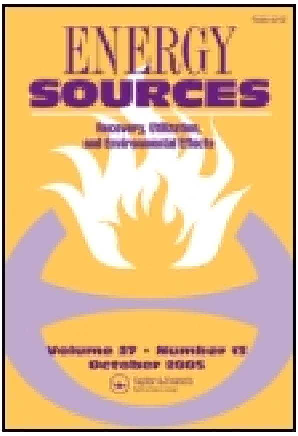

Energy Sources, Part A: Recovery, Utilization, and Environmental Effects
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ueso20

The Influence of Diesel Fuel-biodiesel-ethanol-butanol Blends on the Performance and Emission Characteristics of a Diesel Engine

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Published online: 12 Aug 2013.

Energy Sources, Part A, 35:1873–1881, 2013

ISSN: 1556-7036 print/1556-7230 online
DOI: 10.1080/15567036.2010.529568

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In this study, performance and exhaust emissions of a diesel engine fueled with Fuel A (60% diesel–30% biodiesel–5% ethanol–5% butanol) and Fuel B (40% diesel–50% biodiesel–5% ethanol–5% butanol) were investigated. The biodiesel produced from trap grease was obtained with an oil separator. Fuel A and Fuel B were tested in a single cylinder, four-stroke diesel engine at full load conditions. Compared with diesel fuel, the performance characteristics of blend fuels slightly deteriorated while the emission characteristics improved significantly. CO and HC emissions decreased by 87.01 and 87.50%, respectively.

Keywords: biodiesel, biomass, butanol, ethanol, exhaust emissions

1. INTRODUCTION

Biomass is defined as any organic matter that is available on a renewable or recurring basis (Wright et al., 2009). It includes all plants and plant-derived materials, including agricultural crops and trees, wood and wood residues, grasses, aquatic plants, animal manure, municipal residues, and other residue materials (Singh and Gu, 2010). A variety of fuels can be produced from biomass resources including liquid fuels, such as biodiesel, ethanol, and methanol, and gaseous fuels, such as hydrogen and methane (Zhang et al., 2010). These biofuels could partly replace fossil-based fuels, reduce toxic emissions, and more importantly restrain the life-cycle emission of CO_2 (Zhu et al., 2010).

Bio-fuel production is a rapidly growing industry in many parts of the world. Ethanol and biodiesel are the primary bio-fuels, which can be an alternative for gasoline or diesel fuel, respectively. However, other bio-fuels, such as bio-butanol, are being researched at the present and may be regarded as the next generation of fuels (Rakopoulos et al., 2010; Yasar, 2010). Biodiesel is produced through a process in which organically derived oils are reacted with alcohol (ethanol or methanol) in the presence of a catalyst to form ethyl or methyl ester (Wright et al., 2009; Keskin et al., 2010). It can be blended with petroleum diesel fuel or used alone in neat form in any unmodified diesel engine (Keskin et al., 2008a).

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Biodiesel has an important benefit for decrease of environmental pollution. Besides, biodiesel production in wastelands may help restoration and high rural employment potential in seed production and oil extraction. Energy security and improved balance of payment would enhance investments due to reduced risks. Sustainable seed production can mitigate carbon emissions in oil substitution. Rural income can enhance adaptive capacities (Demirbaş, 2009; Van Gerpen, 2004; Knothe, 2010).

Ethanol is another widely used source of biomass energy, such as biodiesel. It can be produced by alcoholic fermentation of sugar from vegetable materials and agricultural residues (Rakopoulos et al., 2010). Ethanol is used as a blending alternative fuel in diesel or gasoline engines (Kwanchareon et al., 2007). The use of ethanol in diesel fuel can yield significant reduction of particulate matter (PM) emissions for motor vehicles (Shi et al., 2006; Chotwichien et al., 2009). Nonetheless, there are several disadvantages to use of ethanol in diesel engines as a blend fuel. The lower viscosity of ethanol caused a decrease in lubrication and this can create wear problems in fuel pumps. Ethanol has a lower calorific value and Cetane number in comparison with diesel fuel. Low calorific value of ethanol leads to an increase in specific fuel consumption and low Cetane number reduces the Cetane level of the diesel and ethanol blend (Qi et al., 2010; Di et al., 2009). Another alternative bio-fuel for diesel engines is butanol. Compared to ethanol, higher heating value, higher Cetane number, and lower vapor pressure are making butanol more preferable for blending with conventional diesel fuel (Rakopoulos et al., 2010).

There is not much research on using blends of alcohol-biodiesel and diesel fuel in a diesel engine and more of them are on biodiesel and diesel blends. The aim of this study is to investigate the production of biodiesel from trap grease and the effect of diesel-biodiesel-ethanol-butanol blends on diesel engine performance and emission characteristics. The relationship between performance and emission test results of blend fuels and diesel fuel was then discussed.

2. MATERIALS AND METHOD

Biodiesel, used for blends, was produced from trap grease, which was malodorous waste grease mainly from restaurant kitchen traps. Trap grease was obtained from Cukurova University refectory's oil separator. Acid catalyzed esterification was preferred for biodiesel production because trap grease contained higher levels of free fatty acids. It was carried out with 9 wt% acid catalyst amount, at 9:1 molar ratio, 60°C reaction temperature, and 120 min reaction time. Methanol was used as alcohol and sulfuric acid was preferred as catalyst in this production process. A flow diagram of the biodiesel production from trap grease is shown in Figure 1.

The analyzing of test fuels was carried out at Fuel Analysis Laboratory in Cukurova University. The specifications of test fuels have been determined according to EN14214 and EN590 standards. All engine tests were performed in a single-cylinder, direct-injection diesel engine (Lombardini 4LD 640 Anadolu Motor Company, Istanbul, Turkey). The basic specifications of the engine are shown in Table 1. The engine torque values were measured with a hydraulic dynamometer. Technical specifications of the hydraulic dynamometer are presented in Table 2 and a schematic view of experimental set-up is given in Figure 2.

To determine the performance and emission characteristics of test fuels, the engine was pushed to reach maximum speed and it was loaded with the hydraulic dynamometer. Tests were carried out at full load conditions and eight different engine speeds in the range of 1,200–2,600 rpm with 200 rpm interval. During the engine performance tests, the carbon monoxide emissions (CO), nitrogen oxides (NO_x), hydrocarbon (HC), and smoke opacity values were measured. The technical specifications of a CAP 3200 smoke meter (Capelec Company, Montpellier, France) and Testo 350-S diesel emission analyzer (Testo Inc., Sparta Township, NJ) are shown in Tables 3 and 4, respectively.

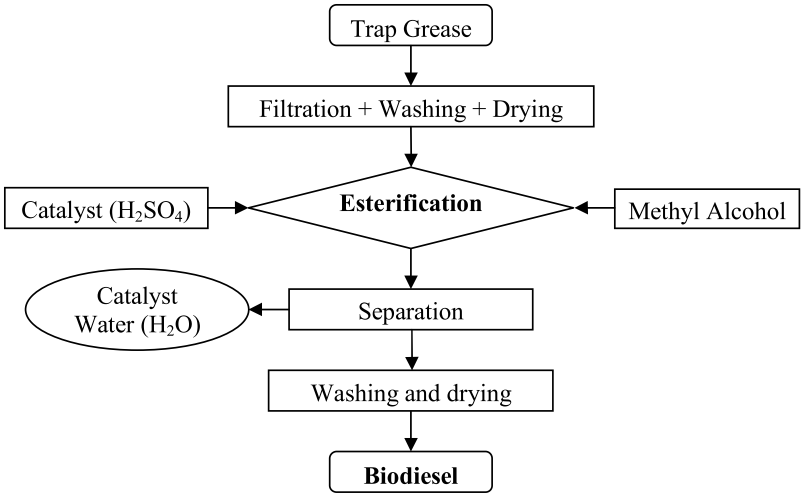

FIGURE 1 Flow diagram of biodiesel production from trap grease.

TABLE 1
Basic Technical Specifications of the Test Engine

Items	*Specification*
Model	Antor Diesel 4 LD 640
Number of cylinders	1
Bore × stroke	95 × 90 mm
Swept volume	638 cc
Compression ratio	17:1
Maximum speed	3,000 rpm
Maximum brake torque	43 Nm at 1,800 rpm

TABLE 2
Technical Specifications of Hydraulic Dynamometer

Items	*Specification*
Maximum torque	1,000 Nm
Maximum speed	7,500 rpm
Capacity of load cell	2,500 N
Length of torque rod	350 mm
Trunk diameter	350 mm
Totally weight	110 kgf

3. RESULTS AND DISCUSSION

3.1. Test Fuels

The chemical and physical properties of blends are presented in Table 5. The test fuels were compared according to EN590 and EN14214 standards for density, viscosity, flash point, sulfur

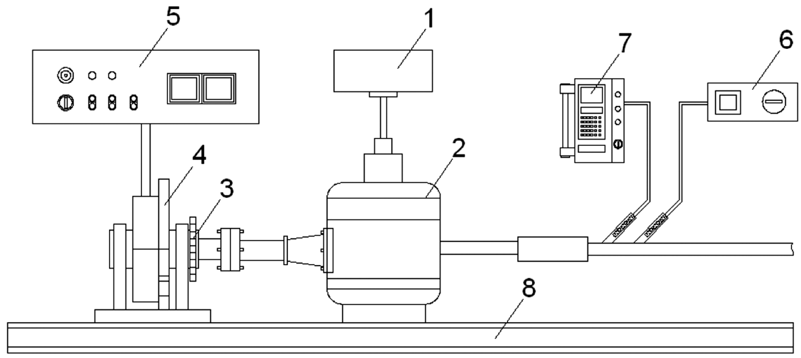

FIGURE 2 Schematic diagram of experimental set-up: 1. Fuel tank; 2. Test engine; 3. Magnetic pick-up; 4. Hydraulic dynamometer; 5. Control panel; 6. Smoke meter; 7. Diesel emission analyzer; 8. Platform.

TABLE 3
Technical Specifications of CAP 3200 Smoke Meter

Parameter	*Measuring Range*	*Accuracy*
Consistency of exhaust fumes (N, %)	0–100	0.01
Light absorption coefficient (1/m)	0–10	0.01
Engine speed (rpm)	0–9,999	0.05
Oil temperature (°C)	0–150	1

TABLE 4
Technical Specifications of Testo 350-S Diesel Emission Analyzer

Parameter	*Unit*	*Measuring Range*	*Accuracy*
O_2	%	0–25	0.01
CO	ppm	0–10,000	1
CO_2	%	0–50	0.01
NO	ppm	0–3,000	1
H_2S	ppm	0–300	0.1
NO_2	ppm	0–500	0.1
SO_2	ppm	0–5,000	1
HC	%	0–4	0.001
Sıcaklık	°C	40–1,200	0.1
Yanma verimi	%	0–120	0.1

content, copper strip corrosion, and calorific value. The viscosity of Fuel A and Fuel B are 3.84 and 4.89 mm^2/s, respectively; these values were higher than diesel fuel. The viscosity values of Fuel A and Fuel B are in good agreement with the EN14214 standards. Because of the lower flash point of alcohols, flash point of Fuel A was decreased compared to diesel fuel. But flash point of Fuel B was found to be higher than diesel fuel. This is probable, since higher biodiesel content of Fuel B was higher than Fuel A. The calorific values of Fuel A and Fuel B were lower than that of diesel fuel.

TABLE 5
Chemical and Physical Properties of Test Fuels

Quality	*Unit*	*Fuel A*	*Fuel B*	*Diesel*	*EN14214*	*EN590*
Diesel	vol.%	60	40	100	—	—
Biodiesel	vol.%	30	50	0	—	—
Ethanol	vol.%	5	5	0	—	—
Butanol	vol.%	5	5	0	—	—
Density	kg/m^3	856	872	829	860–900	820–860
Viscosity (40°C)	mm^2/s	3.84	4.89	2	3.5–5.0	2.0-4.5
Flash point	°C	58.6	65.5	62.5	Min. 101	Min 55
Sulfur content	wt%	0.049	0.043	0.0826	0,001	Max 0.2
Copper strip corrosion	—	1a	1a	1a	—	1
Calorific value	kJ/kg	41,643	40,482	44,717	—	—

3.2. Engine Performance Characteristics

The torque of the test fuels were shown in Figure 3. According to diesel fuel, torque values of the engine with blend fuels showed a trend of decreasing. This may be due to the lower energy content of the blend fuels. The maximum torque values were obtained at 1,800 rpm for all the test fuels. The maximum decreasing ratio of the engine torque was 7.07% with Fuel B in 1,400 rpm. However, performance characteristic curves of the engine with blend fuels didn't changed significantly.

The power variations of test fuel were shown in Figure 4. The engine power values with Fuel A and Fuel B were slightly lower than that of diesel fuel. The maximum power values for diesel fuel, Fuel A, and Fuel B were obtained in 2,600 rpm, which were 13.68, 12.98, and 12.78 HP, respectively. At the maximum engine torque, the decrease in power values of Fuel A and Fuel B were 4.03 and 6.17%, respectively.

The brake specific fuel consumption (BSFC) is defined as the ratio of mass fuel consumption to the brake power (Sayin, 2010). The BSFC of a diesel engine depends on the relationship among volumetric fuel injection system, fuel density, viscosity, and heating value (Qi et al.,

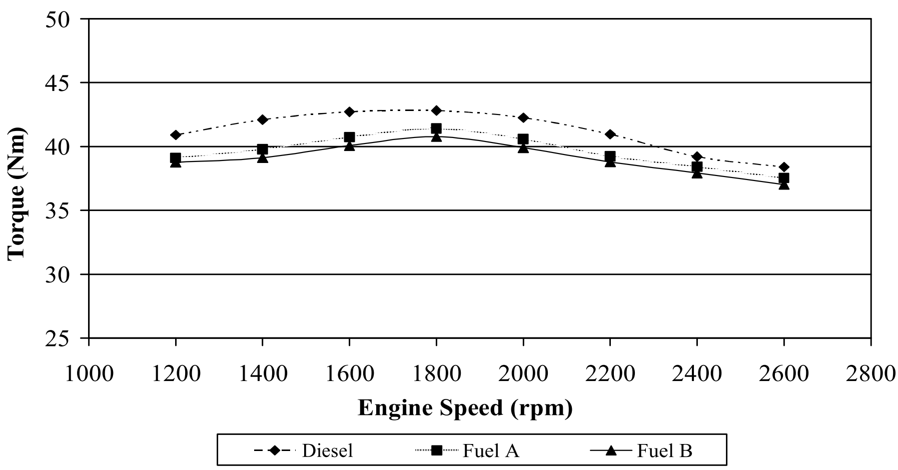

FIGURE 3 Torque values at full load condition.

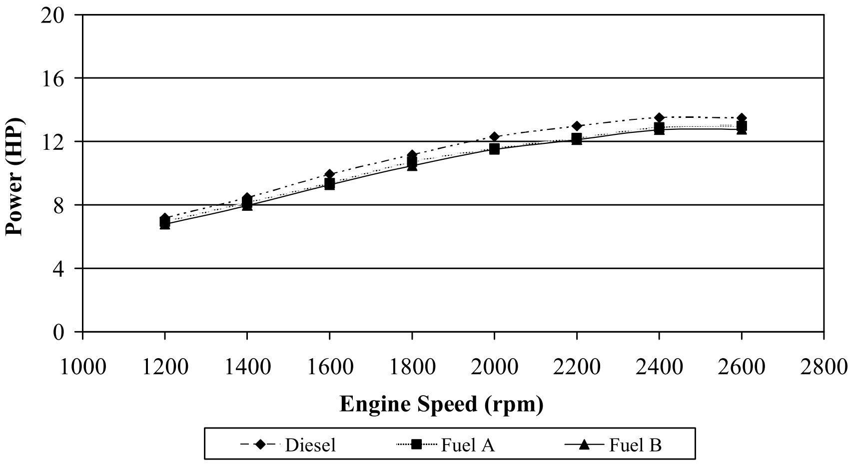

FIGURE 4 Power values at full load condition.

2010). The variation of BSFC values with test fuels was shown in Figure 5. The lowest specific fuel consumption values were obtained at 2,200 rpm with all test fuels. The BSFC of Fuel A and Fuel B are higher than that of the diesel fuel. This is probably due to the lower calorific value of blend fuels. Most of the studies (Aydın and İlkılıç, 2010; Keskin et al., 2008b; Qi et al., 2010) confirmed that the increase in BSFC was, on average, similar to the decrease of the lower heating value for heavy-duty and light-duty engines fueled with alcohols or biodiesel.

3.3. Exhaust Emission Characteristics

The use of alcohols and biodiesel in diesel engines as a blend fuel improved the emission characteristics significantly. Figure 6 shows the variations of CO emissions with respect to engine speeds. CO, formed by incomplete combustion of fuels, is produced most readily from petroleum fuels, which contain no oxygen in their molecular structure (Sayin, 2010). Lower CO emission

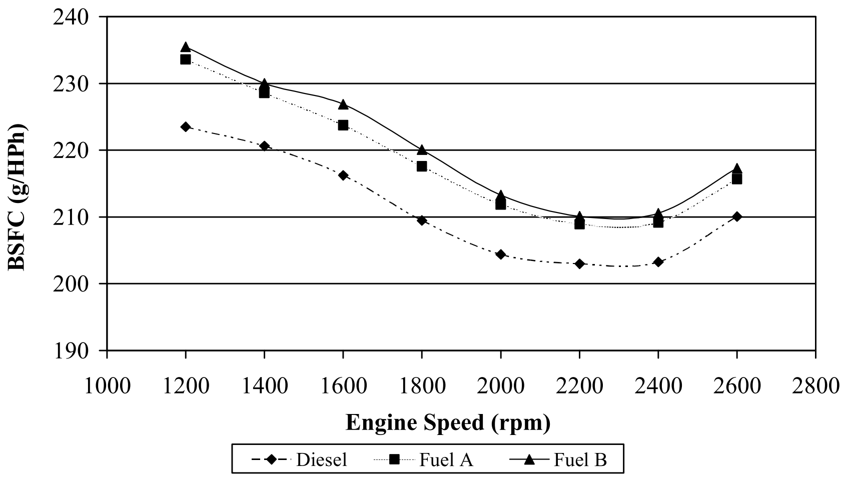

FIGURE 5 Brake specific fuel consumption values at full load condition.

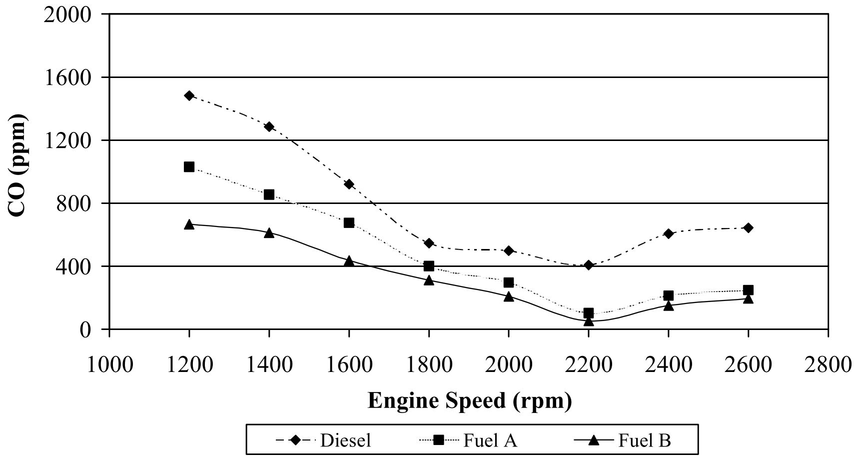

FIGURE 6 CO emissions values at full load condition.

values were measured with Fuel A and Fuel B in comparison with diesel fuel. The use of ethanol, butanol, and biodiesel allows a higher relative concentration of oxygen to exist in the combustion gases and this achieves a greater conversion of CO than for diesel fuel. The maximum decrease in CO emission was 87.01% with Fuel B in 2,200 rpm and the minimum CO emission value was measured at 53 ppm with Fuel B in 2,200 rpm. These results are similar to study of other researchers (Sayin, 2010; Aydın and İlkılıç, 2010; Rakopoulos et al., 2010; Zhu et al., 2010).

The NO_x emission variation for Fuel A, Fuel B, and diesel fuel is indicated in Figure 7. Higher NO_x emission values were measured with Fuel A and Fuel B in comparison with diesel fuel. NO_x concentration generally increased with increasing engine speed. The maximum NO_x emission values for all fuels were measured in 1,600 rpm as 775 ppm for diesel fuel, 791 ppm for Fuel A, and 817 ppm for Fuel B. However, after the speed of 1,600 rpm, NO_x started to decrease. The increasing of NO_x is probably because of the higher oxygen content and better combustion of biodiesel fuels, and as a consequence, the combustion temperature increases (Keskin et al., 2008a).

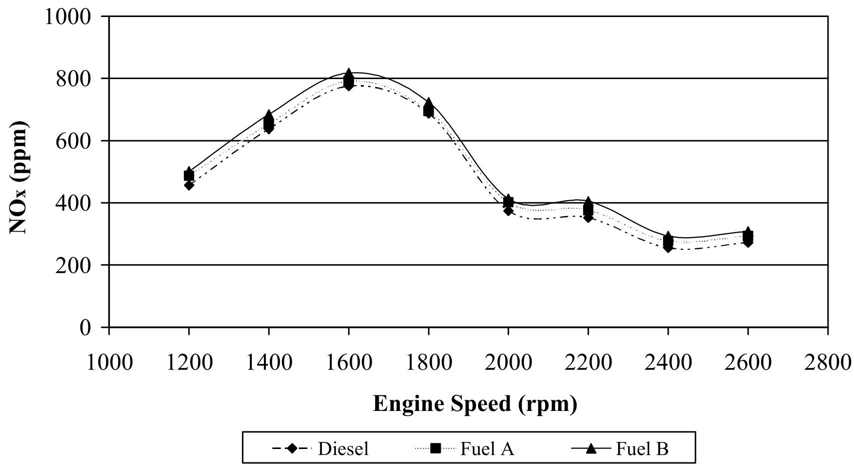

FIGURE 7 NO_x emissions values at full load condition.

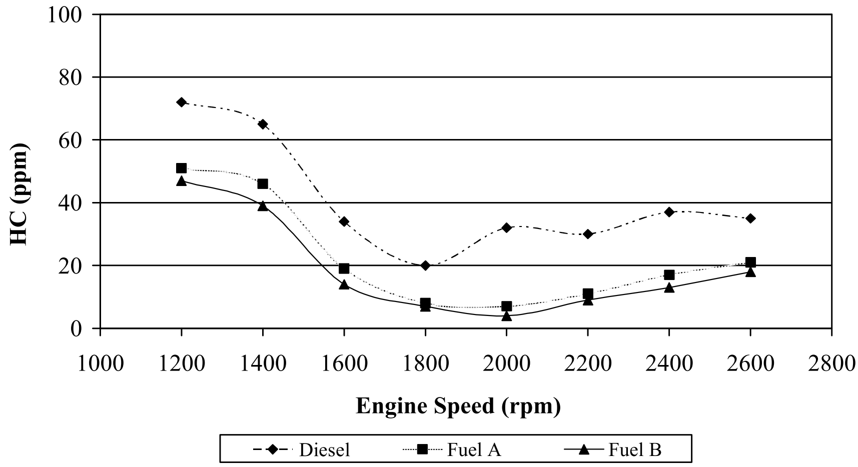

FIGURE 8 HC emissions values at full load condition.

Hydrocarbon emissions result from incomplete fuel combustion and from fuel evaporation (Payri et al., 2009). Engine configuration, fuel structure, combustion temperature, oxygen availability, and residence time are primarily factors for HC emissions (Sayin, 2010). As seen in Figure 8, HC emission values decreased with Fuel A and Fuel B in comparison with diesel fuel. The maximum decrease in HC emission was 87.5% with Fuel B in 2,000 rpm. It might be hypothesized that addition of butanol, ethanol, and biodiesel to diesel fuel improves HC oxidation due to higher oxygen content in the molecular structures. Higher laminar flame speed of alcohols may be another reason for the decrease. High flame speed reduces combustion duration but increases combustion temperature. This promotes more complete combustion and, hence, there are less HC emissions (Di et al., 2009).

Smoke opacity values of the test fuels are shown in Figure 9. The use of ethanol, butanol, and biodiesel exhibited evident reduction of smoke emissions at all engine speeds in comparison with diesel fuel. It can be explained by the higher oxygen content of ethanol, butanol, and biodiesel.

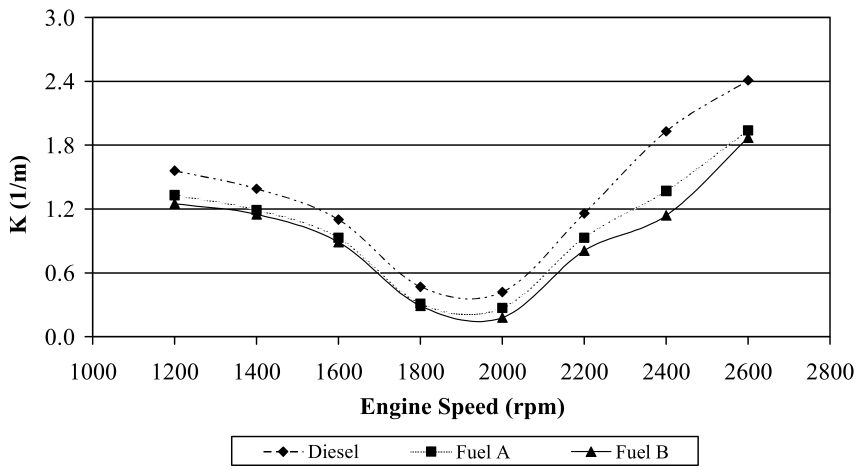

FIGURE 9 Smoke opacity values of exhaust gas at full load condition.

Reduction of smoke opacity ranged from 14.39 to 57.14%. As it can be seen from Figure 9, the reduction ratio was higher at low and high engine speeds. The minimum smoke opacity value was measured as 0.18 1/m at 2000 rpm with Fuel B.

4. CONCLUSION

The blend fuels can be used as alternative fuels in conventional diesel engines without any major modification. Fuel properties of the blend fuels were similar to that of diesel fuel. Lower sulphur content and higher oxygen content were important advantages of the blend fuels.

In comparison with diesel fuel, higher specific fuel consumption values were measured with the blend fuels. Exhaust gas emission profile improved with the blend fuels. CO, HC, and smoke opacity values decreased by 87.01, 57.14, and 87.50%, respectively. However, higher NO_x emission values were measured with blend fuels in comparison with diesel fuel.

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