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Emission characteristics using methyl soyate–ethanol–diesel fuel blends on a diesel engine

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Abstract

A blend of 20% (v/v) ethanol/methyl soyate was prepared and added to diesel fuel as an oxygenated additive at volume percent levels of 15 and 20% (denoted as BE15 and BE20). We also prepared a blend containing 20% methyl soyate in diesel fuel (denoted as B20). The fuel blends that did not have any other additive were stable for up to 3 months. Engine performance and emission characteristics of the three different fuels in a diesel engine were investigated and compared with the base diesel fuel. Observations showed that particulate matter (PM) emission decreased with increasing oxygenate content in the fuels but nitrogen oxides (NO_x) emissions increased. The diesel engine fueled by BE20 emitted significantly less PM and a lower Bosch smoke number but the highest NO_x among the fuel blends tested. All the oxygenate fuels produced moderately lower CO emissions relative to diesel fuel. The B20 blend emitted less total hydrocarbon (THC) emissions compared with base diesel fuel. This was opposite to the fuel blends containing ethanol (BE15, BE20), which produced much higher THC emission.

Keywords: Diesel engine; Oxygenate fuel; Emissions reduction

1. Introduction

Oxygenated fuels are known to reduce PM emissions for motor vehicles and have been evaluated as potential sources of renewable fuels. Among the alternative fuels, biodiesel and ethanol are the most widely studied biofuels for diesel engines and have received considerable attention in recent years [1–19]. Biodiesel has properties similar to those of traditional diesel such that it can be substituted for diesel fuel with little or no engine modification. Biodiesel has been recognized as an environment friendly alternative fuel for diesel engines. The most widely used form of biodiesel is made from methanol and soybean oil and is known as methyl soyate, or soy methyl ester.

Graboski and co-workers tested primarily methyl esters of various fats and oils in neat or blended form in diesel engines [1]. They found that the lubricity of these fuels was superior to conventional diesel fuel, and this property was imparted to blends at levels above 20 vol% by volume. Emissions of PM can be reduced dramatically through the use of biodiesel in engines. Emissions of NO_x increased significantly for both neat and blended fuels in both two- and four-stroke engines. Ali et al. also employed a DD6V-92TA engine and a Cummins NTA-855-C engine to determine the power characteristics and emissions of NO_x, HC, CO and Bosch smoke that resulted from blending methyl soyate and diesel fuel [4]. Their results showed that there was no significant reduction in engine power output on methyl soyate blends up to 30% in volume and as the percentage of methyl soyate in the fuel increased, the NO_x increased but the HC, CO and Bosch smoke decreased. Wang et al. employed nine tractor trucks to determine the emissions from a blend of 35% biodiesel and 65% petroleum diesel, designated as B35 [5]. The test showed

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that the heavy-duty trucks fueled by B35 emitted markedly lower PM, CO and HC compared to emissions with diesel fuel. The heavy duty trucks tested performed well when the diesel engine was fueled with B35 without any modification.

McCormick and coworkers investigated several oxygenates, *n*-octanol (C8), decanoic acid (C12), and methyl soyester (C17) at 1 wt% oxygen in diesel fuel using a 6V-92TA DEC II engine [6]. It was found that all oxygenates tested produced a significant PM reduction in the range of 12–17%. This study also examined the effect of methyl soy ester and *n*-octanol at 2 wt% oxygen on a DDC Series 60 engine. Methyl soy ester and *n*-octanol produced 20 and 12% reductions in particulate matter (PM), respectively. The effect of oxygenates on NO_x emissions was different. Methyl ester increased NO_x by 2–3%, while decanoic acid had no effect on NO_x, and octanol slightly decreased NO_x emissions [6].

On the other hand, studies on ethanol–diesel confirm substantial reductions in PM [7–11]. However, there are many technical barriers to the direct use of ethanol in diesel fuel because of the properties of ethanol: for instance, the low cetane number of ethanol and the solubility of ethanol in diesel fuel at a wide range of temperature. In fact, diesel engines cannot operate normally on an ethanol–diesel blend without special additives. Despite these facts, ethanol is still a low cost oxygenate with high oxygen content [12]. Blending ethanol with diesel produces an effective blended fuel.

The studies cited above clearly indicate that a substantial reduction in PM emissions can be obtained through the addition of oxygenates, and in particular, biodiesel and ethanol, to diesel fuel.

Previous studies have suggested that for PM reduction, the weight percent of oxygen content in the fuel is the most important factor; it is more important than other properties such as chemical structure or volatility [1,5,13]. The oxygen content of ethanol is much higher than that of methyl soyate. Including ethanol in biodiesel and diesel blends can increase the fuel oxygen level. On the other hand, biodiesel is known to act as an emulsifier for ethanol. Solubility and stability of ethanol in fuel blends will be greatly improved without other additives [7]. Additionally, the poor cold flow properties of biodiesel is a barrier to the use of biodiesel and diesel fuels blends in cold weather. The average freezing point of soybean methyl ester was reported to be $-3.8\,^{\circ}C$ [2]. Ethanol might be expected to improve low temperature flow properties. It is assumed that the high cetane number of biodiesel can compensate for the cetane number decrease caused by the presence of ethanol in fuel. Taking these facts into account, it was assumed that blends of biodiesel, ethanol, and diesel fuel may improve some properties compared with biodiesel–diesel blends and ethanol–diesel blends.

Ali et al. used 12 different blends of methyl tallowate, methyl soyate, ethanol and diesel fuel in a Cummins N14-410 diesel engine and found that engine performance with these fuel blends did not differ to a great extent from engine performance with diesel fuel [14]. In their study, the same engine fueled by an 80:13:7 blend of diesel fuel:methyl tallowate:ethanol emitted minimum emissions [15]. It has been suggested that the biodiesel and ethanol blends can be an optimized oxygenate for diesel fuels [7].

In the current study, we investigated the engine performance and emissions characteristics with fuel blends of petroleum diesel fuel, methyl soyate, and ethanol on a diesel engine. Brake specific fuel consumption (BSFC), regulated emissions, including PM, Bosch smoke number, nitrogen oxide (NO_x), carbon monoxide (CO) and total unburned hydrocarbon (THC), were investigated and discussed. Water tolerance and stability of the blends fuels were also considered.

2. Experimental

2.1. Engine and apparatus

All experiments were performed on a commercial DI diesel engine, named Sofim 8140.43C, which met Euro II emission regulations. The major engine specifications are shown in Table 1. Prior to running each experiment, the engine was fully warmed and the injection pressure was adjusted by an outside pressure compensation instrument to ensure the engine operated at the same injection pressure for each fuel. A Zöllner electric eddy dynamometer was coupled to the engine and used to measure the engine power. An exhaust gases analyzer (AVL CEB-11 type) was employed to measure the emissions of NO_x, THC, CO and CO_2 on line. The relative standard deviations of NO_x, CO, THC, and CO_2 concentrations were <1, <5, <3 and $<0.2\%$, respectively. The Bosch smoke number was measured with a FBY-1 smoke analyzer. Total PM was measured by an AVL PM analyzer with exhaust particulate dilution and a sampling system.

Two types of experimental units were carried out in the current study: speed characteristics (engine performance at various speeds with full load, denoted by Run 1) and load characteristics (engine performance at peak torque speed, 1900 rpm, with varying loads, denoted by Run 2), as shown in Table 2.

Table 1
Engine specifications

Cylinder number	4
Bore (mm) × stroke (mm)	94.4 × 100
Displacement (L)	2.8
Compression ratio	18.5:1
Rated power (kW)/speed (r/min)	76/3600
Maximum torque (Nm)/speed (r/min)	245/1900