A Novel Diesel Fuel Additive to Improve Fuel Properties and to Reduce Emissions

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Abstract

Global air pollution is a serious threat caused by excessive use of fossil fuels for transportation. Despite the fact that diesel fuel is a big environmental pollutant as it contains different hydrocarbons, sulphur and crude oil residues, it is yet regarded as a highly critical fuel due to its wide applications. Nowadays, biodiesel as a renewable additive is blended with diesel fuel to achieve numerous advantages such as lowering CO2, and CO emissions as well as higher lubricity. However, a few key drawbacks including higher production cost, deteriorated performance and likelihood to increase nitrogen oxide emissions have also been attributed to the application of diesel-biodiesel blends. Expanded polystyrene (EPS), known as a polymer for packaging and insulation, is an ideal material for energy recovery as it holds high energy value (1 kg of EPS is equivalent to 1.3 liters of liquid fuel). In this study, biodiesel was applied as a solvent of expanded polystyrene (EPS) during a special chemical and physical treatment. Various percentages of EPS in biodiesel blended diesel were tested to evaluate the fuel properties, emissions and performance of CI engine. The results of the variance analysis revealed that the addition of the additive improved diesel fuel properties by increasing the flash point as well as the reduction of density and viscosity. Despite a 3.6% reduction in brake power, a significant decrease in brake specific fuel consumption (7.26%) and an increase in brake thermal efficiency (7.83%) were observed at the full load and maximum speed of the engine. Additionally, considerable reductions of CO, CO2, NOx and smoke were achieved.

Keywords: *Diesel fuel, Biodiesel, Polymer, Fuel additive, Engine Performance, Emissions*

1. INTRODUCTION

Today, most of the developed countries have found mass production and commercialization of bioenergy as a suitable approach to overcome the fuel source leakage and environmental pollution [1]. Biodiesel is one of the biofuels known as a unique alternative to reduce emissions emitted from diesel combustion engines [2,3]. This mono-alkyl ester of long chain fatty acids, known as biodiesel, is synthesized through the transesterification reaction of triglycerides derived from available, abundant and renewable feedstock, like vegetable oils and animal fats. During the reaction, these oils are alcoholized (usually by methanol) in the presence of a catalyst (usually KOH) resulting in ester formation (methyl ester) and glycerin as a byproduct [4]. Despite all the advantages attributed to the application of biodiesel blends such as decreased CO2 and CO emissions as well as higher lubricity, occasionally it leads to increased NOx emissions depending on its inclusion percentage in fuel. Biodiesel also has other disadvantages including lower calorific value and power output in comparison with petroleum diesel which should be addressed [5].

In the recent years, world population growth together with human need for more comfortable life style has led to increased polymer consumption [6]. During last decades, despite progress in science and industry, a great deal of plastic wastes have been generated commonly disposed in landfills or incinerated [6]. Expanded polystyrene (EPS) is a good option for packaging systems due to its acceptable thermal insulation and high impact resistance. EPS is an ideal material for energy recovery as it holds a high energy value. However, conventional recycling methods are non-economic because it contains nearly 98% air in volume [7]. Moreover, it occupies a massive space in order to be transported to recycling facilities [8]. Heat value of EPS degradation is about 800 J/g (191.08cal/g) [9]. Flash point and auto-ignition temperature of EPS are 350 °C and 490 °C, respectively [10]. Considerable air within the cellular and spongy structure of EPS provides an excellent condition for a rapid flame spread [10]. The above-mentioned characteristics of EPS make it suitable to be used as an additive for fuel.

Many parameters determine the quality of biodiesel such as the flash point defined as the lowest temperature at which a volatile material can vaporize to form an ignitable mixture in air [13, 14]. This parameter along with vapor pressure is influencing factors on ignition, combustion and storage of the fuel [15]. Density as a key fuel attribute affects the engine performance as fuel system is calibrated by volume (i.e mass of the injected fuel changed by fuel density) and it also affects the other parameters such as cetane number and heating value [16]. Another contributing factor that affects the fuel spray characteristics is fuel's viscosity [17]. Knothe and Steidley [18] in a study conducted to predict the viscosity of biodiesel found that biodiesel viscosity was significantly influenced by its molecular structure such as chain length, position, number, and nature of double bonds, as well as nature of oxygenated moieties. Alptekin and Canakci [16] investigated the density and viscosity variations in biodiesel-diesel blends. They reported that the density and viscosity of diesel fuel were lower than those of biodiesel.

The objective of this study was to improve the characteristics of biodiesel produced from low cost resources such as waste cooking oil by the inclusion of waste polymers i.e. EPS. To investigate that, EPS was included in biodiesel and extensive engine tests (performance and emissions) were conducted on the formulated diesel/modified biodiesel blend to evaluate the application of this additive.

2. Materials and Methods

Preparation of fuel samples

Biodiesel was produced from waste cooking oil through the reaction of methanol and KOH as a catalyst in a batch reactor located at Urmia University. After separating biodiesel from glycerin, it was washed and purified. EPS waste was obtained from foam protectors of electronic devices with the density of 17 kg/m3. Three EPS levels (2.5, 5 and 7.5 g) were dissolved in 100 ml of biodiesel with a heating treatment at 60°C with dissolution reaction time set at 40, 50, 60 min, respectively. Fuel samples were homogenized using 5% acetone (wt. /wt. biodiesel) as a co-solvent. These samples were blended with diesel fuel to make 5% blends.

3. Engine tests

The produced B5 blends (EPS-biodiesel-diesel) along with B5 without EPS inclusion (control) were tested in a diesel engine. The engine specifications are presented in Table 1

Table 1. The tested engine specifications

MT 4.244 engine	
Bore	100 mm
Stroke	127 mm
No. of cylinders	4-in line, vertical
Cubic capacity	3.99 lit
Max. power	82 bhp @ 2000 rpm
Max. torque	360 N.m @ 1300 rpm
Combustion system	Direct injection
Induction system	Turbocharged
Compression ratio	17.5:1

The engine tests were performed according to the8-mode ECE-R96 standard. In each mode, some parameters such as speed, torque, power, consumed air and fuel, lambda and emissions i.e.CO, CO_2, NO_x, smoke, and O_2 were measured.

4. Engine performance characteristics calculation

Engine performance parameters are defined as follows:

$$P_b = \frac{2\pi.\omega.T}{1000} \quad (1)$$

where ω is the rotational speed (rev/s), T is brake torque (N.m), and P_b is brake power (kW).

$$bmep = \frac{P_b.n_r}{V_d.\omega} \times 10^3 \quad (2)$$

where n_r is the number of crank revolutions for one complete cycle, V_d is displacement volume of cylinders and bmep is brake mean effective pressure (Pa).

$$bsfc = \frac{\dot{m}_f}{P_b} \times 10^3 \quad (3)$$

where $\dot{m}_f$ is fuel mass flow rate (kg/h) and bsfc is brake specific fuel consumption (g/kW.h).

$$bte = \frac{P_b}{\dot{m}_f.Q_{LHV}} \times 3600 \quad (4)$$

where Q_{LHV} is lower heating value of fuel (kJ/kg) and bte is brake thermal efficiency.

The equivalence ratio of burning fuels was calculated as shown in Eq. 5:

$$\psi = \frac{(F/A)_{actual}}{(F/A)_{stoich}} \qquad (5)$$

On the other hand, Lambda (λ) is the ratio of actual air-fuel ratio to stoichiometry and is defined as:

$$\lambda = \frac{1}{\psi} \qquad (6)$$

5. Results and Discussion

Multiple comparison procedure using Duncan and ANOVA analysis were conducted to assess the influence of EPS content and speed on the engine performance parameters and emissions at full load ($p < 0.05$). The results of the engine tests were prepared to determine the optimum composition of the fuel additive. Moreover, the influence of the fuel additive was investigated on performance and emission parameters at the full load. Variations of engine performance parameters and emissions due to the different inclusion percentage of EPS are demonstrated in Fig. 1. At the full load of engine operation condition, for the highest speed (2000 rpm), by increasing the EPS content, O2 increased yet NOx, CO and CO2 decreased significantly. Moreover, a meaningful increase of bte and significant declination of bsfc were observed. Pb and bmep also declined. Taking into consideration the results of the engine tests, it can be concluded that the inclusion of 5 g EPS in 100 ml biodiesel followed by its combustion as B5 could be a promising breakthrough in order to achieve emission reduction from diesel engines and simultaneous improvement of fuel quality. In a similar study, Kuzhiyil and Kong [11] founded that the feasible limit of polystyrene concentration was 10% by weight, beyond which the fuel mixture became too viscous for proper fuel pump operation. Results indicated that the optimal polystyrene concentration that could be used without difficulties in fuel flow and injection was 5% by weight.

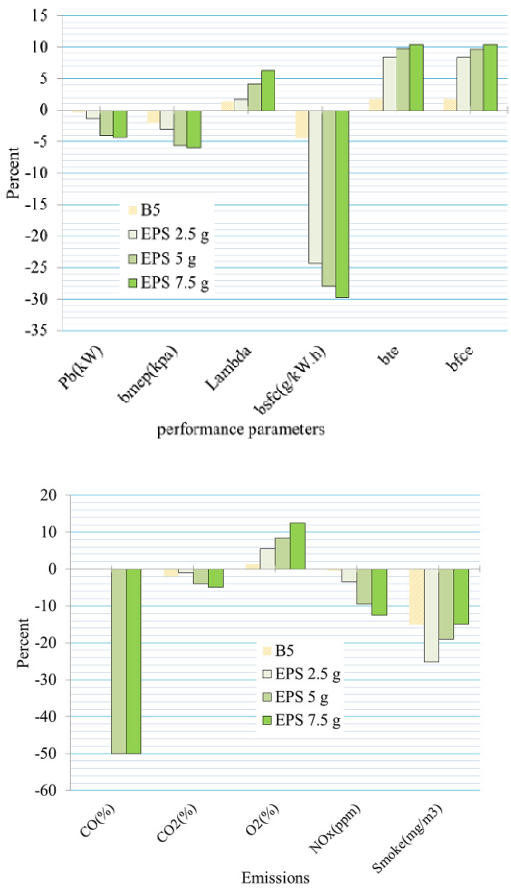

Fig1. Influence of EPS content on engine parameters a) performance, b) emissions

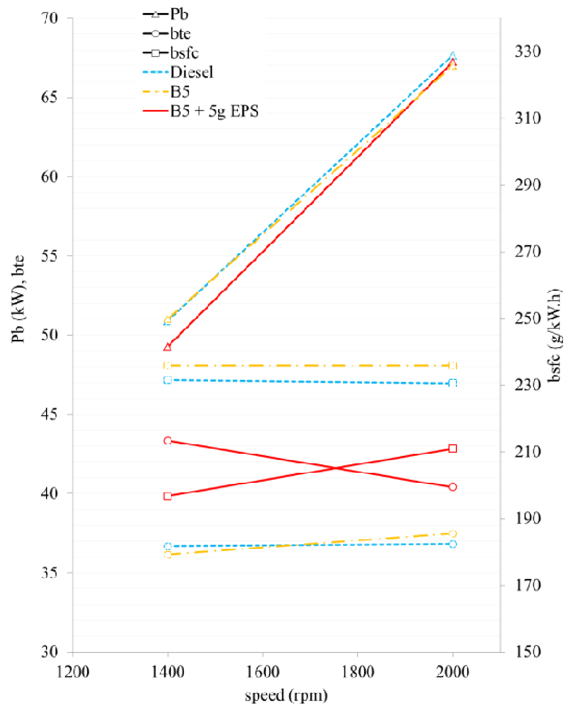

Fig2. Performance parameters vs. speed at full load

As demonstrated in Fig. 2, in comparison with diesel and B5 fuels and despite a negligible reduction of Pb, a significant increase of bte and a meaningful reduction of bsfc for the B5 plus 5 g EPS fuel were achieved. This can be justified by the high heating value of EPS. Also, Kuzhiyil and Kong [11] reached a maximum power at 5% polystyrene concentration and reported that power decreased for higher concentrations.

As shown in Fig. 3, CO emission was measured to be lower with increasing the speed at equal torques. The results showed that the presence of 5% biodiesel in fuel had no influence on CO emission, while adding the additive (5% biodiesel including 5 g EPS) reduced the CO emission (37.1 and 50% at speed of 1400 and 2000 rpm, respectively). Kuzhiyil and Kong [11] concluded that increasing EPS concentration led to higher CO emissions due to possibly poor fuel spray atomization. Conversely, in this study CO emission was significantly decreased with EPS blending that can be justified by the lower viscosity of acetone. This result demonstrated that the additive improved the combustion through the preparation of good conditions in combustion chamber to burn fuel-air mixture completely [1]. The results of other emission analyses are illustrated in Fig. 4. Unlike an increase observed in CO2 emission at the speed of 1400 rpm, when the B5 EPS free fuel was applied, CO2 reductions of 3.96 and 1.6 % were observed when the fuel additive was blended in fuel at 1400 and 2000 rpm, respectively. This is additionally observable from lower bsfc and lower carbon to form CO2 [1].

As generally presented in the literature, adding biodiesel to diesel fuel and its combustion lead to increased exhaust NOx pollutant [1]. The results obtained in this study revealed a reducing effect of the additive on NOx emission (12.45%) at maximum rated power and speed, as demonstrated in Fig. 4. In a similar research, Kuzhiyil and Kong [11] also reported that NOx emissions were reduced slightly by increasing EPS concentrations. Furthermore, higher oxygen content of biodiesel provides a better combustion resulting in lower amounts of smoke [1]. This is clearly depicted in this study. Generally, there was a decreasing trend for smoke emission when the additive was used compared to using B5 fuel.

The results of flash point, density, dynamic and kinematic viscosities analyses of the fuel containing the additive along with diesel and conventional B5 fuels are shown in Table 2. ASTM D93 defines a minimum flash point of 130 °C for biodiesel [15]. This, as one of advantages of biodiesel, leads to an overall increase of the flash point of the fuel and consequent safer storage and transport when biodiesel is blended with petroleum diesel [16].

Alptekin and Canakci [16] demonstrated that the density of the blended fuels increases dramatically proportional to the biodiesel percentage. When fuel density increases by a constant volume, mass of fuel (moles of hydrocarbons) will increase. As injectors commonly operate based on the adjustments of fuel volume, this in turn introduces some problems within the engine's fueling system. In other words, it means higher fuel/air ratio leading to deteriorated combustion process in the engine [19]. Due to reduction of CO, CO2 and smoke, it can be stated that the higher density of additive-blended fuel would have no inappropriate impact on combustion.

Results obtained in this study suggest that the inclusion of the additive improves B5 fuel viscosity. Knothe and Steidley [18] reported the kinematic viscosity values based on the diesel fuel standards (ASTM D445) at 1.9-4.1 and 1.9-6.0 mm^2/s corresponding to diesel and biodiesel fuel, respectively. High values of viscosity interferes with the injection system operation causing poor atomization, deteriorated cold weather flow properties, increased engine deposits and increased energy needs for fuel pumping [16]. Therefore, reduction of B5 fuel viscosity using EPS and acetone should be a considerably unique approach to improve high viscosity challenges of biodiesel blended diesel fuel.

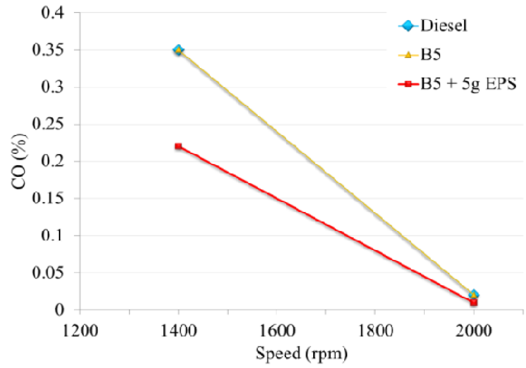

Fig3. CO emission vs. speed at full load

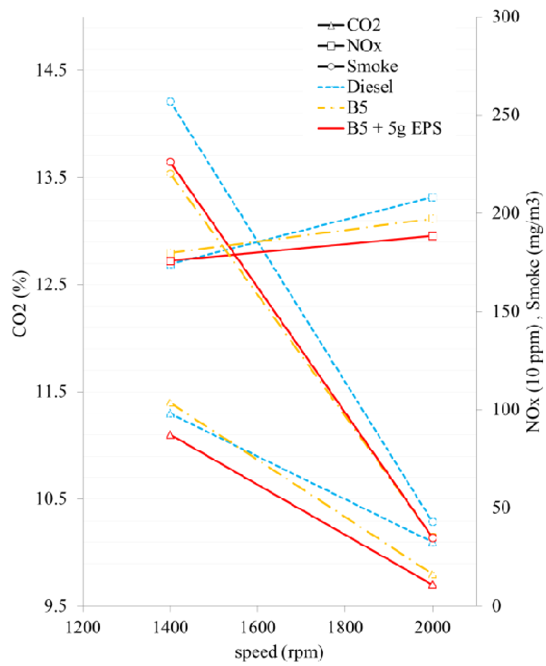

Fig4. Emissions vs. speed at full load

Table 2. Physical parameters of fuels

	Flash Point (°C)	Density (g/cm^3)	Dynamic viscosity (mPa.s)	Kinematic viscosity (mm^2/s)
Diesel	52	0.8169	2.3902	2.9259
B5	56	0.8233	2.7943	3.3458
$Diesel^{5+}$	59	0.8222	2.4626	2.9952

6. Conclusions

Performance and emissions of diesel engine fuelled by biodiesel-blended fuel; B5 including 5 g EPS were evaluated. The results demonstrated that the inclusion of B5+5g EPS to diesel fuel decreased all the emissions and improved engine performance parameters. Five grams EPS dissolved in the petrodiesel fuel blended with 5% biodiesel provided the best response considering the engine performance and emission criteria. Hence, the produced fuel will serve as a serious alternative for reduction of environmental pollutions. Moreover, it provides a recycling approach for plastic wastes resulting in an environmental-friendly way of energy generation.

References

[1]. Xue, J., Grift, T.E., Hansen, A.C., 2011. “Effect of biodiesel on engine performances and emissions”. Renewable and Sustainable Energy Reviews 15, pp. 1098–1116

[2]. McCarthy, P., Rasul, M.G., Moazzem, S., 2011, “Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different bio-diesels”. Fuel, 90, pp. 2147–2157.

[3]. Lin, C.Y., Li, R.J., 2009, “Engine performance and emission characteristics of marine fish-oil biodiesel produced from the discarded parts of marine fish”. Fuel Processing Technology, 90, pp. 883–888.

[4]. Guo, Y., Yang, F., Xing, Y., Li, D., Fang, W., Lin, R., 2009, “Study on volatility and flash point of the pseudo binary mixtures of sunflower-based biodiesel + methylcyclohexane”, J. Hazard. Mater.,276, pp. 127–132.

[5]. Buyukkaya, E., 2010, "Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics”, Fuel, 89, pp. 3099–3105.

[6]. Achilias, D.S., Roupakias, C., Megalokonomos, P., Lappas, A.A., Antonakou, E.V., 2007, “Chemical recycling of plastic wastes made from polyethylene (LDPE and HDPE) and polypropylene (PP)”, Journal of Hazardous Materials, 149, pp. 536–542.

[7]. Xue, F., Takeda, D., Kimura, T., Minabe, M., 2004, “Effect of organic peroxides on the thermal decomposition of expanded polystyrene with the addition of a-methylstyrene”, Polymer Degradation and Stability, 83, pp. 461–466.

[8]. Shin, C., Chase, G.G., Reneker, D.H., 2005, “Recycled expanded polystyrene nanofibers applied in filter media”, Colloids and Surfaces A: Physicochem Eng. Aspects, 262, pp. 211–215.

[9]. Kannan, P., Biernacki, J.J., Visco Jr., D.P., 2007, “review of physical and kinetic models of thermal degradation of expanded polystyrene foam and their application to the lost foam casting process”, J. Anal. Appl. Pyrolysis, 78, pp. 162–171.

[10]. Doroudiani, S., Omidian, H., 2010, “Environmental, health and safety concerns of decorative mouldings made of expanded polystyrene in buildings”, Building and Environment, 45, pp. 647–654.

[11]. Kuzhiyil, N., Kong, S.C., 2009, “Energy Recovery from Waste Plastics by Using Blends of Biodiesel and Polystyrene in Diesel Engines”, Energy & Fuels, 23, pp. 3246–3253.

[12]. Zhang, Y., Mallapragada, S.K., Narasimhan, B., 2010, “Dissolution of Waste Plastics in Biodiesel”, Polymer Engineering and Science, 50, pp. 863–870.

[13]. Boog, J.H.F, Silveira, E.L.C., Caland, L.B.d., Tubino, M., 2011, “Determining the residual

alcohol in biodiesel through its flash point", Fuel, 90, pp. 905–907.

[14]. Kouame, S.D.B., 2011, Comparative characterization of Jatropha, soybean and commercial biodiesel. j. Fuel Chem. Technol., 39, pp. 258-264.

[15]. Candeia, R.A., Silva, M.C.D., Filho J.R.C., Brasilino, M.G.A., Bicudo, T.C., Santos, I.M.G., Souza, A.G., 2009. "Influence of soybean biodiesel content on basic properties of biodiesel–diesel blends". Fuel, 88, pp. 738–743.

[16]. Alptekin, E., Canakci, M., 2008. "Determination of the density and the viscosities of biodiesel– diesel fuel blends". Renew. Energy. 33, pp. 2623–2630.

[17]. Shu, Q., Yang, B., Yang, J., Qing, S., 2007. "Predicting the viscosity of biodiesel fuels based on the mixture topological index method". Fuel, 86, pp. 1849–1854.

[18]. Knothe, G., Steidley, K. R., 2005. "Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components". Fuel. 84, pp. 1059-1065.

[19]. Gumus, M., Kasifoglu, S., 2010. "Performance and emission evaluation of compression ignition engine using a biodiesel (apricot seed kernel methyl ester) and its blends with diesel fuel". Biomass Bioenergy. 34, pp. 134-139