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IDENTIFYING THE IMPACT OF METHANOL-DIESEL FUEL ON THE ENVIRONMENT USING A FOUR-STROKE CI ENGINE

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This work aims to investigate the influence of blending diesel fuel with different percentages of methyl alcohol on reducing the emission of exhaust gases. The study was performed using a laboratory diesel engine, which is an internal combustion, single-cylinder, and four-strokes engine. The study involved investigating three volume percentages of methyl alcohol (methanol), which are 7, 14, and 21. The emission results of the blending fuels were compared with that of non-blending fuel. The analysis of the exhaust gases was done under three engine loads, which are two, four, and six N.m, with a constant speed of 2000 rpm. The analysis involves measuring carbon oxides (CO and CO_2), unburned hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). The results showed a positive impact of methanol on reducing the emission of all gases except NOx. Increasing the methanol ratio increases the reduction of the emissions of CO, CO_2, PM, and HC, where the highest reductions of the gaseous emissions were observed with the percentage of 21% of methanol under all engine loads. Specifically, the drop recorded by using 21% of methanol was 69-83% for CO, 60-69% for CO_2, 80-83% for HC, and 25-30% for PM. These reductions in emissions are assigned to the high oxygen content of methyl alcohol that influences the complete combustion of diesel. On the other hand, the NOx emission increased by 135-346%, but a possible reduction in these emissions can be achieved through a proper engine modification. The results of this investigation provide essential insights that would inspire using methanol as a fuel additive with modifying the diesel engines to be compatible with blending fuel.

Keywords: fuel blending, NOx, Cox, exhaust gases, particulate matter

1 INTRODUCTION

Diesel is an essential type of fuel that is used broadly in different sectors such as industry, transportation, and agriculture. The abroad of using diesel fuel has led to a massive demand for it in the last decades. Increasing fuel consumption resulted in the high emission of pollutants, which is the direct cause of the global warming issue [1, 2]. This was an important motivation to find alternative fuels such as biofuel, still the limitation of the availability of biofuel motivates the improvement processes of the fossil fuels, which are usually done by adding some additives. This addition aims to reduce the emission of pollutants such as particular matter (PM), unburned hydrocarbons (HC), nitrogen oxides (NOx), and carbon oxides (COx) [3]. Fuel additives are used widely due to their enhancement of the quality of the fuel, which results in better fuel performance and engine efficiency [4]. In addition, the addition aims to reduce fuel consumption and minimize the emissions of pollutants. Thus, several investigations have been performed to improve diesel fuel by blending it with alcohol (ethanol) in different ratios [5]. Several researchers have reported better engine performance and lower pollutant emissions after such blending in a proportion from 5% to 15% due to the better combustion of blending diesel resulting from the rich oxygen content of alcohol [6].

Although methanol has a poor cetane number and a low mixing rate with diesel, it is counted as a favourable additive because of its several advantages such as low cost, high oxygen content, high octane ratings, and low tendency for knocking, and being non-soot [7, 8]. Furthermore, methanol releases less pollutants than fossil fuels [9]. The production of methanol is done at a low cost from different sources such as biomass, natural gas, or coal [10]. Blending diesel with methanol in diesel machines has been studied by some investigators with and without modifying the machines [11]. Most of the previous studies focused on investigating the impact of the ratio of blending on the performance of the engine and the fuel consumption. Therefore, there is a need to conduct more investigations to specify the influence of blending methanol with diesel fuel in a four-stroke engine on the environment.

In a previous work, the impact of methanol blending with diesel fuel in various volume percentages (7, 14, and 21%) on the machine efficiency and performance was investigated using a TD212 four-stroke single-cylinder machine using 1% of 1-dodecanol to avoid the phase separation [12]. Based on the results of our previous investigation, mixing methanol with diesel, in general, showed promising performance. However, the blending ratio of 14% showed the best performance in regarding the brake-specific fuel consumption, brake-specific energy consumption, and the noise level at the same investigated loads in comparison to non-blending diesel. In contrast, it showed a significant increase in engine effective power (Ne) and brake thermal efficiency (BTE). Thus, in this work, the same engine and fuel types were used to identify the composition of the effluent gases to determine the influence of blending on the environment. This work provides important information regarding the influence of blending diesel fuel with methanol on the exhaust emission using different volume percentages of methanol that have not been reported previously.

2 MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Machine Test and Measurement Unit

The experimental work was done using a laboratory internal combustion diesel machine (TD 212) at Alkut Technical Institute – Wasit- Iraq. The engine is a single-cylinder with four-strokes and pneumatic cooling (Figure 1-a). It was linked by a coupling to a hydraulic dynamometer to shed the desired torque on the machine to record the engine efficiency. In addition, the engine was connected to the unit of measurement, where all test measurements from the machine was taken. More details about the engine and its specification, as well as the measurement unit (Figure 1-b), are presented elsewhere [12].

2.2 Experimental Procedure

The experimental work was done using four fuel types. One of them was a non-blending diesel, which will be called later as type D. The other used types were blending of methanol (ACS grade > 99.8%) with diesel in a methanol volume ratio of 7, 14, and 21%, which we will be later named as MD7, MD14, and MD21, respectively. The non-blending diesel fuel was provided by Al-Dorra refineries station (Iraq), and the blended fuels were prepared in the laboratory with 1% of 1-dodecanol (ACS grade > 98%) to prevent the phase separation phenomena. Methanol and 1-dodecanol were obtained from Sigma- Aldrich. More details about the four fuel types and their specifications are provided elsewhere [12].

2.3 Experimental Procedure

The experimental procedure is described in detail elsewhere [12]. Shortly the engine fuel tank was evacuated and refilled with the desired fuel type, and the engine was run at the desired torque (2, 4, and 6 N.m), while the engine speed remained constant at 2000 rpm for all experiments. After turning on the engine, it was left to warm up for ten minutes before applying the desired load by a dynamometer control. Then the emission tests were performed to identify the gaseous percentages and particulate matter released from the exhaust. The exhaust emissions include carbon oxides (CO and CO2), hydrocarbons (HC), nitrogen oxides (NOx), and PM. The emission analyzer used was AIRREX, HG-540 (Figure 1-c), which is connected to an engine exhaust by a line with a gas meter to measure the volume of the flue gas. A fiberglass filter (Grade 934-AH, Whatman) was used to prevent the PM from entering the analyzer. The emitted gases go across the filter, while particulate matter weight was calculated from the difference in the weight of the filter before and after the experiment. Each experiment was duplicated, and the average value is adopted here.

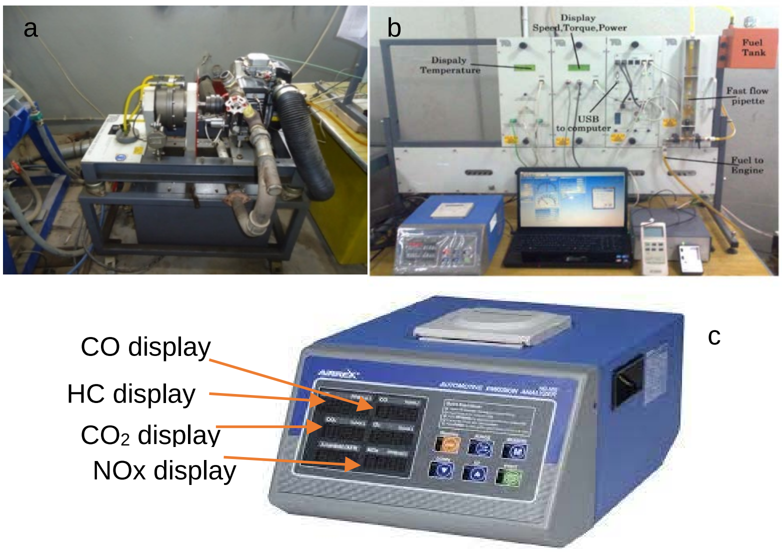

Figure 1. (a) TD 212 diesel engine, (b) measurement unit, and (c) AIRREX, HG-540 emission analyzer

3 RESULTS AND DISCUSSION

Figure 2 shows the results of measuring the CO emissions for the four types of diesel fuel resulting from the Four-Stroke machine under different torques. As expected, raising the load on the engine resulting in increasing the CO emissions for all fuel types due to an increasing in the fuel pumped to the engine, which reduces the air/fuel ratio and increases the rate of partial combustion of fuel, and resulted in higher carbon oxides (CO and CO2) emissions. The positive impact of increasing the methanol percentage on reducing the CO emission is greatly noticed at the highest load, where adding 7, 14, and 21% of methanol minimizes the CO percentage from 0.132% to 0.076, 0.031, and 0.024%, respectively. Similarly, the CO emissions at the lowest load are also decreased when blending diesel with methanol by similar percentages. Specifically, adding 7, 14, and 21% of methanol minimizes the CO percentage at the load of 2 N.m from 0.042% to 0.026, 0.011, and 0.007%, respectively. For load of 4N.m, the CO percentages of D, MD7, MD14, and MD21 are 0.061, 0.052, 0.043, and 0.019%, respectively. That means methanol can reduce around 69, 83, and 82% of CO emissions at 2, 4, and 6 N.m, respectively.

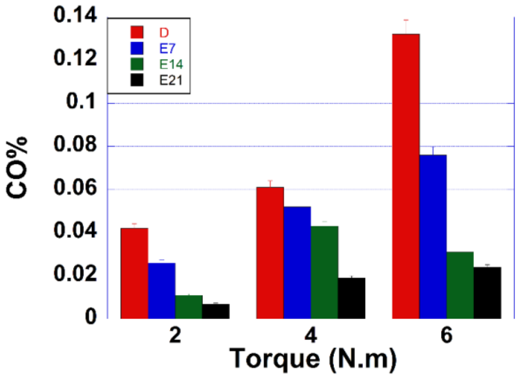

Figure 2. CO emissions for all fuel types at different loads

Figure 3, shows the emissions of CO2 for all fuel types under different loads. Similar to what was observed with CO, increasing the load on the engine resulted in increasing the CO2 percentage for all fuel types. The resulted raising in CO2 emission is due to the increase in the pumping fuel to the engine, which minimizes the air/fuel ratio. Increasing the methanol percentage resulted in reducing the CO2 emission. Precisely at 6 N.m, the CO2 portions of D, MD7, MD14, and MD21 are 8.12, 3.42, 2.72, and 2.48%, respectively. For 4 N.m, the CO2 percentages of D, MD7, MD14, and MD21 are 3.43, 2.39, 2.31, and 2.01%, respectively. Finally, with the load of 2 N.m the CO2 percentages of D, MD7, MD14, and MD21 are 2.31, 1.61, 1.42, and 1.39%, respectively. This means that the reduction of CO2 percentages by adding 21% of methanol is 69, 59, and 60% at 6, 4, and 2 N.m, respectively. It can be noticed that the reduction percentages for CO gas are higher than that of CO2, which is attributed to the high oxygen content of methanol that oxidizes CO to CO2 [13].

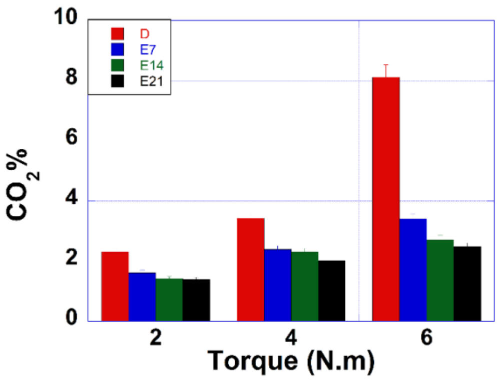

Figure 3. CO2 emissions for all fuel types at different loads

Figure 4 shows the NOx concentration in the exhaust gases in ppm. The results show an opposite trend to what was observed with the emission of carbon oxides, where increasing the methanol ratio increases the emission of NOx. In general, NOx emission increases with increasing the engine load and that is agreed with other investigations, which were done using other diesel engine and, or other diesel blending types [14, 15]. At the lowest engine load (2 N.m), the NOx emission of D, MD7, MD14, and MD21 were 98, 177, 193, and 230 ppm, respectively. At the medium used-engine load (4 N.m), the NOx emission of D, MD7, MD14, and MD21 were 111, 200, 210, and 330 ppm, respectively. At the highest engine load (6 N.m), the NOx emission of D, MD7, MD14, and MD21 were 120, 263, 391, and 536 ppm, respectively. These results indicate that there is a massive increase in the percentages of the NOx emission at all tested loads, where the increasing percentage are 135, 197, and 346% for the load of 2, 4, and 6 N.m, respectively.

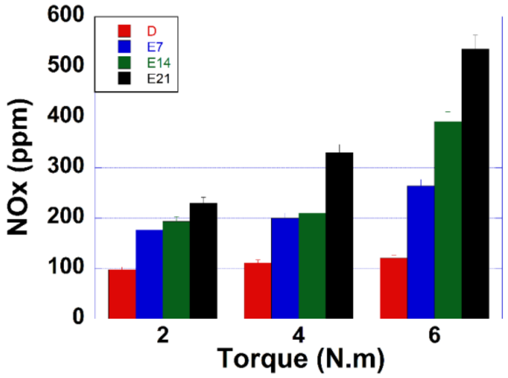

Figure 4. NOx emissions for all fuel types at different loads

The aromatic content of diesel fuel is one of the main reasons in the formation of NOx gases because it increases the flame temperature leading to an increase in NOx formation. However, several reasons might be responsible for the massive increase in NOx emissions. One of these reasons is the difference in the chemical properties between diesel fuel and methanol. Specifically, the lower cetane number and the higher volatility of methanol, compared to non-blending diesel fuel, decreases the diesel fuel vaporization during the ignition period. This decrease resulted in an increasing in the ignition delay, which in NOx is mainly formed [15]. In addition, methanol reactions are one of the sources to form aromatic compounds, which are enhances the formation of NOx gases [16]. The other possible reason for increasing the NOx emissions with increasing the methanol percentages is the oxidation of nitrogen due to the higher oxygen content of methanol. The oxidation of nitrogen is possible at higher temperatures (above 1100 oC) that could change it from inert gas to active gas [17]. It is well known that the cylinder's temperature reaches around 1500 oC, which allows oxidizing the nitrogen of the air when a high oxygen rate is available. However, a possible reduction of NOx emission can be achieved with some modification of engine [17].

Figure 5 shows the formation of gaseous HC for different fuel types at different loads. Increasing the load increases the emission of HC gases. In contrast, increasing the methanol percentage decreases the HC percentages. Specifically, at 2 N.m, the HC emission of D, MD7, MD14, and MD21 were 13.6, 5.8, 5.0, and 2.3%, respectively. At 4 N.m, the HC emission of D, MD7, MD14, and MD21 were 19.5, 6.1, 5.9, and 3.1%, respectively. On the other hand, at 6 N.m, the HC emission of D, MD7, MD14, and MD21 were 25.7, 9.9, 9.0, and 5.1%, respectively. This means that the reductions in HC emissions after the addition of 21% of methanol are 83, 84, and 80% for the engine load of 2, 4, and 6 N.m, respectively. This lowering in HC emission is also attributed to the high oxygen content of methanol, which enhances the complete combustion of fuel, and it agrees well with biodiesel behavior reported in the literature [18]. Generally, hydrocarbons with carbon number range between 9-20 are the main components of diesel fuel, which makes its boiling point falls in the range 163–357 °C. On the other hand, methanol is much lighter, where it includes only one carbon atom and its boiling point is 64.7 oC. This difference is the reason behind the positive influence of the blended fuel on the emission of the exhaust gases.

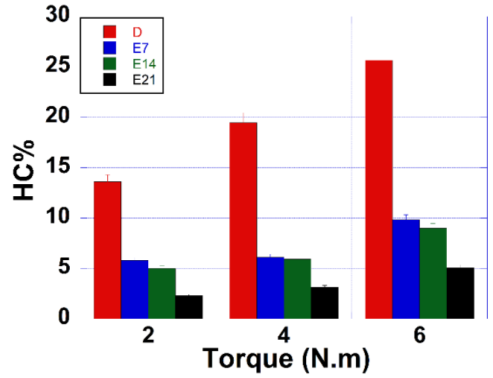

Figure 5. HC emissions for all fuel types at different loads

Several parameters such as the fuel composition, operating conditions, as well as engine type and design can influence the formation of PM [15]. Figure 6 shows the rate of PM emission for all types of fuel under different engine loads. In general, increasing the load increases the emission of PM. On the other hand, the increase in the methanol ratio has an opposite influence on the PM emission. At the lowest engine load, decreasing in PM emissions was obvious. However, with increasing the engine load, the reduction in PM emissions in high blending ratios was more significant. One of the most crucial reasons behind the emission of PM is the lack of oxygen content in diesel fuel. Thus, blending with methanol increases the oxygen content of the fuel and minimizes the formation of PM. Furthermore, methanol presence dilutes the heavy compounds in the diesel fuel, resulting in reducing the soot emission. In addition, mixing diesel fuel with methanol lowers the concentrations of sulfur compounds, which responsible of PM emissions through the generation of sulfates [15]. At 2 N.m, the PM emission of D, MD7, MD14, and MD21 were 1.2, 1.1, 1.0, and 0.9 g/hr, respectively. At 4 N.m, the PM emission of D, MD7, MD14, and MD21 were 1.5, 1.3, 1.2, and 1.1 g/hr, respectively. At at 6 N.m, the PM emission of D, MD7, MD14, and MD21 were 1.7, 1.5, 1.4, and 1.2 g/hr, respectively. This means that the reductions in PM emissions after adding 21% of methanol are 25, 27, and 30% for the engine load of 2, 4, and 6 N.m, respectively.

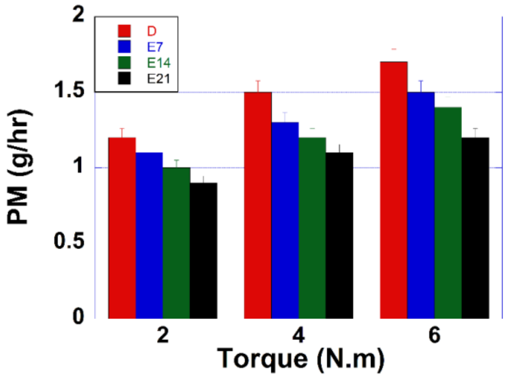

Figure 6. PM emissions for all fuel types at different loads

4 CONCLUSIONS

The experimental study has done to evaluate the influence of mixing diesel fuel with methanol in different volume percentages under different engine loads on the environment. From a previous investigation, methanol was found to be a promising additive for diesel fuel in the range of 7 to 21%, with the best machine performance at the ratio of 14%. In this investigation, the analysis of exhausted gases shows a massive decreasing in the releasing of CO, CO2, and HC with increasing the methanol ratio. This reduction is assigned to the high oxygen content of methyl alcohol, which influences the fuel's complete combustion. In addition, the high oxygen content of methanol oxidizes CO to the less toxic compound CO2. Furthermore, the high oxygen content is also partially responsible for the lowering of PM emissions. The other factors involve in the reduction of PM are the dilution of sulfur compounds that exist in diesel as well as the heavy compounds that are responsible for the formation of PM. On the other hand, increasing the methanol ratio influences the emission of NOx, which could be a result of forming more aromatic compounds or due to the oxidation of nitrogen by the high oxygen content of methanol at high temperatures reached by the cylinders. However, the reduction of NOx can be achieved by some modifications on the engines, as reported in the literature. The results of this investigation show a significant improvement in reducing exhaust gases released from the four-stroke CI engine. Thus, the outcome of this work can be an excellent motivation to modify the engine design to be more compatible with using of methanol-diesel blending fuel to reduce the emissions of greenhouse gases.

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