EXHAUST EMISSIONS OF METHANOL AND ETHANOL-UNLEADED GASOLINE BLENDS IN A SPARK IGNITION ENGINE

by

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In this study, the effect of unleaded gasoline and unleaded gasoline blended with 5% and 10% of ethanol or methanol on the performance and exhaust emissions of a spark-ignition engine were experimentally investigated. The engine tests were performed by varying the engine speed between 1000 and 4000 rpm with 500 rpm period at three-fourth throttle opening position. The results showed that brake specific fuel consumption increased while brake thermal efficiency, emissions of carbon monoxide and hydrocarbon decreased with methanol-unleaded gasoline and ethanol-unleaded gasoline blends. It was found that a 10% blend of ethanol or methanol with unleaded gasoline works well in the existing design of engine and parameters at which engines are operating.

Key words: *engine performance, exhaust emissions, methanol, ethanol*

Introduction

The increasing demand for energy and stringent pollution regulations, as a result of the population growth and technological development in the world, promote research on alternative fuels [1]. In this sense, using alternative fuels such as alcohol fuels in internal combustion engines have the potential to reduce the dependency on petroleum fuels and exhaust emissions. Ethanol, for example, has been identified as having the potential to improve air quality when used to replace conventional gasoline in engines because of its good anti-knock characteristics and the reduction of CO and unburned hydrocarbon (HC) emissions [1, 2]. Presently, ethanol is used in spark ignition (SI) engines with gasoline at low concentrations without any modification. Pure ethanol can be used in SI engines but necessitates some modifications to the engine. To avoid modifying engine design, using ethanol-gasoline blended fuel was suggested and so, cold start and anti-knock performance will be improved [3]. The addition of ethanol to gasoline has shown to reduce HC emissions, with the reduction increasing as the blend ratio is increased. The reason given for this is the reduction of the higher boiling point gasoline fractions in the fuel blend [4]. The combustion characteristics, fuel economy, and regulated emissions of SI engines have also been widely researched using methanol-gasoline blends [5-7]. Like ethanol, methanol has also better anti-knock characteristics than gasoline. Alcohols burns with lower flame temperatures and luminosity owing to decreasing the peak temperature inside the cylinder. Both methanol and ethanol have high latent heat of vaporization. The latent heat cools the intake air, so the increased charge density and increases volumetric efficiency. However the oxygen con-

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tent of methanol and ethanol reduces their heating value compared to gasoline [8]. Several works made have been related to the comparison of different alcohols' effects as gasoline additive on performance and emissions [9-11]. Taylor *et al*. [12], for instance, compared the performance of four alcohols. They found little difference in combustion efficiency of the four alcohols from gasoline. In that study, the emissions of HC and CO decreased 40% and 75%, respectively, when using alcohol-gasoline blends contained by mass ratio of 5% oxygen. Sezer *et al.* [13] investigated the use of ethanol and methanol in SI engines. They found that brake specific fuel consumption (BSFC) for methanol and ethanol was higher about 132.2% and 65.5%, respectively, than isooctane. Regarding the unregulated emissions with alcohol fuels, according to Rehnlund [14], there is a significant increase in aldehydes, especially acetaldehyde and formaldehydes emissions. In the same way, Yacoub *et al*. [15] reported that unburned alcohol emission rates were higher for blends with higher content of alcohol, and aldehyde emissions were higher for all alcohol blends with formaldehyde as the main constituent. Jia *et al.* [16] also found that the SI engine fueled with alcohol-gasoline blended fuel produced more ethylene, acetaldehyde, and ethanol emissions than unleaded gasoline engine does.

The present paper reports the results of an experimental study carried out to the comparison of the effects of two gasoline additives, methanol and ethanol, on performance and exhaust emissions of a SI engine.

Material and method

The engine tests were conducted on a four-cylinder, four-stroke, and water-cooled SI engine manufactured by Ford Engine Company. The engine used in experiments is an electronic fuel injection gasoline engine with a cylinder bore of 89 mm, a stroke of 95 mm, and a compression ratio of 11.1. The fuel injectors opening pressure of 5 bar. Four kinds of fuels were tested in this study. Reidel-Haen brand methanol and ethanol (absolute) with purity of 99.7% and 99.8%, respectively, were employed as gasoline additives in the experiments. Unleaded gasoline (UG) was provided from a commercial fuelling station, located in Elazig, Turkey. It was used as the baseline fuel for the present experimental study. The mass percentages tested were 0%, 5%, and 10% of methanol with 100%, 95%, and 90% of UG, respectively, which were named as UG, M5, and M10. The same processes for the mixing were performed with the blends of ethanol and UG, the mass percentages were 5%, and 10% of ethanol, which were named as E5 and E10. These rates were selected because low alcohol rates in gasoline predominate worldwide. Especially E10 (a blend of 10% ethanol and 90% gasoline) is a blended fuel that can be used in vehicles powered by SI engines without modification on the engine or fuel injection system. The fuel blends were prepared just before starting the experiment to provide that the fuel mixture is homogenous. The experimental set-up was installed in the Motor Laboratory of Department of Machine Education in Fyrat University, Elazig, Turkey. The schematic illustration of the experimental set-up is shown in fig. 1.

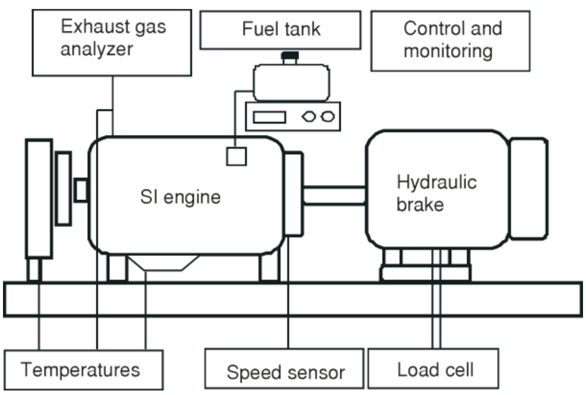

Figure 1. The schematic illustration of the experimental set-up

A hydraulic dynamometer is connected to test engine to provide brake load. The required engine load was obtained through the dynamometer control. The engine tests were performed by varying the engine speed in the range of 1000-4000 rpm with 500 rpm period at three-fourth throttle opening position. The throttle opening position was adjusted to maintain same brake torque values at the given engine speed for all tested fuels. In the experiments performed at mentioned conditions, nearly the same brake torque values were obtained when using different rates of alcohol-unleaded gasoline blends compared with UG. However, the brake torque values obtained using ethanol blends were higher than that of UG especially at low speed/high load conditions. The fuel consumption rate of the engine was determined with a weighing scale (Oertling brand) and an electronic chronometer. The exhaust emissions were measured by Sun MGA 1500 model exhaust analyzer. The exhaust temperature was measured using a CrAl-NiAl thermocouple (type K) located at 0.3 m downstream of the exhaust valve. The accuracy of the measurements is shown in tab. 1.

Table 1. The accuracy of the measurements

Measurements	Accuracy
Load	±3 Nm
Speed	±25 rpm
Time	±0.2 s
Temperature	±1 °C
CO	0.001%
CO_2	0.1%
HC	1 ppm

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 data was taken after the engine was run with the new fuel for enough time. Table 2 presents a comparison of properties of gasoline, methanol, and ethanol [17, 18].

Table 2. Comparison of fuel properties

Properties	Gasoline	Methanol	Ethanol
Chemical formula	C_8H_{15}	CH_3OH	C_2H_5OH
Molecular weight	111.21	32.04	46.07
Oxygen content, [wt.%]	–	49.93	34.73
Carbon content, [wt.%]	86.3	37.5	52.2
Hydrogen content, [wt.%]	24.8	12.5	13.1
Stoichiometric AFR	14.5	6.43	8.94
Lower heating value, [MJkg^{-1}]	44.3	20	27
Heat of evaporation, [kJkg^{-1}]	305	1178	840
Research octane number	96.5	112	111
Motor octane number	87.2	91	92
Vapor pressure [kPa]	61.4	32.4	19.3

Results and discussion

Engine performance

Figure 2 indicates the variations of the BSFC for different blended fuels against various engine speeds. BSFC demonstrated a slight increase for the alcohol-unleaded gasoline blends with respect to reference UG. Methanol blends also gave higher BSFC values than ethanol blends. This is the expected behavior due to the lower heating value (LHV) of the alcohols compared to that for the UG. As shown in tab. 1, the maximum LHV (44.3 MJ/kg) belongs to UG, followed by ethanol (27 MJ/kg), and the lowest one (20 MJ/kg) belongs to methanol. Therefore, when using methanol or ethanol blends, a larger amount of fuel is required for supplying the same amount of energy in the cylinder because of their lower heating values and stoichiometric air/fuel ratios [13]. He *et al*. [19] also reported that since ethanol has low heating value, in order to produce the same power at the same operating conditions, more fuel will be burned as the proportion of ethanol increases. Figure 3 presents the effect of using alcohol-UG blends on brake thermal efficiency (BTE). The BTE increases with an increase in engine speed, and then the BTE decreases at engine speeds of 3500-4000 rpm. Compared with the UG, the blended fuels gave almost the same BTE at low engine speeds. In general, the BTE values calculated for alcohol-UG blends were slightly lower than that for UG. BTE is calculated as lower than UG since BTE is inversely proportional to BSFC and LHV.

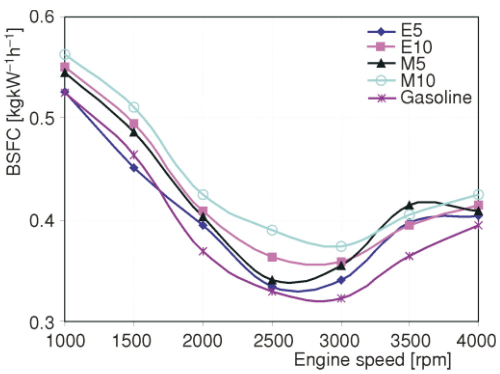

Figure 2. The comparison of BSFC

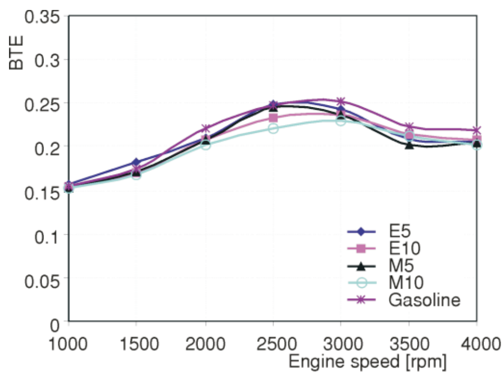

Figure 3. Change in brake thermal efficiency

Exhaust emissions

Figure 4 represents the influence of alcohol addition to UG on CO emissions. CO is a product of incomplete combustion due to insufficient amount of air in the air-fuel mixture or insufficient time in the cycle for completion of combustion. As shown in fig. 4, compared to UG, using blended fuels containing alcohol resulted in a significant reduction in CO emissions. This is because the properties of the blended fuels are changed because ethanol and methanol are oxygen containing fuels, and their oxygen content in the blended fuels can improve the combustion process. The ethanol-UG fuels are E5 and E10, on average; the relative decreases in the CO emission are about 7% and 9.8%, respectively. In addition, the CO emission of M5 and M10 decreased about by about 9% and 10.6%, respectively. The comparison of CO_2 emissions for test fuels is shown in fig. 5. The percent change in CO_2 emissions have an opposite behavior when compared to the CO emissions as CO_2 emission depends on air-fuel ratio and CO emission concentration, and this is clear in both figs. 4 and 5. It can be seen in fig. 5 that highest CO_2 emissions are obtained with M10, following by E10. As a result of the lean burning associated with increasing oxygen content, the CO_2 emission increase because of the improved combustion [20-22].

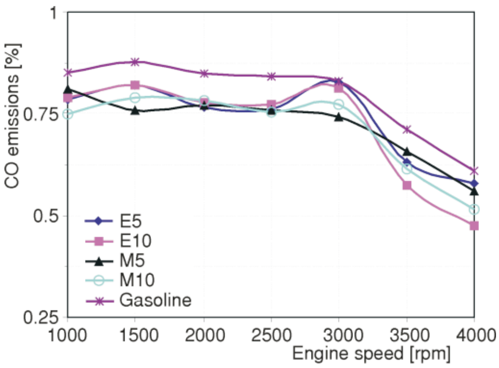

Figure 4. The comparison of CO emissions

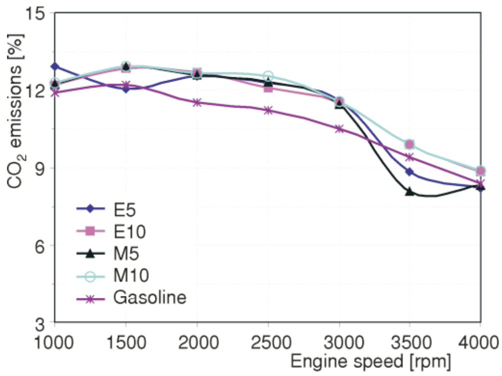

Figure 5. The comparison of CO_2 emissions

The comparison of HC emissions for test fuels is shown in fig. 6. It can be seen that blended fuels can decrease HC emissions. Compared to UG, HC emissions of M5 and M10 are reduced by about 6.7% and 13%, respectively, while E5 and E10 are reduced by about 5.3% and 15%, respectively, on average. When the complete combustion is more, the HC emission is lower. Alcohol fuels have higher oxygen content than UG, which could improve the combustion and lead to low HC emissions. The reduction of the higher boiling point gasoline fractions in the fuel blend may also be given a reason for the lower HC emissions produced by alcohol-UG blends. Because a high boiling point indicates that the fuel may comprise fractions or components that may not be completely vaporized and burnt, thereby increasing HC emissions.

Figure 7 shows comparison of exhaust gas temperature for the tested fuels. As shown in fig. 7, while the exhaust gas temperature rises with the increase of engine speed for tested fuels but then at high speed, it shows a downward trend. Also, it can be seen in fig. 7 that E10 shows higher exhaust gas temperature, and those of M10 and UG are very close to each other. For blended fuels containing 5% alcohol,

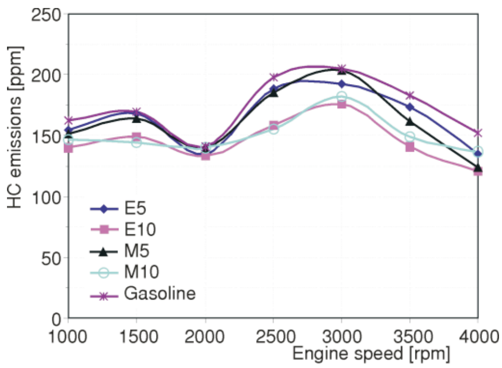

Figure 6. The comparison of HC emissions

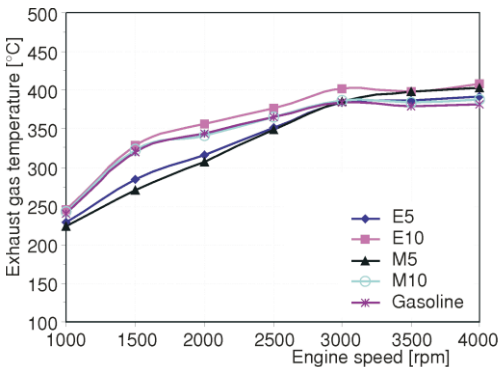

Figure 7. Change in exhaust gas temperature

lower exhaust gas temperatures were obtained compared with UG, M10 and E10, especially at low speed/high load conditions. At high engine speeds (after 3000 rpm), an increase in exhaust gas temperature was observed for E5 and M5.

Conclusions

The addition of ethanol or methanol to UG can reduce exhaust emissions. Compared to UG, M10 and E10 blended fuels produced the best results in exhaust emissions. The HC emission of M10 and E10 are reduced about 13% and 15%, respectively, and the CO emission by about 10.6% and 9.8%, respectively. On the other hand, increased CO_2 emissions were observed for M10 and E10 compared with UG. The addition of ethanol or methanol to UG caused an increase in the BSFC and a decrease BTE in comparison to UG. This is because the heating value of blended fuels being lower than UG.

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