Emissions characteristics of spark ignition engine operating on pure and high alcohol blended gasoline fuels

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Summary
An experimental investigation of emissions characteristics of pure and high alcohol blended gasoline fuels is presented in this paper. The alcohol component of the blends consisted of methanol, ethanol, propanol, butanol and pentanol. Apparatuses used in the present study were a single cylinder spark ignition engine, a hydraulic dynamometer and an exhaust analyzer. The variables that were continuously measured include engine rotational speed (rpm), CO, CO_2, HC and NO emissions. During a variable load tests, the results indicate that CO and HC levels in the engine exhaust are reduced with the operation on alcohol gasoline blends. NO emissions with alcohol gasoline blends are higher than with gasoline.

***Key word:* spark ignition engine, emissions characteristics, alcohol gasoline blends, alternative fuels**

Introduction

Depletion of fossil fuels and environmental considerations has led researchers to anticipate the need to develop alternative fuels. Between alternative fuels are also the alcohols (Zhao et al., 1999; Freudenberger, 2009). Lower alcohols (ethanol and methanol) have been used as fuel extenders by mixing them with gasoline. The ethanol is produced from sugars (particularly sugar cane) and starch by fermentation. The methanol can be produced from coal, biomass or even natural gas with acceptable energy cost. Higher alcohols (propanol, butanol and pentanol) used as additives in pure alcohol gasoline blends. Higher alcohols can be produced from coal derived syngas. Consequently alcohols are particularly attractive as alternative fuels at least with criterion their origin.
The combustion of fuel in an engine generates by-products that are known as emissions. The four main engine emissions are carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), and oxides of nitrogen (NOx) (though others, such as particulates and formaldehyde, are also produced). Gasoline, as a compound hydrocarbon, is not a particularly clean-burning fuel. Lower alcohols, in comparison, burn nearly pollution-free. Alcohols already contain oxygen integral with the fuel, which can lead to a more homogenous combustion. Alcohols burn with a faster flame speed than gasoline, and they do not contain additional elements such as sulphur and phosphorus. All these factors work in lower alcohol's favour with regard to emissions (Niven, 2005). When added very small amounts of alcohol (methanol) in the blend were drastically increased the Reid Vapor Pressure (RVP). It was due to the fact that methanol forms low-boiling azeotropes with certain hydrocarbons. However, using higher alcohols as co-solvents in alcohol gasoline blends seems to control RVP and evaporative emissions (Furey, 1985; Pumphrey, 2000).
Research studies of exhaust emission levels from combustion engines are important from different perspectives. Rajan and Saniee (1983) investigated the characteristics of hydrated ethanol with gasoline as a means of reducing the cost of ethanol/gasoline blends for use as a spark ignition engine fuel. Engine experiments indicate that, at normal ambient temperatures, a

water/ethanol/gasoline mixture containing up to 6 vol% of water in the ethanol constitutes a desirable motor fuel with power characteristics similar to those of the base gasoline. As a means of reducing the smog causing components of the exhaust gases, such as the oxides of nitrogen and the unburnt hydrocarbons, the water/ethanol/gasoline mixture is superior to the base gasoline. Gautam et al. (2000) investigated the emissions characteristics between higher alcohol/gasoline blends and neat gasoline. It was found that the cycle emissions of CO, CO_2 and organic matter hydrocarbon equivalent from the higher alcohol/gasoline blends were very similar to those from neat gasoline. Cycle emissions of NOx from the blends were higher than those from neat gasoline. However, for all the emissions species considered, the brake specific emissions (g/kW h) were significantly lower for the higher alcohol/gasoline blends than for neat gasoline. This was because the blends had greater resistance to knock and allowed higher compression ratios, which increased engine power output. The contribution of alcohols and aldehydes to the overall organic matter hydrocarbon equivalent emissions was found to be minimal. Al-Hasan (2002) investigated the effect of using unleaded gasoline/ethanol blends on a four stroke, four cylinder SI engine performances and exhaust emission. The results showed that the CO and HC emissions concentrations in the engine exhaust decrease, while the CO_2 concentration increases. Hsieh et al. (2002) investigated the engine performance and pollutant emission of a commercial SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20%, 30%). It was found that with increasing the ethanol content, the RVP of the blended fuels initially increases to a maximum at 10% ethanol addition, and then decreases. Results of the engine test indicated that using ethanol/gasoline blended fuels, CO and HC emissions decrease dramatically as a result of the leaning effect caused by the ethanol addition, and CO2 emission increases because of the improved combustion. Finally, it was noted that NOx emission depends on the engine operating condition rather than the ethanol content. He et al. (2003) investigated the effect of ethanol blended gasoline fuels on emissions and catalyst conversion efficiencies in a spark ignition engine with an electronic fuel injection system. Ethanol can decrease engine-out regulated emissions. The fuel containing 30% ethanol by volume can drastically reduce engine-out total hydrocarbon emissions (THC) at operating conditions and engine-out THC, CO and NOx emissions at idle speed, but unburned ethanol and acetaldehyde emissions increase. According to Yüksel and Yüksel (2004) one of the major problems for the successful application of gasoline–alcohol mixtures as a motor fuel is the realization of a stable homogeneous liquid phase. To overcome this problem, authors designed a new carburetor. Sixty percent ethanol and forty percent gasoline blend was exploited to test the performance, the fuel consumption, and the exhaust emissions. Experimental results indicated that using ethanol–gasoline blended fuel, the CO and HC emissions decreased dramatically as a result of the leaning effect caused by the ethanol addition, and the CO_2 emission increased because of the improved combustion. Bayraktar (2005) investigated experimentally and theoretically the effects of ethanol addition to gasoline on an SI engine performance and exhaust emissions. Experimental applications have been carried out with the blends containing 1.5, 3, 4.5, 6, 7.5, 9, 10.5 and 12 vol% ethanol. Numerical applications have been performed up to 21 vol% ethanol. Engine was operated with each blend at 1500 rpm for compression ratios of 7.75 and 8.25 and at full throttle setting. Experimental results have shown that among the various blends, the blend of 7.5% ethanol was the most suitable one from the engine performance and CO emissions points of view. However, theoretical comparisons have shown that the blend containing 16.5% ethanol was the most suited blend for SI engines. Jia et al. (2005) investigated emission characteristics from a four-stroke motorcycle engine using 10 vol% ethanol/gasoline blended fuel (E10) at different driving modes on the chassis dynamometers. The results indicate that CO and HC emissions in the engine exhaust are lower with the operation of E10 as compared to the use of unleaded gasoline, whereas the effect of ethanol on NOx emission is not remarkable. Hydrocarbon species except ethanol, acetaldehyde and ethylene emissions are decreased somewhat from ethanol/gasoline blends-fuelled motorcycle engine relative to gasoline-fuelled engine. Additionally, this analysis shows that aromatic compounds and fatty group ones are major compounds in motorcycle engine exhaust. Ceviz and Yüksel (2005) investigated the effects of using ethanol/unleaded gasoline blends on cyclic variability and emissions in a spark-ignited engine. Results of this study showed that using ethanol/unleaded gasoline blends as a fuel

decreased the coefficient of variation in indicated mean effective pressure, and CO and HC emission concentrations, while increased CO_2 concentration up to 10 vol.% ethanol in fuel blend.
While the use of lower alcohols (methanol and ethanol) in blends with gasoline has been investigated adequately, very little research has been done reported on higher alcohols (propanol, butanol and pentanol). The objective of this study is to obtain more quantitative information on the exhaust emissions characteristics of pure and high alcohol blended gasoline fuels.

Material and methods

Apparatuses used in the present study were an engine, a dynamometer (Figure 1) and an exhaust analyzer. A single cylinder, carburetted, four-stroke, spark ignition non-road engine (type Bernard moteures 19A), was chosen. Non-road gasoline engines differ from automotive engines in several technical specifications. Because of these design differences, the effects of alcohol/gasoline blended fuel changes on emissions from non-road gasoline engines are quite different compared to the effects of alcohol/gasoline blended fuel changes on emissions from automotive gasoline engines. This engine had a 56 mm bore and a 58 mm stroke (total displacement 143 cm^3). Its rated power is 3HP. The ignition system was composed of the conventional coil and spark plug arrangement with the primary coil circuit operating on a pulse generator unit. The engine was coupled to a hydraulic dynamometer. Exhaust gases were sampled from the outlet and then were measured on line by an exhaust analyzer Bosch.

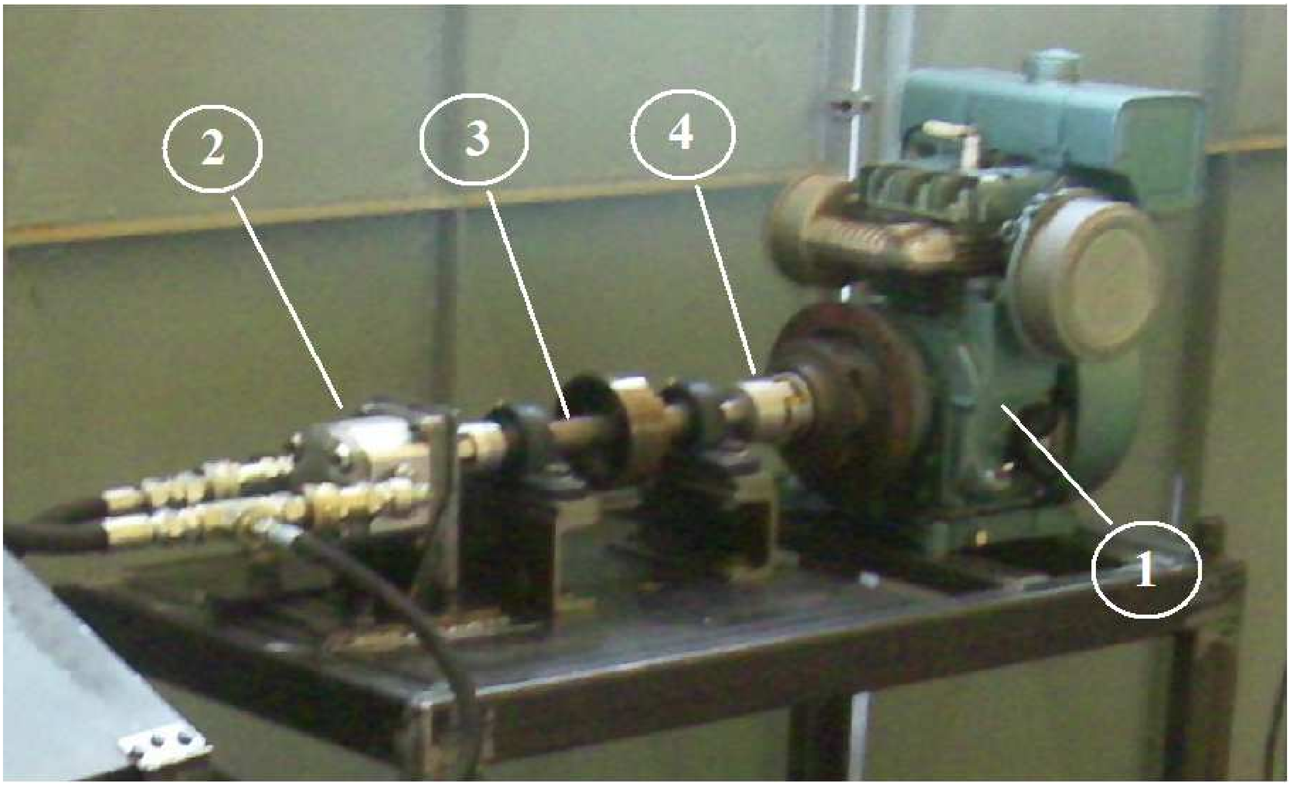

Figure 1: Photograph of the experimental set-up. 1-Engine, 2-Dynamometer, 3-Shaft, 4-Flywheel.

The unleaded gasoline was blended with alcohols to get five test blends ranging from 10% to 30% alcohols with an increment of 5%. Table 1 lists the volumetric composition of the five test blends. The alcohol component of the blends consisted of methanol, ethanol, propanol, butanol and pentanol (the concentrations of ethanol in the blends varied). The test blends were prepared just before starting the experiment to ensure that the fuel mixture was homogeneous and to prevent the reaction of ethanol with water vapor.
The engine was started and allowed to warm up for a period of 20–30 min. Before running the engine with a new fuel blend, it was allowed to run for a sufficient time to consume the remaining

fuel from the previous experiment. Engine tests were performed at maximum to idling rpm engine speed. The lowest desired speed is maintained by the load adjustment. The required engine load was obtained through the dynamometer control. For each experiment, three runs were performed to obtain an average value of the experimental data. The variables that were continuously measured include engine rotational speed (rpm), CO, CO_2, HC and NO emissions. CO, CO_2, HC, and NO emissions had average values of the acquired data within 20s for each stable operating condition. The exhaust gas temperature was monitored during the experiments to ensure that the engine was in a steady state condition.

Table 1. Volumetric composition of the test blends.

Blend No	Unleaded gasoline	Ethanol	Methanol	Propanol	Butanol	Pentanol
1	90%	2%	1.9%	3.5%	1.5%	1.1%
2	85%	7%	1.9%	3.5%	1.5%	1.1%
3	80%	12%	1.9%	3.5%	1.5%	1.1%
4	75%	17%	1.9%	3.5%	1.5%	1.1%
5	70%	22%	1.9%	3.5%	1.5%	1.1%

Results and Discussion

Six test fuels were used in this study. The first was unleaded gasoline as a base fuel for alcohol blended gasoline fuels. The rest five tests were alcohol blended gasoline fuels containing 10%, 15%, 20%, 25% and 30% pure and high alcohols in fuel blend by volume, respectively. The results of CO, CO_2, HC, and NO emissions for different engine speed are presented in Figures 2, 3, 4, 5.

Figure 2 shows, the variation of CO exhaust emissions in relation to the engine speed. It can be observed that the CO emitted by the alcohol/gasoline fuel blends is significantly lower than the corresponding neat gasoline fuel case at all speed range, with the reduction being higher the higher the percentage of ethanol in the blend. The high percentage of CO emissions greatly depends on the operating condition of engine and air–fuel ratio. Figure 3 shows CO_2 exhaust emissions in relation to the engine speed. The CO_2 exhaust emissions have an opposite behavior when compared to the CO exhaust emissions, and this is clear in both Figures 2 and 3. This is due to improving the combustion process as a result of the oxygen content in the ethanol fuel. This is the behaviour reported by almost all investigators on various types of engines and conditions (Poulopoulos et al., 2001; Koç et al., 2009; Momani, 2009).

Figure 4 shows, for the different engine speed, the total HC exhaust emissions for the various percentages of the alcohol in its blends with gasoline fuel. It can be observed that the HC emitted by the alcohol/gasoline fuel blends is lower than the corresponding neat gasoline fuel case. Especially, it was observed that HC emission was 838 ppm vol. at 1600 rpm, if engine was fueled with unleaded gasoline, whereas HC emission was 667 ppm vol. for blend No 4. This indicated that the HC emission was reduced by nearly 20.4 %. Moreover, the results show clearly that for all fuel blends the engine hydrocarbon emissions will decrease with an increase in the engine speed, and the hydrocarbon concentration with the engine speed retaining almost the same trend for neat gasoline and alcohol/gasoline blends (Huang et al., 2000). The high value of HC emissions is closely related to many design and operating variables. Combustion chamber and ignition system design are two important design variables while air–fuel ratio, speed and load are main operating variables.

Figure 5 shows, for different engine speed, the NO exhaust emissions for the various percentages of the alcohol in its blends with gasoline fuel. It can be observed that the NO emitted by the alcohol/gasoline fuel blends is higher than the corresponding neat gasoline fuel case. Alcohol/gasoline fuel blends are generally observed to cause higher emissions of nitrogen oxides (NOx) than neat gasoline (Koshland et al., 1998; Hsieh et al., 2002), with some studies indicating mixed results (Mulawa et al., 1997; Knapp et al., 1998) and lower emissions (Wang et al., 2002). Longer-chain alcohol additives (propanol, butanol and pentanol), at 10% by volume, each also increase NOx emissions (Gautam et al., 2000). NO emission levels mainly depend on the peak temperatures achieved during combustion. Secondly, oxygen concentration is important. NO emissions peak at slightly lean mixtures (λ>1).

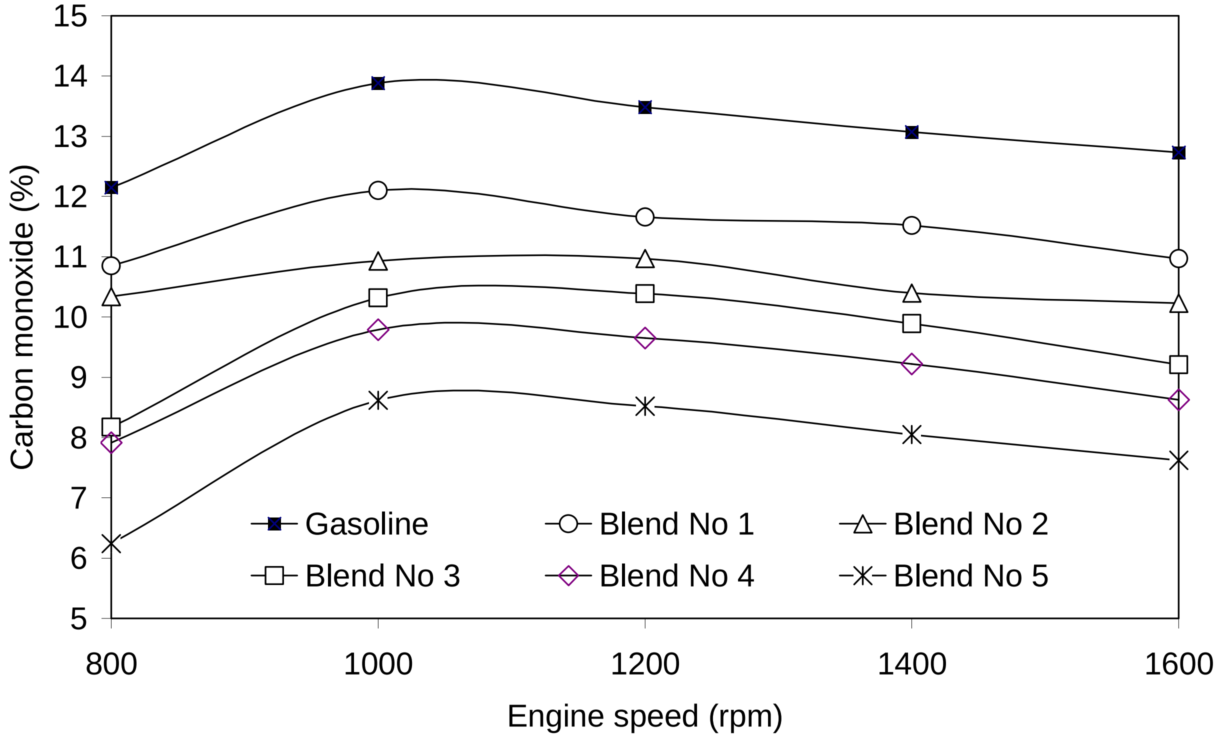

Figure 2: The variation of Carbon monoxide (CO) emissions in relation to the engine speed.

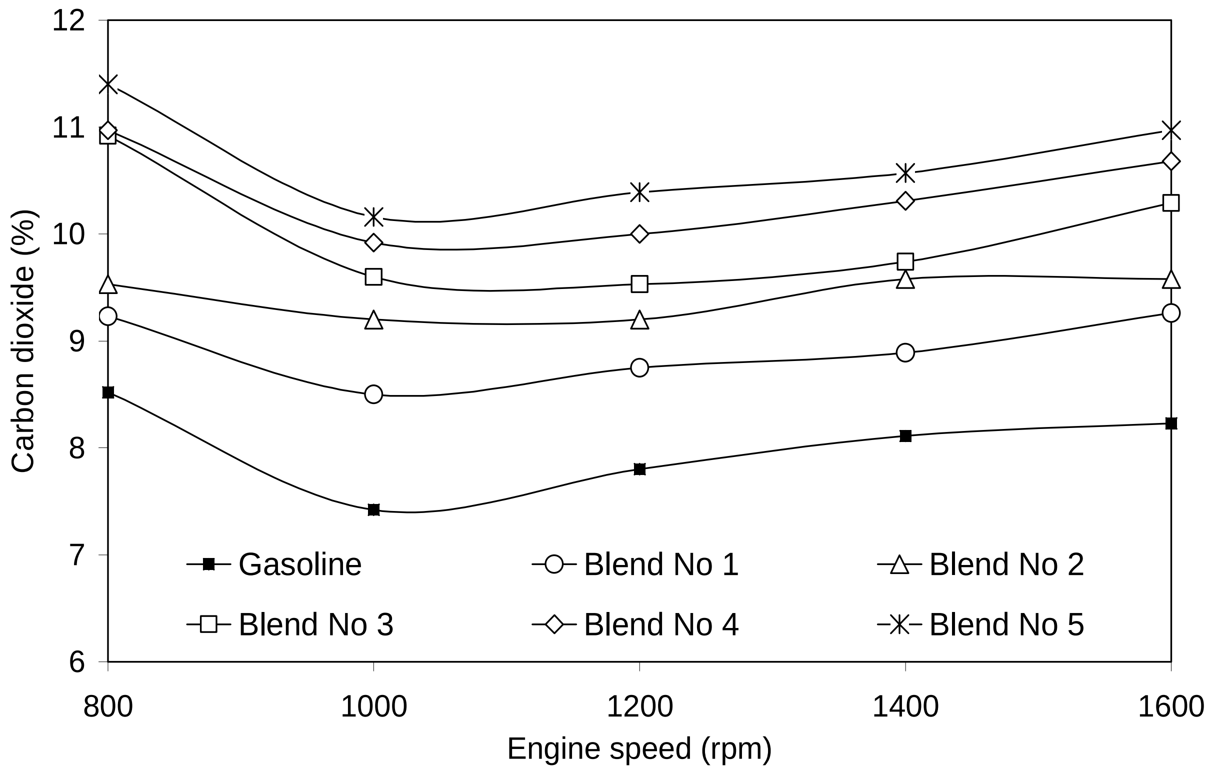

Figure 3: The variation of Carbon dioxide (CO_2) emissions in relation to the engine speed.

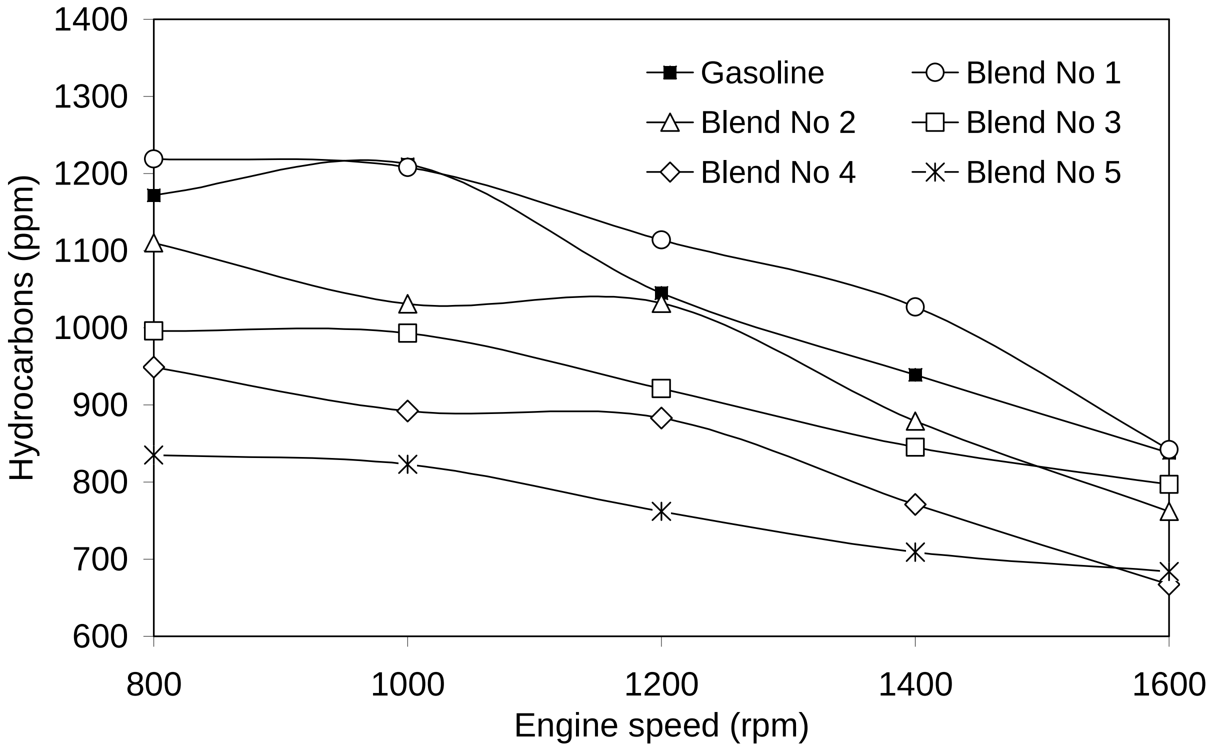

Figure 4: The variation of Hydrocarbons (HC) emissions in relation to the engine speed.

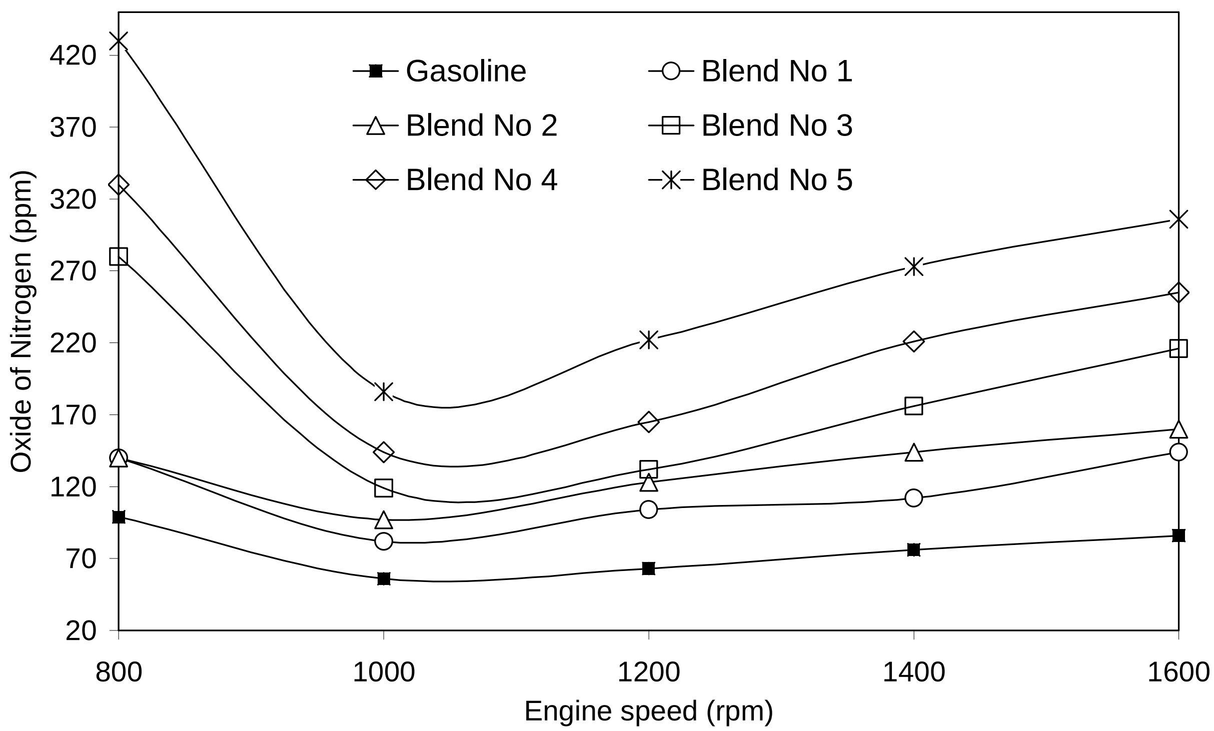

Figure 5: The variation of Oxide of Nitrogen (NO) emissions in relation to the engine speed.

To further examine the effect of high alcohols (propanol, butanol and pentanol) in the exhaust emissions, these alcohols were removed from the above five blends and the tests were repeated following always the same procedure.

Figure 6 shows, the comparative results of CO exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blends at 1200 rpm. CO emissions from the engine were decreased by higher ethanol addition to the fuel blends. CO emissions of pure-high alcohol/gasoline fuel blend ranged from 11.7 to 8.1% by volume, while pure alcohol/gasoline blend emissions ranged from 12.1 to 8,7% vol. Therefore, pure alcohol/gasoline fuel blend causes slightly higher CO emission than pure-high alcohol/gasoline blend.

Figure 7 shows, the comparative results of CO_2 exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blends at 1200 rpm. CO_2 emissions from the engine were increased by higher ethanol addition into fuel blends. Pure-high alcohol/gasoline blend is generally observed to cause higher emissions of CO_2 than pure alcohol/gasoline fuel blend. CO_2 emissions of pure-high alcohol/gasoline fuel blend ranged from 10.4 to 8.7 % by volume.

Figure 8 shows, the comparative results of HC exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blends at 1200 rpm. The first four fuel blends of pure-high alcohol/gasoline have higher HC emissions than pure alcohol/gasoline blends. Only in the fifth blend is observed higher HC emission from pure alcohol/gasoline fuel.

Figure 9 shows, the comparative results of NO exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blends at 1200 rpm. Pure-high alcohol/gasoline blend generally produces higher emissions of NO than pure alcohol/gasoline fuel blend. NO emissions of pure-high alcohol/gasoline fuel blend ranged from 104 to 222 ppm vol., while pure alcohol/gasoline blend emissions ranged from 79 to 154 ppm vol.

Based on this analysis of exhaust emissions, it is evident that longer-chain alcohols (propanol, butanol and pentanol) additions to pure alcohol/gasoline fuel blends increase CO_2, HC, and NO emissions.

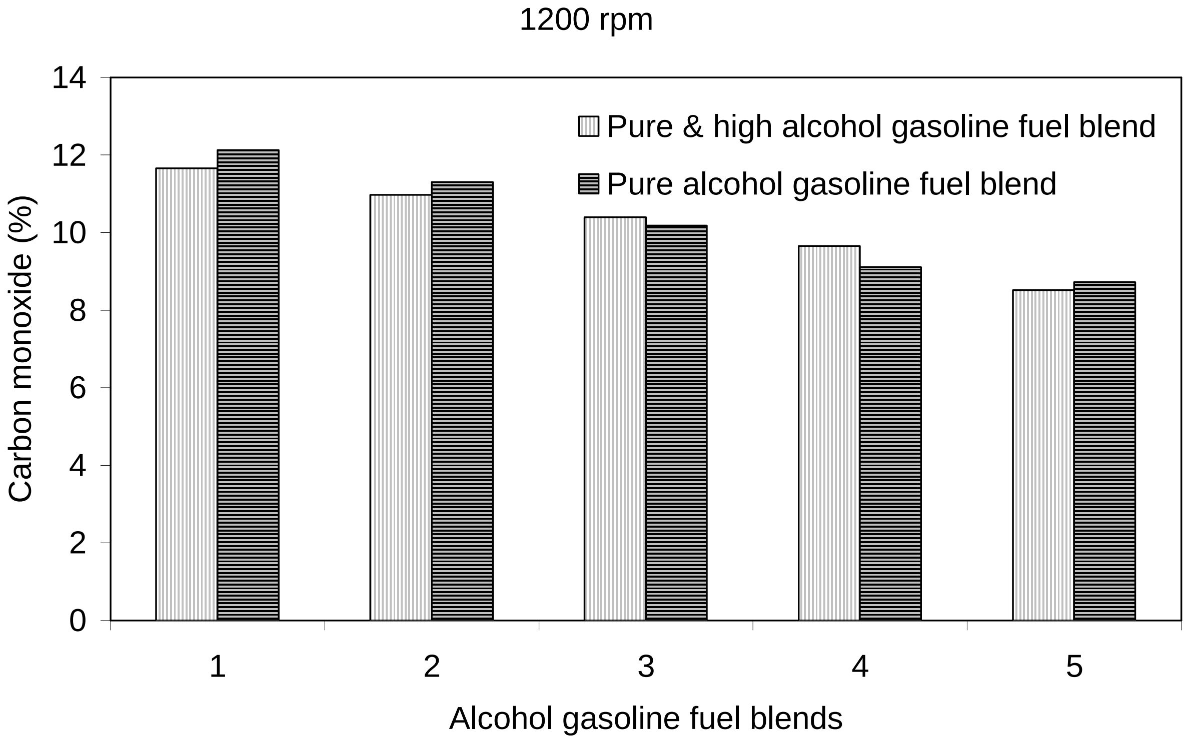

Figure 6: Comparison of CO exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blend at 1200 rpm.

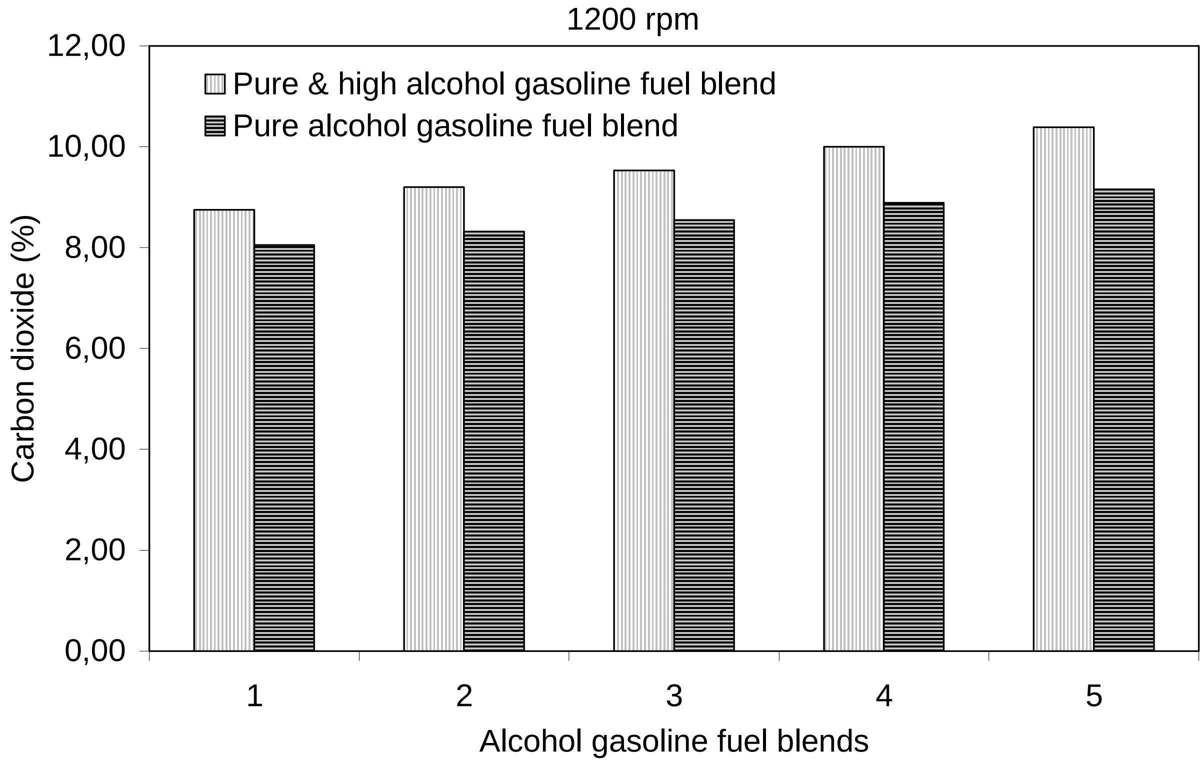

Figure 7: Comparison of CO_2 exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blend at 1200 rpm.

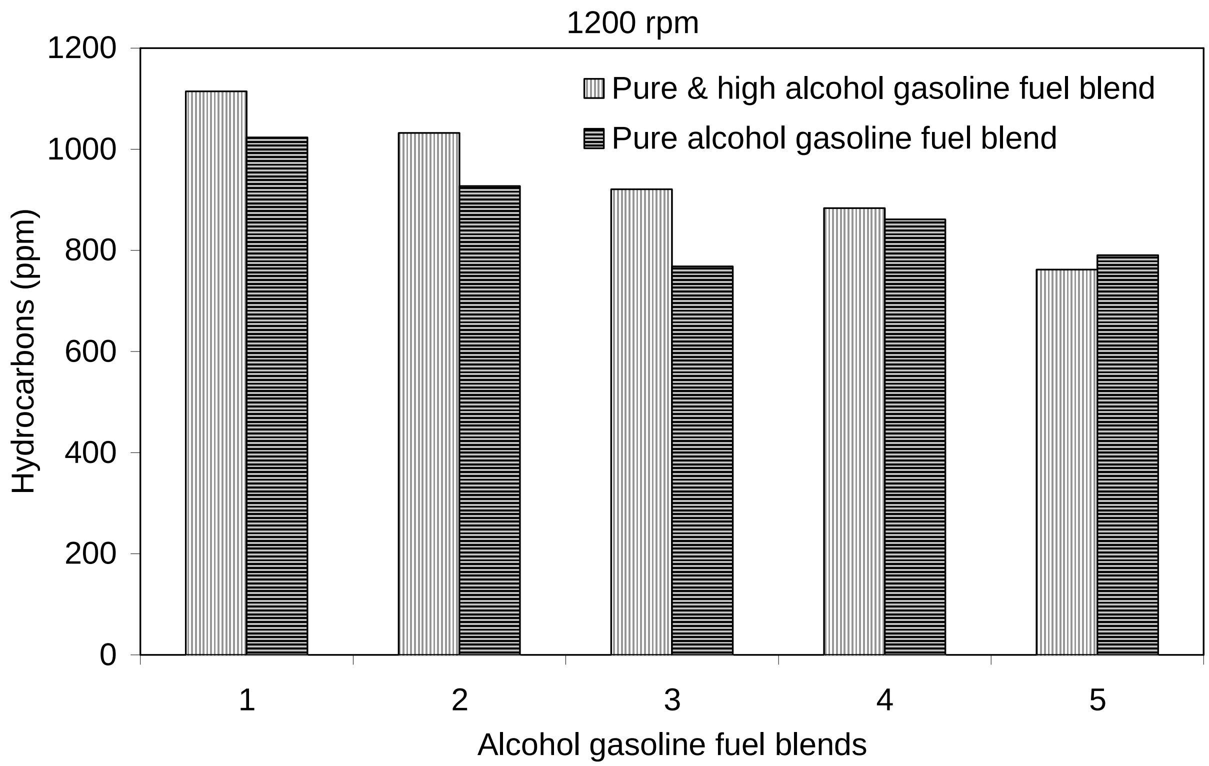

Figure 8: Comparison of HC exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blend at 1200 rpm.

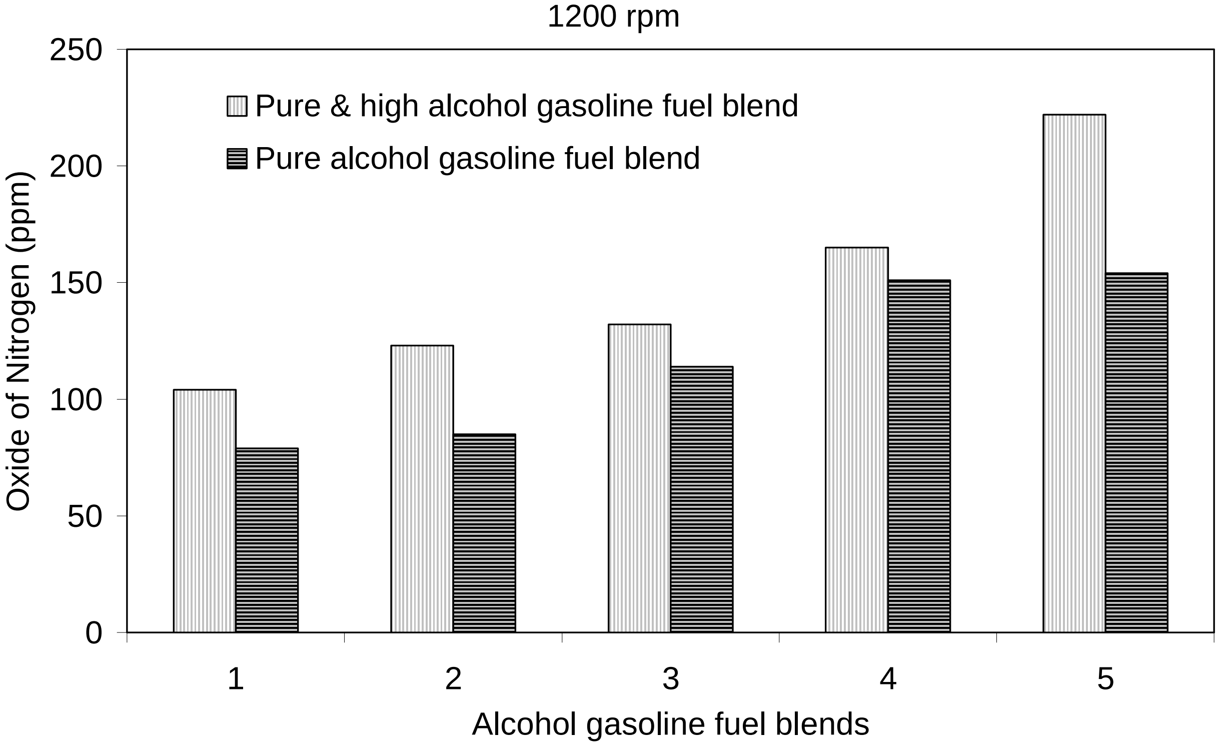

Figure 9: Comparison of NO exhaust emission between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blend at 1200 rpm.

Conclusions

An experimental investigation of emissions characteristics of pure and high alcohol/gasoline fuel blends was conducted. The exhaust emissions of CO and HC from the pure-high alcohol/gasoline blends are lower than those emissions from neat gasoline, with the reduction being higher the higher the percentage of ethanol in the blend. The high values of CO and HC emissions are closely related to many design and operating condition of non-road engine. The CO_2 exhaust emissions have an opposite behavior when compared to the CO exhaust emissions. Emissions of NO from the pure and high alcohol/gasoline fuel blends were higher than those from neat gasoline. The comparative results of CO, CO_2, HC and NO exhaust emissions between pure-high alcohol/gasoline and pure alcohol/gasoline fuel blends indicate that addition of longer-chain alcohols cause higher emissions except CO.

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