Effects of Various Fuel Blends on the Performance of a Two-stroke Internal Combustion Engine

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The purpose of this project was to study the influence of different fuel blends including gasoline, ethanol, stabilized hydrogen peroxide, water and Brown's gas (oxy-hydrogen or HHO gas) on the operation of a two-stroke engine. Fuel consumption and temperature at the exhaust port were measured while the rpm of the engine was kept constant at 3600 rpm. Our tests did not show any significant effects of the addition of HHO gas on engine operation and fuel consumption. Increasing concentrations of ethanol in gasoline resulted with significant increasing trends of fuel consumption with ethanol concentrations above 20 % in gasoline and increased combustion temperatures. Hydrogen peroxide – water – ethanol blends did not increase engine efficiency. The engine did not function with more than 10 % H_2O_2 and 10 % H_2O in ethanol. The presence of hydrogen peroxide had negative impact on the properties of carburetor membranes. Results indicate that fuel comprising 20 % ethanol in gasoline achieves the highest efficiency as compared to other blends, pure gasoline and pure ethanol. The components of the blends did not show any signs of separation/stratification from the mixture.

Introduction

Decreasing supplies of fossil fuels and steadily rising concentrations of atmospheric carbon dioxide concentrations and levels of atmospheric pollutants are some of major challenges to the modern society. The scientific community is addressing these problems by an attempt to replace fossil fuels with cleaner and renewable sources of energy (EU Directive 2009/28/EC). The research conducted so far indicates the biomass-based fuels to be the best option because they do not require changes in the existing technologies in use. Probably the best alcohol that can be an alternative to petroleum is ethanol. Thus a new path has been opened for flex-fuel engines, i.e. engines that can operate with gasoline blended with anhydrous ethanol (18–25% vol/vol), 100% hydrous ethanol (4.0–4.9% vol/vol of water) or any blend of these fuels (Melo et al., 2012).

The goal of this study was to elucidate the hypothetical synergistic combustion effects of various fuel mixtures including gasoline, ethanol, HHO gas and stabilized hydrogen peroxide, and offer the optimal fuel mixture for existing two-stroke internal combustion engines with no modifications to existing injection and ignition systems.

Ethanol is interesting because of various reasons: a) the cost of fuel and minimal environmental effects, b) can blend with gasoline and diesel c) higher heats of vaporization and octane number, d) reduction in particulate emissions, e) can be made from wastes, agricultural crop residues and residues from processing. Ethanol was seriously considered in programs designed for conservation of natural resources (U.S. Department of Energy, 1999; California Energy Commission, 1999).

Most of the research conducted so far focuses primarily on ethanol that contains 35% oxygen as a stand-alone fuel and as an oxygenated additive to hydrocarbon fuels to decrease emissions of nitrogen oxides (NO_x), unburned total hydrocarbons (THC) and carbon monoxide (CO). The idea was superimposing oxidation over pyrolysis. Even though considerable research effort has been conducted in this respect (Dunphy, Petterson and Simmie, 1991; Borisov et al., 1992; Dagaut, Boettner and Cathonnet, 1992; Norton and Dryer, 1992; Marinov, 1999; Li, 2004; Assad et al., 2011), there are still many uncertainties associated to use of ethanol in flex-fuel engines and high-octane-rated fuels (85/15 v/v ratio ethanol/gasoline) associated with high rates of emissions of particulate matter (soot).

The role of hydrogen in emission reduction of gasoline (Wang and Zhang, 2011; Musmar and Al-Rousan, 2011), spark ignition (Al-Baghdadi, 2003) and diesel (Bose and Banerjee, 2012) engines was also investigated. HHO gas is renewable and clean burning fuel that does not generate carbon dioxide. Hydrogen has about nine times higher flame speed than diesel (Bari and Esmaeil, 2012), and six times higher than that of the gasoline air mixture (Al-Baghdadi, 2003). Adding HHO gas beyond 5% does not have significant effect in enhancing the diesel engine performance (Bari and Esmaeil, 2012). Small amount of hydrogen addition produces an antiknock quality of fuel. In this study one of the goals was to test if the addition of HHO gas as source of active intermediate substances would result with measurable effects on engine operation and fuel consumption.

In early 1960-ies some studies identified a blend of ethanol, water and stabilizer-free hydrogen peroxide (H_2O_2) to be as highly explosive (Monger, Seello and Lehwalder, 1961; Heitler, Scaife and Thompson, 1967). One of the goals of this study was to investigate if such a blend with stabilized hydrogen peroxide can be applied directly to an internal combustion engine and if the conditions in the compression chamber could initiate explosion of the mixture as a consequence of the oxidation of ethanol by hydrogen peroxide. Hydrogen peroxide is very strong, storable oxidizer/monopropellant. Hydrogen peroxide, oxygen enriched additive generates hydroxyl radicals in the thermal decomposition, and OH radicals can reproduce the HO_2 radicals (Kasper, Cclausen and Cooper, 1996). Iron complexes catalyze the decomposition of H_2O_2.

Direct utilization of fuels with significant amounts of water can reduce water separation cost, but conventional fuel delivery system is not designed for water.

Homogeneous charge compression ignition engines with efficient heat recovery can run on low-grade fuels, 35% ethanol-in-water with good performance and emissions (Mack, Aceves and Dibble, 2009). Water in ethanol–water mixture reduces the mass-burning rate due to increase in the boiling point and in the latent heat of vaporization (Parag and Raghavan, 2009). Hydrous ethanol addition reduced CO and THC, but increased CO_2, aldehydes and unburned ethanol emissions (Melo et al., 2012).

Predictions of complex mechanisms are often inconsistent to studying individual components due to synergistic reactions from coupling of chemical reactions including convective and diffusive processes. The aim of this project is to study the resulting outcomes of complex combustion processes in a standard two-stroke internal combustion engine without modifications to the engine and its injection and ignition systems.

Method

Fuel Blends. Tests with gasoline were conducted with 95-octane unleaded gasoline (760 g L^{-1}) mixed 50:1 with Dolmar synthetic two-stroke oil. For ethanol blends, anhydrous ethanol (789 g L^{-1}, Sigma-Aldrich) was used. Gasoline was first mixed with two stroke oil after which ethanol was added to achieve 5/95, 20/80, 50/50 and 80/20 v/v ratio ethanol/gasoline. Measurements with pure ethanol were conducted without adding lubricant oil due to poor dilution properties of lubricant in alcohol. Emulsions 20/80, 50/50 and 80/20 v/v alcohol/gasoline with the lubricant produced a nontransparent white mixture (the components did not separate over time) after the addition of ethanol to gasoline-oil mixture.

Electrolyte for HHO gas generator was prepared by diluting 5 g NaOH (Trgomar) with 95 g distilled water. The electrolysis of one mole of water produces a mole of hydrogen and a half mole of oxygen gas.

For hydrogen peroxide - ethanol tests, stabilized 50 wt % hydrogen peroxide solution in H_2O (1200 g L^{-1}, Sigma-Aldrich) was mixed with anhydrous ethanol to achieve concentrations of 2, 5, 10, 20, 50 and 86 % in ethanol.

Experimental Engine Setup. The experiment was conducted on a single cylinder two stroke Tomos 4 engine as depicted in Table 1.

Table 1. The technical engine specifications

Type	Tomos 4, spark ignition engine
Cycle	Two stroke, air cooled
Number of cylinder	1
Compression ratio	10:1
Cubic capacity	59.3 cu cm
Cylinder bore	42 mm
Stroke	43 mm
Rated output	2.2 kW (3.0 HP) @ 5400 rpm
Engine speed	3600 rpm
Ignition timing	Variable

To obtain convenient access for measurement, the engine was mounted on a horizontally sliding frame with needle bearings (Fig. 1), all together connected to a hanging scale also positioned horizontally (Fig. 2). To achieve constant load and cooling of the engine, an airplane propeller (Biela 18x10 three blade carbon propeller) was mounted on the output shaft of the engine. Hanging scale and tachometer were used to monitor and adjust the eventual changes in rotation speed and pull force of the propeller. In all experiments the engine was run at a constant rotation speed of 3600 rpm. The Stihl Bing 48 carburetor with high and low needle adjustment has been used for fuel supply coupled with a Trgomar H_2O Maxpower SS1 oxy-hydrogen gas generator (Fig. 3). Inlet of the HHO gas was placed between the Venturi throat and throttle plate in the carburetor. Engine fuel enters the air stream through the liquid fuel discharge tube in the carburetor body and is dispersed and mixed by the air stream passing the throttle plate and intake manifold. HHO gas mixes with fuel-air mixture before throttle valve to enter the intake manifold. To measure the temperature of the exhaust gases a T type Cu-CuNi thermocouple was mounted over the exhaust port of the cylinder and Omega microprocessor thermometer model HH21 was used for all temperature measurements. Fuel consumption was estimated by measuring the flow of fuel through a graduated 60 ml syringe.

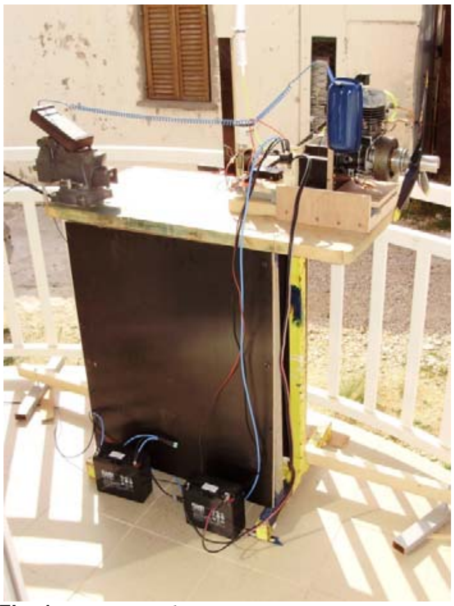

Fig. 1. *Experimental engine setup*

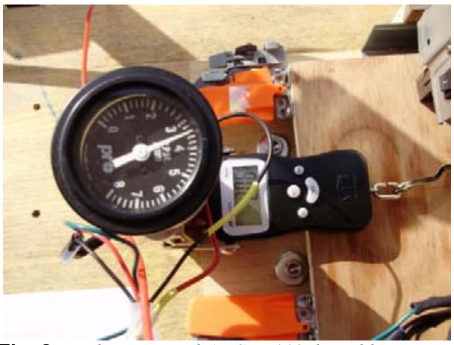

Fig. 2. *Tachometer and AWS H-110 digital hanging scale*

Fig. 3. *Trgomar H_2O Maxpower SS1 setup*

Experiment Procedure. The tests were conducted on 21st, 22nd, 23rd, 24th and 26th March 2012 in Dubrovnik, Croatia on an outdoor terrace. The ambient temperature was 19.1°C, 17.2°C, 18.8°C, 17.3°C and 17.9°C, respectively. During the course of the experiments, the weather was stabile with air pressure of 1020.0 hPa and humidity of 33 %. The engine was firstly started with the pure gasoline; rotation speed was adjusted to 3600 rpm and the engine was left to warm up for 10 min. Temperature at the exhaust port was recorded at the beginning and the end of each separate test. Fuel consumption for each blend was measured by timing the flow of 20-60 ml fuel through a graduated 60 ml syringe with a digital stopwatch. After switching to a different fuel blend, the engine was run on 60 ml of each new blend before measurements, and if necessary, the rotation speed was adjusted with high and low speed adjustment needles on the carburetor before temperature and fuel consumption measurements were recorded. Throttle always remained at the same position.

Each fuel blend was tested with and without the input of HHO gas. After each test cycle including all the above-mentioned blends the measurements with initial gasoline fuel were repeated. The engine was left to burn the remaining gasoline in the system and left to cool down.

Results

All measurements were recorded with engine running at a constant speed of 3600 rpm. The pull force of the 18x10 three-blade propeller at 3600 rpm was 2.16 kg.

Figs. 4-8 show the effect of ethanol and HHO addition on fuel flow rate and temperatures at the exhaust port. The temperature at the exhaust port in all tests ranged from 268 - 325°C. It could be noted that the lowest temperatures refer to the engine running on pure gasoline. Increasing concentrations of ethanol in gasoline resulted in increasing nonlinear trends in temperatures. Temperature peaks can be observed at 20/80 v/v ethanol/gasoline emulsion (Figs. 4-6, 8). To maintain the same rotation speed of the engine, high and low needle adjustments on the carburetor were necessary for ethanol concentrations from 50 % and higher and for all ethanol-water-hydrogen peroxide tests. The influence of HHO gas on combustion temperatures as measured in this study is not conclusive (Fig. 10); the variances were ± 17°C or ± 5.7 %. No correlation was found between the two cases.

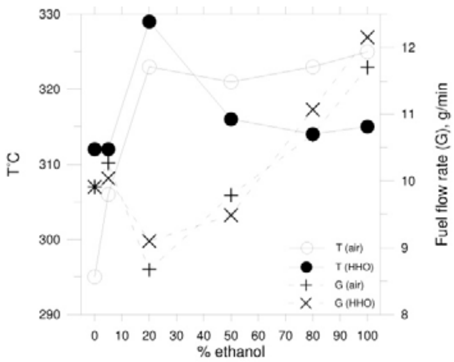

Fig. 4. *Effect of ethanol and HHO enrichment of gasoline, Test 1*

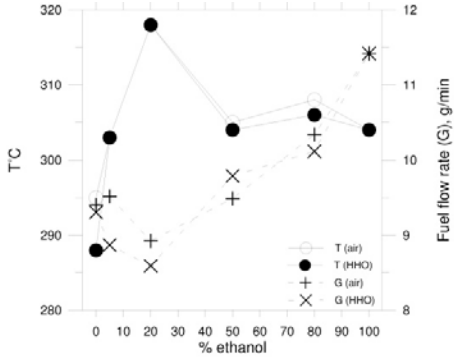

Fig. 5. *Effect of ethanol and HHO enrichment of gasoline, Test 2*

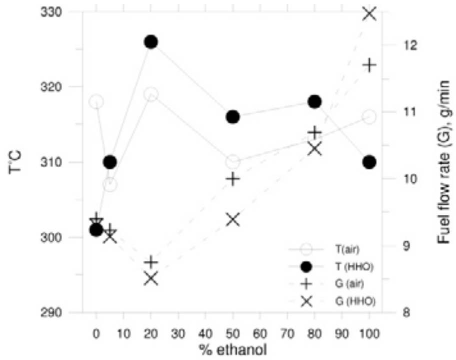

Fig. 6. *Effect of ethanol and HHO enrichment of gasoline, Test 3*

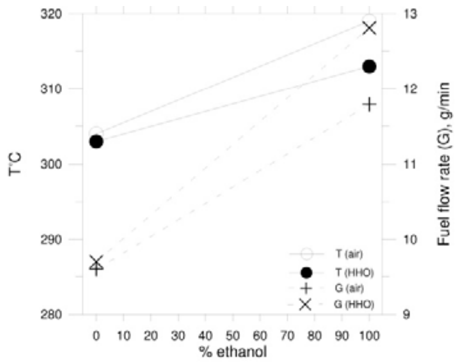

Fig. 7. *Effect of ethanol and HHO enrichment of gasoline, Test 4*

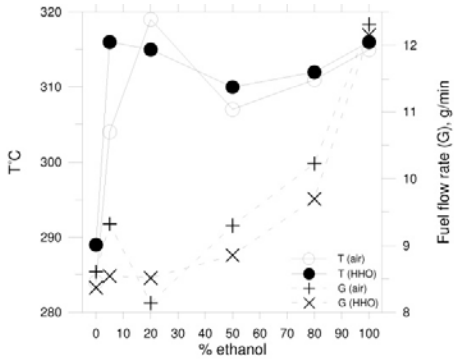

Fig. 8. *Effect of ethanol and HHO enrichment of gasoline, Test 5*

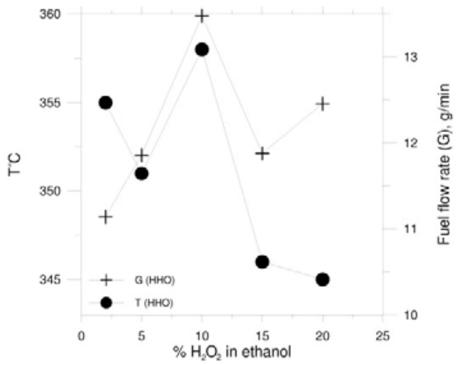

Fig. 9. *Effect of ethanol, water and hydrogen peroxide blending*

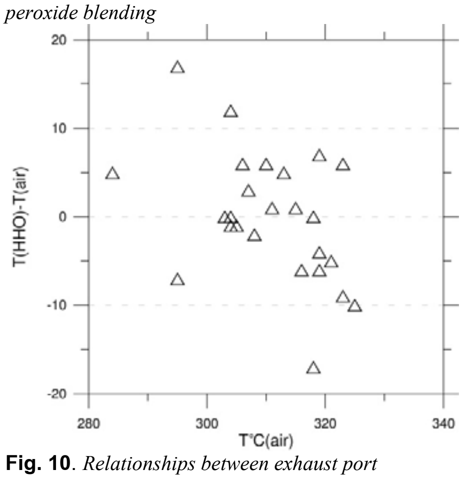

Fig. 10. *Relationships between exhaust port temperatures in conditions with HHO gas and air only*

Temperature peaks for 20/80 v/v ethanol/gasoline emulsion correlate with the lowest fuel flow rates in all tests (Figs. 4-6, 8). Fuel flow rates in 20/80 v/v ethanol/gasoline tests with air as carrying gas were 5.1 - 12.5 % lower than pure gasoline, and 1.04 - 9-46 % lower than in pure gasoline tests with HHO as carrying gas. The highest fuel flow rates were recorded in pure ethanol tests; the values were 18.1 - 43.14 % higher than with pure gasoline tests with air as carrying gas, and 21.49 - 48.95 % higher than pure gasoline with HHO as carrying gas, indicating that the presence of HHO gas increases pure ethanol fuel flow rates.

The effects of ethanol, water and stabilized hydrogen peroxide blends are shown in Figure 9. Increasing amounts of water in the blends results with improper functioning of the engine. With more than 20 % hydrogen peroxide in ethanol it was impossible to maintain the engine running at 3600 rpm. With 50/50 v/v ethanol/hydrogen peroxide the engine could achieve the maximum of 1400 rpm and the rotation speed did not remain constant, varying from 900-1400 rpm. These measurements are not included in the Figure 9. At 17/83 v/v ethanol/hydrogen peroxide the engine operated for 23 seconds at speeds 1100-1200 rpm and most probably due to too much water (dense white smoke was observed coming out of the muffler) in the blend (41.5 %). The engine could not be ignited. Carburetor membranes had to be replaced after these tests. Hydrogen peroxide significantly softened the membranes that the engine could not be set to operate normally with pure gasoline. The temperatures measured at the exhaust port ranged from 345-358°C and fuel flow rates ranged from 15.96-17.44 g/min, indicating pronounced influence of hydrogen peroxide on combustion temperatures and fuel flow rates.

Discussion

A single cylinder, two-stroke, spark ignition engine was operated on gasoline-ethanol and ethanol-hydrogen peroxide-water fuel blends with air and HHO gas as carrying gases at compression ratio 10:1 and constant speed of 3600 rpm. It has been previously shown that ethanol enrichment of gasoline leads to a reduction in exhaust emissions of CO, HC and NO_x with the degraded engine's fuel efficiency due to lower calorific value of the blends (Assad et al., 2011; Al-Baghdadi, 2003; Yüksel, F., and Yüksel, B., 2004). Ozsezen and Canakci (2011) indicated increased CO emissions and decreasing NO_x emissions at increasing load of the engine, while Al-Hasan (2003) denoted that CO and CO_2 concentrations have opposite peaks in exhaust emissions with increasing load of the engine. It has also been shown that small additions of hydrogen to ethanol and gasoline can lead to decreased NO_x emissions (Wang and Zhang, 2011; Al.Baghdadi, 2003).

Our results indicate that increasing ethanol enrichment of gasoline to pure ethanol significantly reduces the engine's fuel efficiency. The only exception can be seen at 20 % ethanol enrichment, which significantly (5.1 - 12.5 %) increases fuel efficiency than with pure gasoline and other blends as well, corroborating previous findings in a four-stroke engine (Al-Hasan, 2003). Ethanol addition cause the spark timing increase avoiding knocking addition and leading to lower temperatures inside the combustion chamber (Melo et al., 2012).

We hypothesized that HHO gas can be used as a source of small amounts of hydrogen to improve the engine performance. Our results do not show any measurable impact on performance except for pure ethanol when the presence of HHO gas significantly increased the fuel flow rate, most probably due to the presence of free radicals in the gas, which can improve oxidation of ethanol.

Our results have also shown that a two-stroke engine can operate on ethanol-water-stabilized hydrogen peroxide blend, however with not more than 10 % water and 10 % hydrogen peroxide in ethanol. The presence of hydrogen peroxide significantly increases combustion temperatures. Furthermore, this approach would require different materials resistant to hydrogen peroxide for carburetor membranes since the existing materials are dramatically weakened by the presence of hydrogen peroxide. Engines can run on a large variety of fuels as long as the fuel can be heated to the point of auto ignition (Mack, Aceves and Dibble, 2009). Water in fuels has dilution effects. Heat released during the reaction goes to water evaporation, and water effects on reduction in peak flame temperatures. Ethanol also burns slower than gasoline (Parag and Raghavan, 2009).

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