was reported that either the constant or rise, of CO2 emissions is due to more efficient combustion.

It was pointed out in some literatures that in the case of biodiesel, the higher carbon dioxide emission should cause less concern because of Nature's recovery by raising biodiesel crops, while others evaluated the effect of biodiesel on global greenhouse gas emissions through the life cycle of CO2 emissions. And they pointed out that; biodiesel will cause 50–80% reduction in CO2 emissions compared to petroleum diesel [1-4].

4. Conclusion

i. The use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel, but there is the so-called power recovery for biodiesel engine, as the result of an increase in biodiesel fuel consumption. Especially for the blend fuel including a portion of biodiesel, it is not easy for drivers to perceive power losses during practical driving.

ii. An increase in biodiesel fuel consumption due to low heating value and high density, and viscosity of biodiesel, has been found, but this trend will be weakened as the proportion of biodiesel reduces in the blend. The use of biodiesel favors to reduce carbon deposit and wear of the key engine parts compared with diesel. It is attributed to the lower soot formation, which is consistent to the reduced PM emissions of biodiesel, and the inherent lubricity of biodiesel.

iii. The PM emissions for biodiesel are significantly reduced compared with diesel. The higher oxygen content and lower aromatic compounds has been regarded as the main reasons. The NOx emissions will increase by using biodiesel. This increase is mainly due to higher oxygen content for biodiesel. Moreover, the cetane number and different injection characteristics also have an impact on NOx emissions for biodiesel.

iv. The CO emissions reduce when using biodiesel due to the higher oxygen content and the lower carbon to hydrogen ratio in biodiesel compared to diesel. The HC emissions reduce when biodiesel is fueled instead of diesel. This reduction is mainly contributed to the higher oxygen content of biodiesel, but the advance in injection and combustion of biodiesel also favor the lower THC emissions.

v. It can be concluded that the blends of biodiesel with small content by volume could replace diesel in order to help in controlling air pollution and easing the pressure on scarce resources to a great extent without significantly sacrificing engine power and economy.

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