Effect of a Mixture of Biodiesel-Diesel-Ethanol as Fuel on Diesel Engine Emissions

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Abstract—An experimental study of exhaust emissions of a diesel engine is carried out using biodiesel-diesel-ethanol (indicated as BDE), and results compared with both petroleum diesel fuel and biodiesel-diesel blend known as B20. Biodiesel used in this study was obtained from waste cooking oils. Experiments were conducted on a 4-cylinder, naturally aspirated DI diesel engine at speed characteristics of full engine load. An increase in brake specific fuel consumption (BSFC) for blended fuels were observed compared with diesel fuel. A reduction in carbon monoxide (CO) was found for blended fuels while emissions of nitrogen oxides (NOx) were slightly higher for B20, and lower for BDE compared with diesel fuel.

Keywords—Biodiesel, Waste Cooking Oil, Performance and Emissions.

I. INTRODUCTION

The interest of using alternative renewable fuels in diesel engines has been accelerated recently due to a rapid decrease in world petroleum reserves, increase in the prices of the conventional petroleum fuels and restrictions on exhaust emissions from internal combustion (IC) engines triggered by environmental concerns [1]. Among the renewable fuels, biodiesel, vegetable oils and especially their derived bio-diesels (methyl or ethyl esters) are recently considered as most promising ones (oxygenated by nature) [2]. Biodiesel is an alternative fuel for diesel engines that is produced by chemically reacting a vegetable oil or animal fat with an alcohol such as methanol. The reaction requires a catalyst, usually a strong base, such as sodium or potassium hydroxide, and produces new chemical compounds called methyl esters. It is these esters that have come to be known as biodiesel [3]. Compared to petroleum-based diesel, biodiesel has a more favourable combustion emission profile, such as low emissions of carbon monoxide, particulate matter and unburned hydrocarbons [4]. However, a diesel engine fueled with biodiesel or its blend generally releases higher NOx emission than that of petroleum-based diesel fuel [5].

Additionally, ethanol has also been considered as oxygenated alternative fuel for diesel engines as the blended fuel for a long time. However, using ethanol as fuel or fuel additive in diesel engines is limited by their miscibility problems with diesel fuel. Other problems are low cetane number, low lubricity and reduced heating value [6]. A mixture of biodiesel-diesel-ethanol can be utulized to improve the poor cold-flow properties of biodiesel besides to low cetane number and lubricity of ethanol-diesel blends. Also, biodiesel is known to improve the phase stability of blends. The experimental studies have been done using diesel-biodiesel-ethanol or methanol as fuel in diesel engines, and they reported affirmitive results rather than ethanol-diesel blends [7-10].

Currently, compared to petroleum diesel fuel, the high cost of biodiesel is a major barrier to its commercialization. Use of low-cost feedstock such as waste cooking oil should help make biodiesel competitive in price with petroleum diesel [11].

Therefore, in this study, a mixture of biodiesel-diesel-ethanol was prepared and used as fuel in a direct injection diesel engine to investigate the performance and exhaust emissions. Biodiesel used in this study was obtained from waste cooking oils. The experimental results were compared with those of diesel fuel and a blend of biodiesel and diesel known as B20.

II. MATERIAL AND METHOD

The performance and exhaust emission tests were conducted on a four-cylinder, four-strokes, naturally aspirated, water-cooled and direct-injection diesel engine. The basic specifications of test engine is given in Table 1. A hydraulic dynamometer (Netfren brand) is connected to test engine to provide brake load. A Magnetic pick-up sensor was used to measure the speed of the engine. The load on the dynamometer was measured using a S Type Load Cell. Fuel consumption was measured with a gravimetric fuel consumption meter. The exhaust emissions were measured by an exhaust analyser (Testo 350-XL), which was calibrated before each test. A schematic diagram of the experimental setup is shown in Fig. 1. The engine was started with petroleum diesel fuel and warmed up for a sufficient time in order to reach steady state operational conditions for each fuel. The results evaluated here were obtained at full-load conditions at the engine speeds between 1000 and 2000 rpm with intervals of 500 rpm. For every fuel change, the fuel tank and lines were cleaned. Before running the engine to a new fuel, it was allowed to run for some time to consume the remaining fuel from the previous experiment.

The tested fuels were petroleum diesel fuel, a mixture of biodiesel and diesel known as B20 (20% biodiesel+80%diesel) and a mixture of biodiesel-diesel-ethanol named as BDE (70%diesel+20% biodiesel+10%ethanol). Petroleum diesel fuel was obtained from a commercial supplier (Petrol Office Firm, located in Adana, Turkey). It was used as the baseline fuel for the present experimental study.
Table 1: The basic specifications of test engine

<table>
<thead>
<tr>
<th>Engine Brand</th>
<th>Mitsubishi Canter Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine type</td>
<td>Naturally aspirated, water-cooled</td>
</tr>
<tr>
<td>Operating principle</td>
<td>Four stroke, direct injection</td>
</tr>
<tr>
<td>Number of cylinder</td>
<td>Inline four cylinders</td>
</tr>
<tr>
<td>Bore x Stroke</td>
<td>104 mm x 115mm</td>
</tr>
<tr>
<td>Fuel injection pump</td>
<td>Mechanically controlled in-line</td>
</tr>
<tr>
<td>Maximum torque</td>
<td>243 Nm at 1600 rpm</td>
</tr>
</tbody>
</table>

Waste cooking oil biodiesel used in this study was produced from waste cooking oils and methyl alcohol via a transesterification reaction, and provided by a commercial biodiesel producer (Kolza biodiesel and petroleum products corp., an authorized waste oil collector), located in Istanbul, Turkey. Waste oil collector are obtained these oils from restaurants, hospitals and food industry. The fuel properties are presented in Table 2.

Table 2: The properties of fuels used

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>B20</th>
<th>BDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³) (at 15 °C)</td>
<td>833</td>
<td>842</td>
<td>841</td>
</tr>
<tr>
<td>Viscosity (mm²/s) (at 40 °C)</td>
<td>2.95</td>
<td>3.21</td>
<td>3.63</td>
</tr>
<tr>
<td>Heating Value (MJ/kg)</td>
<td>45.65</td>
<td>39.6</td>
<td>36.9</td>
</tr>
<tr>
<td>Cetane Number (CN)</td>
<td>54.63</td>
<td>54.4</td>
<td>43.7</td>
</tr>
</tbody>
</table>

A comparison of brake specific fuel consumption (BSFC) for tested fuels is shown in Figure 2. The measured brake specific fuel consumption values in blended fuels was higher in comparison with diesel fuel. This is probably because of the lower heating value of blended fuels because of their biodiesel or ethanol content. Maximum increase of brake specific fuel consumption was 8% and 13.2% with B20 and BDE at 2500 rpm, respectively, and minimum increase was 2.7% with B20 at 1000 rpm. The result obtained are in agreement with that observed by other authors [12-14].

The emissions of nitrogen oxides (NOₓ) for tested fuels are shown in Fig. 4. When the engine is operated on B20, NOₓ emissions are increased with respect to pure diesel operation, except at 1000 rpm where diesel fuel gave the lowest, as seen in Fig.4. Compared with diesel fuel and B20, BDE produced the lower amounts of emission levels of nitrogen oxides. An increase of NOₓ emissions is probably because of the higher oxygen content and better combustion of biodiesel fuels, and as a consequence, the combustion temperature increases, as reported by researchers [15-19]. Also, it was reported that the
timming advance attributable to the elevated bulk modulus of biodiesel is likely responsible for the increase in NOx [20, 21]. However, reducing NOx emissions with the use of blended fuel containing ethanol (BDE) may be attributed to the cooling effect of ethanol as its heat of evaporation is much higher than biodiesel and diesel. This is also reported by researchers [22-25]. The lower heating value of BDE, which can be seen from Table 2, may be given as another possible reason for less NOx emissions from BDE.

![Figure 4: Comparison of NOx emission](image)

**References**


