EMISSION CHARACTERISTICS OF POLYMER ADDITIVE MIXED DIESEL-SUNFLOWER BIODIESEL FUEL

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Emission Characteristics of Polymer Additive Mixed Diesel-Sunflower Biodiesel Fuel

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Abstract

Combustion of fossil fuels has a significant share in producing harmful emissions in the global emission context. With a threat of fossil fuel crisis and the necessity of reducing emission from diesel engine combustion system, biodiesel is considered as one of the key environmentally-friendly diesel fuel alternatives. In this study, sunflower biodiesel has been considered as a key ingredient to infuse waste plastic (polystyrene, PS) as another cleaner source of hydrocarbon fuel in the diesel engines. Polystyrene was infused (5\% w/v) into sunflower biodiesel to produce a blend of diesel-biodiesel-polymer (DBP) fuel. The emission characteristics of the diesel, diesel–biodiesel (binary blend) and diesel-biodiesel-polymer (ternary blend) were compared in an unmodified diesel engine. The results showed that the emission compositions of the DBP were comparable to those of diesel which effectively reduced the NOx emission, as compared to diesel-biodiesel blend. In addition, the brake specific fuel consumption (BSFC) and CO emission were reduced in DBP, as compared to biodiesel and diesel fuels. Based on these results, it can be concluded that the polymer blended fuels could be potentially used as another emission reducing fuel source in an unmodified diesel engine. The utilisation of waste polymers in biodiesel production could help find an alternative use for non-recyclable plastics, while also contributing to cleaner emission.

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1. Introduction

Biodiesel has been recognized as a biodegradable and renewable alternative to fossil fuels that can potentially be used in the diesel combustion engines [1, 2]. Biodiesel fuels can include long-chain mono-alkyl fatty acid esters produced from edible and non-edible vegetable oils, waste oils, grease, and animal fats to comply with either the US (ASTM D6751) or European (EN14214) fuel standards [3]. Regardless of the feedstocks used in biodiesel production, the replacement of fossil fuel diesel with biodiesel is one strategy that can contribute to reduction of greenhouse gas (GHG) emissions to the environment. For example, researchers from the Argonne National Laboratory have reported that the combustion of pure biodiesel (B100) in the diesel engine emits about 74% less GHG than a conventional diesel fuel derived from crude petroleum oil [4].

Although the potential of biodiesel to reduce net CO₂ emissions has been reported, two of the challenges that limit more extensive replacement of fossil fuel diesel with biodiesel are (1) an increased emission of NOx (nitrogen oxides) from biodiesel and (2) the high viscosity of biodiesel fuels [1, 3]. Thus, one biodiesel adoption strategy is to blend biodiesel with fossil fuel diesel fuels, and acceptable limits of diesel-biodiesel blend compositions have been developed to safely use the biodiesel without affecting the diesel engines and to minimize NOx emissions. [1, 3] In this paper, we explore the blending of an ultra-low sulphur diesel (fossil fuel derived) with a sunflower (SF) biodiesel and with a biodiesel-polymer (BP) produced from the SF biodiesel and waste polystyrene plastics.

The objectives of this investigation are to observe the suitability of using non-recyclable waste plastics as a fuel additive, and to promote recycling of waste plastics. Various types of polymer and plastic wastes are generated every year from the global consumption of more than 280 million tonnes of plastic products (2012 data) [5-7], and because the overall plastic waste recycling rate is very low [6, 8] and large volumes of plastic are buried in landfills. These waste plastics contain large amounts of energy due to their chemical composition and their production processes consumes significant amount of energy supply. For example, Migdał et al. [9] summarized reported calorific values of polyethylene (PE) 43 MJ/kg, polypropylene (PP) 44 MJ/kg, polystyrene (PS) 40 MJ/kg, polyvinylchloride (PVC) 18 MJ/kg and polyethylene terephthalate (PET) 34 MJ/kg (PET). This paper explores the use of waste plastics in biodiesel fuel blends as one potential recycling routes for plastic wastes that would otherwise be disposed to landfill [7].

2. Materials and Methods

Ultra-low sulphur diesel (ULSD), sourced from a local gas station, contained less than 10 ppm of sulphur, had a cetane number of 51, and a calorific value of 45.65 MJ/kg. The referenced sunflower biodiesel had about 56.6% linoleic acid (C18:2) and 29.9% oleic acid (C18:1), an iodine value of 130, cetane number of 54.3, and a calorific value of 40.58 MJ/kg. Polystyrene with a calorific value of 40 MJ/kg [9] was considered as a polymer additive. Three fuel blends were combusted in a Kubota V3300 diesel test engine (i) ULSD, (ii) ULSD + 5% volume SF biodiesel, and (iii) ULSD + 5% volume SF + 5% volume PS. Emission contents have been investigated from the combustion of diesel (ULSD), diesel with 5% SF, and diesel with 5% PS+ 5% SF (SF5PS5). Engine test were run at a full load condition and the speeds were 800, 1200, 1500, 1800, 2100 and 2400 rpm. Emission of particulate matter (PM) from the engine was measured with a MAHA MPM-4M instrument, and other emissions such as CO₂, CO, NOx and unburnt hydrocarbon were measured with a CODA 5 gas analyser.

3. Results and Discussion

Among the emitted pollutants from diesel engines [10], CO₂ is an obvious product due to combustion of hydrocarbons, but the incomplete combustion of fuel generates CO and HC, while the higher combustion temperature influences the NOx emissions. Apart from these gases, there are some particles inherently present in the fossil fuels, which lead to PM emissions due to incomplete burning of these elements, sulphur contents, lube oil as well as the ash contents along with the water present in the combustion of fuel.
3.1. Particulate Matter (PM) Emission

Low emissions engine technologies have excelled the concerns of nanoparticle emissions from diesel engines [11, 12]. Usually the organic volatile compounds, elemental carbons, inorganic compounds and several trace metals produced from combustion of liquid fuels contribute to emission of particulates from engines. In this research, the MAHA MPM-4M particle measurement device was used in the engine exhaust streams with special arrangements provided by the manufacturers to measure the PM emission level as mass per volume (mg/m$^3$) which applies a laser light-scattering photometry method to analyse particles less than 100 nm width. Figure 1 shows the emission level of PM for the three tested fuels - diesel, SF5, and the diesel-SF5-PS5 (SF5PS5). The results show that the biodiesel composition reduces the quantity of PM in the engine exhaust compared to the diesel, and factors that may cause this reduction in PM include the biodiesel contains more oxygen, no sulphur, and long chain fatty acids. Another reason for low particulate emission could be due to the use of ULSD fuel with biodiesel fuel, where the excess oxygen from the biodiesel fuel in the diesel-biodiesel blend did not have enough opportunity to produce sulphur nanoparticles.

3.2. Nitrogen Oxides (NOx) Emission

The NOx emissions from combustion of diesel, SF5 and SF5PS5 are presented in Fig. 2, which shows that the mixing of PS polymer in the diesel-biodiesel blend increased the NOx emission but at speeds less than 1800 rpm. The NOx emission from SF5PS5 are not significantly higher than the diesel fuel until 1500rpm. The reason for increased particulate emission after addition of PS could be the efficient burning of carbon in the SF5PS5 blend. With the increase in speed, the formation of NOx increases due to the increased fuel flow rate for all the fuels. Although biodiesel-diesel blend emits more NOx than diesel fuel only, the addition of polymer in the diesel-biodiesel blend reduces the emission level. The percentile reduction of NOx emission with SF5PS5 fuel in comparison to diesel fuel is presented in Fig. 4. Both 1800 rpm and 2100 rpm levels have shown large amount of NOx reduction with the polymer additive. The reason could be oxygen deficiency in comparison to the amount of nitrogen. The extra carbon and hydrogen from the PS causes better combustion in the combustion chamber.

3.3. Carbon Dioxide (CO$_2$) Emission

The CO$_2$ emissions from combustion of ULSD, SF5 and SF5PS5 fuels at full loaded engine operation are compared in Fig. 3. In general, CO$_2$ emission is lower at 800 rpm but increases sharply towards 1200 rpm level and keeps almost a reduced steady level at other speed conditions. At 1200 rpm the torque was recorded as 224, 224 and 222 N/m for diesel, SF5 and SF5PS5 fuel respectively, which implies a better burning condition of the fuels. Though the biodiesel blend reduces the emission quantity at all speed levels, the addition of polymer increases the amount of hydrocarbon available for more combustion and lead to the rise of CO$_2$ emission. The emission level of SF5PS5 fuel is of almost similar profile to the diesel fuel emissions. Hence the addition of polymer PS into the diesel fuel does not appear to have any negative impact on CO$_2$ emissions.
Inadequate combustion of the fuel in the combustion chamber with improper fuel oxidation can produce carbon monoxide (CO) gas, which is odourless as well as colourless and could cause severe health issues, if inhaled. The concentration of CO in the emission stream largely depends on the air to fuel mixture condition and ratio. Mostly, if the equivalence ratio (λ) is less than 1 and at the time of ignition starting or rapid acceleration condition causes improper oxidation of the carbon resulting in the formation of CO [13]. Since the diesel engines are operated with higher equivalence ratio, the emission of CO is expected to be very low [14]. The variation in CO emission and AFR at various speeds of the diesel, SF5 and SF5PS5 fuels are shown in the Fig. 5 and Fig. 7 respectively. It can be seen that the CO emission is very high at the 800 rpm and 1200 rpm for all the fuels. After the higher torque condition at 1200 rpm, the emission of CO reduces to minimal for both SF5 and SF5PS5 fuels, but diesel fuel continues to generate more CO than the other fuels but less than that produced at 1200 rpm. The AFR was very high at the beginning, but inconsistent combustion of the fuel causes higher CO emission at that condition. The results show that the polymer blend fuel could be a useful practice due to its less harmful emission in comparison to diesel fuel.

### 3.5. Unburnt Hydrocarbon (HC) Emission

Improper oxidation and inconsistent combustion of the fuel in the combustion system can lead to emission of unburnt hydrocarbon in the diesel fuel exhaust emission stream. In Fig. 6, the HC emission of diesel, SF5 and SF5PS5 fuels are shown at speeds between 800 and 2400 rpm at a full load operation condition. The SF5 blend
shows less HC emission when compared to the diesel fuel emission due to presence of more oxygen in the mixture and better combustion. But the addition of polymer in the system, i.e. the fuel blend SF5PS5 causes almost a steady higher rate of unburnt hydrocarbon emission due to increased HC addition to the combustion system.

![Fig.5. Carbon Monoxide (CO) Emission](image1)

![Fig.6. Unburnt Hydrocarbon (HC) Emission](image2)

![Fig.7. Air-Fuel Ratio (AFR) of the Fuels](image3)

![Fig.8. Exhaust Gas Temperature (EGT)](image4)

### 3.6. Exhaust Gas Temperature (EGT)

Exhaust gas temperature was measured in the engine combustion analyser system. The variation in exhaust gas temperature is presented in Fig. 8 for the test fuels at operating conditions for exhaust emissions analysis. While observing the exhaust gas temperature, the diesel fuel exhaust gas temperature varied from 401 °C to 571 °C, the SF5 blend exhaust temperature varied between 391 °C and 570 °C, whereas the SF5PS5 fuel blend exhaust temperature ranges from 401 °C to 565 °C. With almost similar exhaust gas temperature profile at the given operating conditions, the SF5 fuel emits more NOx due to increased availability of oxygen, whereas, the SF5PS5 blend reduces the NOx emission by reducing the oxygen content in the combustion chamber as well as in the exhaust stream. With polymer addition in the fuel mixture, the cooling system did not require any extra effort to cool down the combustion chamber in comparison to the diesel fuel system only. Since the higher temperature and higher residence time of the combustion gases provokes the NOx formation process, effective cooling system could be another factor in reducing the EGT as well as NOx emission in the diesel engines.
4. Conclusions

In this study, two fuel blends were considered for comparison of emission characteristics. These blends were used in an unmodified diesel engine, with mineral diesel being used as the control fuel. The calorific values of the SF5 and SF5PS5 were very close, but the SF5PS5 contained more hydrocarbon along with oxygen from the biodiesel fuel. Therefore, the NOx emission and CO emission were seen to be reduced with the SF5PS5 blend. In addition, the BSFC reduced significantly for the SF5PS5 blend compared to SF5, demonstrating less fuel consumption for a negligible torque reduction at peak operating conditions. Although the CO2 and PM emission increased with the SF5PS5 fuel blend in comparison to SF5 fuel, these emission were not much higher than the diesel fuel and they were rather equivalent. Thus, the polymer additive may not be considered as a threat to environmental emissions. Further study is recommended to investigate for a range of second-generation biodiesel.

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