EVALUATING ENVIRONMENTAL EFFECTS OF BIOETHANOL-GASOLINE BLENDS IN USE A SI ENGINE

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Abstract
Bioethanol produced from sugarcane is anticipated to make a major input on transportation fuel markets. In this paper, the environmental effects of bioethanol-gasoline blends were evaluated in use a spark ignition (SI) engine. The bioethanol used in this study was produced by a sugar refinery in Turkey. To determine the exhaust emissions of bioethanol and gasoline blends, SI engine operated at different engine test conditions, and also the test results of bioethanol-gasoline blends compared with those of pure gasoline. The experimental results showed that when the test engine was fueled with bioethanol-gasoline blends, CO and unburned HC emissions decreased, but CO_2 and NO_x emissions increased. At the same time, the results indicated that the air-fuel equivalence ratio increased with the increase of bioethanol percentages in fuel blends.
Keywords: Bioethanol, spark ignition engine, performance, emission.

1. Introduction

Energy security and environment friendly technologies necessitate the use of biological fuels in gasoline or diesel engines, to substitute gasoline and diesel. So, recent years there has been increasing interest in the use of biofuels in internal combustion engine. The latest European regulations force the utilization of biofuels by at least 10% as energy source in transport by 2020 to reduce the pollutant emissions. One of these biofuels is Bioethanol (C_2H_5OH) which is a renewable fuel, and it can be produced from agricultural feedstocks such as sugarcane, wood wastes and agricultural residues. It also contains an oxygen atom, which can be viewed as partially oxidized hydrocarbon. The addition of ethanol to gasoline results in the enhancement of the octane number of blended fuels increases engine knock resistance and reducing the engine emissions (Ozsezen and Canakci, 2011; Stein et al., 2013).

Indeed, the idea of ethanol use as a vehicle fuel dates back to the initial development of the automobile one century ago. When Henry Ford designed his first automobile (Model T), it was built to run on both gasoline and pure ethanol (Sward, 1948). At the present time, it's a well-known fact that bioethanol can be used in blends with petroleum based engine fuels. The smaller the bioethanol addition, the easier typical blending problems (phase separation, corrosion, changed vapor pressure, changed air requirement etc.) can be solved (Pischinger, 1983). Bioethanol has high octane number; consequently their addition to gasoline enhances the octane number of the fuel, therefore reducing the knock problem in the engine (Menrad et. al., 1982). Bioethanol have nearly the same anti-knock effect (Popuri and Bata, 1993). However, increasing bioethanol content of the fuel blend results in decreasing the power, and increasing fuel consumption caused by its lower energy content (Raveendran and Ganesh, 1996). Palmer (1986) stated that the addition of ethanol to unleaded gasoline resulted in an increase in the research octane number by 5 units for each 10% addition. He also found that 10% ethanol addition to gasoline improved the engine power by 5%.

In literature, some researchers (Topgül et. al., 2003; Canakci et. al., 2012; Costagliola et al., 2013; Masum et. al., 2013) showed depending upon air-fuel mixture ratio that the bioethanol-gasoline blends reduce exhaust emissions levels compared to gasoline fueled engine. Generally in these studies, the reductions in the exhaust emissions have been presented depending upon the oxygen content in bio-ethanol. Some researchers (Costa and Sodre, 2010; Li et. al., 2003) have obviously shown reductions in CO and HC emissions, it could be appeared an increasing in NO_x emission. They also explained with faster flame speed of ethanol which increases the high peak pressure inside combustion chamber; this situation produces peak temperature in the combustion chamber. In this study, the effect of bioethanol-gasoline (E5, E10) blends on the SI engine performance and emissions has been discussed. And also, the objective of this study is to provide the information about an SI engine operated with bioethanol-gasoline blends.

2. Material and Method

For this study, bioethanol provided from a commercial company in Turkey. Since the bioethanol production utilizes organic sugar beets contributing to the environment by producing oxygen, and also the produced bioethanol has a purity of 96%. The bioethanol and regular grade gasoline's properties are shown in Table 1.

For the experimental work used a single cylinder spark ignition (Honda GX 390) with 8:1 compression ratio. The engine bore and stroke are 88 and 64 mm, respectively, 9.75 kW power with rated speed of 3600 rpm, giving a displacement of 389 cm^3. A hydraulic dynamometer is used to be kept at 5 kW of engine load. The experiments were performed at variable speeds of 1000, 1500, 2000, and 2500 rpm (±25) with constant engine output. In the experiments, the values of CO, CO_2, unburned HC, and NO_x for stable running modes in the exhaust gases were monitored by the Bosch BEA-250 exhaust analyzer with pre-calibration. Air mass flow was determined with use of a sharp edged orifice plate and digital differential manometers. The relative humidity and ambient temperature were monitored by a hygrometer. Six different digital thermocouples monitored the temperatures of the intake air, fuel, engine oil, exhaust gas, coolant inlet and outlet.

Table 1. The properties of pure bioethanol and regular grade gasoline

Fuel Property	**Unit**	**Gasoline**	**Bioethanol**
Formula		~ C_7H_{17}	C_2H_5OH
Molar C/H ratio		0.44	0.33
Molecular weight	kg/kmol	98.18	46.07
Net heating value	MJ/kg	44	26.9
Stoichiometric air-to-fuel ratio		14.7	9
Auto ignition temperature	°C	257	425
Heat of vaporization	kJ/kg	305	840
Research octane number		88ï 100	108.6
Freezing point	°C	-40	-114
Boiling point	°C	27ï 225	78
Density	kg/m^3	765	785

The engine was sufficiently warmed up for each test and exhaust gas temperature until it was maintained at certain level. During the tests, the engine did not show any starting difficulties when it was fueled with bioethanol-gasoline blends, and it ran satisfactorily throughout the entire tests at room temperature. The brake thermal efficiency and *bsfc* were corrected depending upon the atmospheric conditions as defined in Society of Automotive Engineers (SAE) standard (2001), since the engine tests had been carried out in different days.

3. Result and Discussion

3.1. Performance Results

Fig.1 show that bioethanol addition to the fuel blend results to an increase in brake specific fuel consumption (*bsfc*). As seen Table 1, the energy content of bioethanol is approximately 39% less than that of pure gasoline on a mass basis. Based on this fact, Fig.1 indicates that the engine need much more fuel amount when it is fueled with bioethanol blends to produce the same power output as a gasoline-fueled engine. Thus, the utilization of bioethanol-gasoline fuel blends led to a slightly increasing fuel consumption compared to the use of pure gasoline. This penalty can be absorbed by improved brake thermal efficiency, but thermal efficiency does not improved with use of bioethanol-gasoline blends.

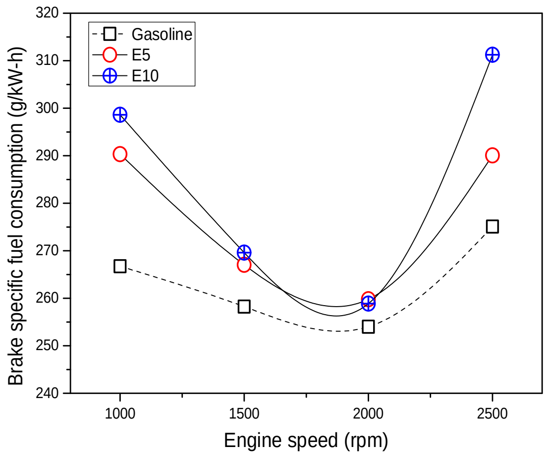

Fig.1. The *bsfc* values for test fuels

As seen Fig.1, for all test fuels, the minimum *bsfc* values were obtained at 2000 rpm of engine speed which are possibly maximum thermal efficiency of the test engine. The minimum *bsfc* for pure gasoline, E5, and E10 was measured as 254 g/kWh, 260 g/kWh, and 259 g/kWh at 2000 rpm, respectively.

For all test fuel blends at 1000 and 2500 rpm of engine speeds, the *bsfc* increased in proportion with the bioethanol content in the fuel blend. However, this case may be explained with the higher octane value of ethanol. In literature, some research (He et al., 2003; Ozsezen and Canakci, 2011) stated same expressions for explaining this fact.

Two important efficiency expressions are used to show the combustion and energy conversion quality in an internal combustion engine; brake thermal and combustion efficiency. The fuelôs chemical energy is not entirely converted to the mechanical energy due to the losses in the combustion process. Thus, the completeness of combustion must be defined (Heywood, 1998). In this study, the combustion efficiency was calculated from the exhaust emission values using the following formula;

$$\eta_C = \frac{H_R(T_0) - H_P(T_0)}{\dot{m}_f Q_{LHV}} \tag{1}$$

where; η_c is combustion efficiency (%); H_R is the enthalpy of reactants (fuel and air) at ambient temperature (T_o); H_P is the enthalpy of products (exhaust gases) at ambient temperature; Q_{LHV} is the lower heating value of the fuel (kJ/kg). And then, the thermal efficiency (η_{th}) was calculated as seen in eq.2 depending on the combustion efficiency, engine brake power ($\dot{W}_b$), fuel consumption per second ($\dot{m}_f$), and lower heating value. Fig.2 shows the calculated combustion and thermal efficiencies versus fuel type.

$$\eta_{th} = \frac{\dot{W}_b}{\dot{m}_f Q_{LHV} \eta_C} \tag{2}$$

Fig. 2 shows that the combustion efficiency slightly increased with the use of the bioethanol-gasoline blends. The combustion efficiency enhanced with increasing ethanol content in the fuel blend at 1000 and 1500 rpm, but similar trend was not seen at 2000 and 2500 rpm. The maximum combustion efficiency for pure gasoline, E5, and E10 was calculated as 98.37%, 98.58% and 98.65%, respectively, at 2500 rpm of engine speed. These results are as expected, because bioethanol have 10-20% higher oxygen than their stoichiometric condition. The slight rich of oxygen provide complete combustion of the fuel carbon and hydrogen, and the combustion efficiency appeared at maximum level. It is noted that combustion efficiency is little affected by other engine operating and design variables, provided the engine combustion process remains stable.

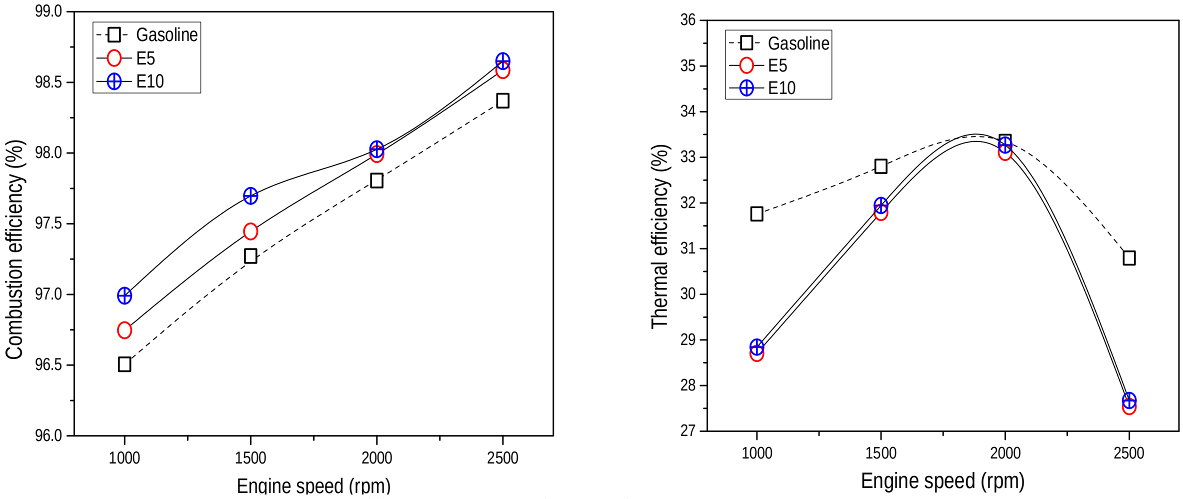

Fig.2. Combustion and Thermal efficiency values for test fuels

As seen in the Fig. 2, the maximum brake thermal efficiency values for pure gasoline, E5, and E10 were calculated as 33.35%, 33.11%, and 32.27% at 2000 rpm, respectively. The brake thermal efficiency is simply the inverse of the product of the specific fuel consumption and the lower heating value of the fuel; thus, the maximum brake thermal efficiency values were obtained in the minimum fuel consumption region. And also, it was seen that the brake thermal efficiency decreased with the increasing amount of bioethanol in the fuel blend. This means that the increase of *bsfc* for the bioethanol-gasoline fuel blends is lower than the corresponding decrease of the lower heating values of the blends.

Additionally, the complete combustion reaction formulas of pure gasoline and bioethanol with atmospheric air are shown below in eq. 3-4. For the same concentration air, the ethanol is higher energy release than pure gasoline. As a result of this situation, the brake thermal efficiency improved. In a similar study (Yanju et. al., 2008), the low content alcohol-gasoline blends were seen to be improving in brake thermal efficiency.

Gasoline:

$C_7H_{14} + 10.5(O_2 + 3.76N_2)$ Ÿ $7CO_2 + 7H_2O + 39.5N2 + 4.568$ MJ (3)

Bioethanol:

$4.66C_2H_5OH + 10.5(O_2 + 3.76N_2)$ Ÿ $9.32CO_2 + 11.65H_2O + 39.5N_2 + 6763$ MJ (4)

3.2. Emission Results

One of the key parameters which affect CO and unburned HC emission formations is the air-fuel ratio (Abdel-Rahman, 1998). Fig.3 show that air/fuel ratios for test fuels on the engine operating conditions.

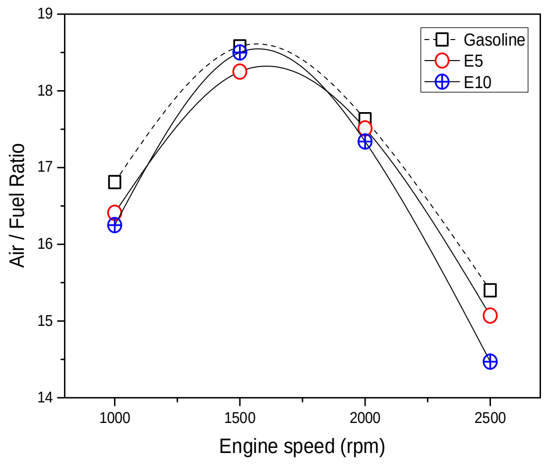

Fig.3. Air/fuel ratios for test fuels

Especially, if the engine is running in rich conditions, CO emission concentrations will increase because there is not enough oxygen to convert all carbon atoms of fuel into CO_2 (Wu et al., 2004). Fig.4 shows CO and unburned HC emissions values for test fuels. Emission test results indicate that when bioethanol is added to gasoline, the combustion of the engine becomes better and therefore CO emission is reduced. The mean average of CO emission decreases to 0.3%, 6%, 3.6% and 2% with E5, and 3.5%, 8%, 13% and 13.7% with E10, respectively, at 1000, 1500, 2000 and 2500 rpm of engine speeds. One of the most important properties of bioethanol is having oxygenated atoms in their molecular compounds which provide significant reduction in the CO and HC emissions. In the past, some researches (Zervas et. al., 1999; Hsieh et. al., 2002) explained that the decrease of CO emissions is due not only to dilution of the fuel but is also because addition of oxygenated compounds promotes the combustion of CO in the cylinder. The inclination of CO emission increased when the engine speed increased from 1000 to 2500 rpm.

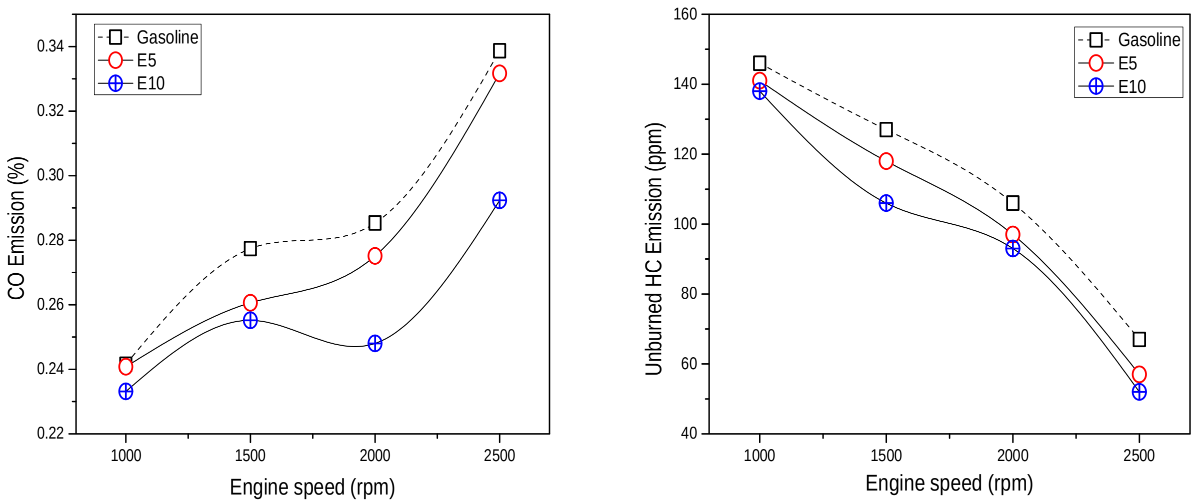

Fig.4. The effect of test fuels on CO and unburned HC emissions

The mean average of unburned HC emissions decreased 3.4%, 7.1%, 8.5% and 14.9% by E5, and 5.5%, 16.5%, 12.3% and 22.4% by E10, respectively, at 1000, 1500, 2000 and 2500 rpm of engine speeds. The explanation is that increasing engine speed leads to an increase in the combustion temperature, which combined with the high level of excess oxygen at these loads results in lower unburned HC emissions when compared with pure gasoline.

Other significant emissions are CO_2 and NO_x which contribute to serious air pollution and public health problems. In this study, the humidity correction factor for the NO_x was calculated as assured in the reference, Society of Automotive Engineers (SAE, 2001). Fig. 5 shows CO_2 and NO_x emissions values for all test fuels. As seen in figure, NO_x emissions with the use of E5 and E10 approximately increased by 1% and 2.2%, respectively. On average of CO_2 emissions with the use of E5 and E10 increased by 1.7% and 3.9%, respectively. Maximum increase ratios in NO_x emission was calculated, with E5 (1.6%) and E10 (3.6%), respectively, at 2500 rpm of engine speed compared with pure gasoline values.

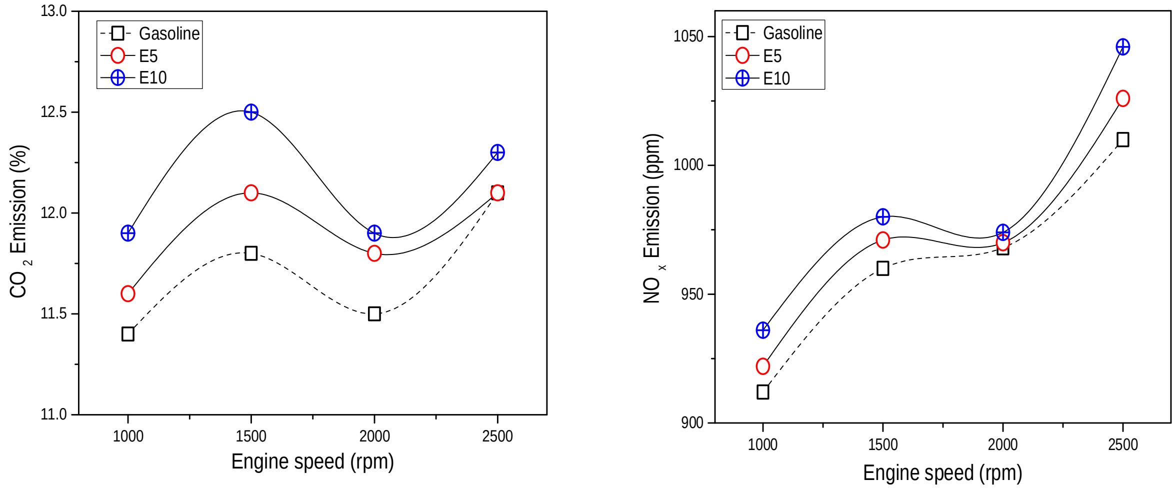

Fig.5. The effect of test fuels on CO_2 and NO_x emissions

4. Conclusion

This paper evaluates the environmental effects of bioethanol-gasoline blends in use a SI engine. The experimental results showed that when the test engine was fueled with bioethanol-gasoline blends, there is an increase in brake fuel consumption (~ 5% with E5 and ~ 7.5% with E10) compared with pure gasoline. With use of the bioethanol-gasoline blends, CO (~ 3% with E5 and ~ 9% with E10), unburned HC emissions (~ 8.5% with E5 and ~ 14.2% with E10) decreased and NO_x (~ 1% with E5 and ~ 2.2% with E10), CO_2 (~ %1.7 with E5 and ~ 3.9% with E10) slightly increased. The best combustion efficiency was obtained with the use of bioethanol-gasoline blends. It can be said that the decreases in unburned HC emission levels with use of the alcohol-gasoline blends led to increase in the combustion efficiency. And also it did not appear a cold start problem when using the fuel mixtures.

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