AEC021

Effects of Hydrous Ethanol Fuels on the Performance of Small Spark Ignition Engine and Deterioration of Engine Oil

Supoj Sirisenapan[1], Preechar Karin[2] and Chinda Chareonphonphanich[1]*

[1] Faculty of Engineering
[2] International College
* King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand 10520.
E-mail: supoj531@gmail.com

Abstract

This research investigates the performance of an SI engine generator powered by anhydrous ethanol (E100), hydrous ethanol (Eh95), Eh90, and Eh85. In addition, it examines the effects that the four fuels have had on the engine oil deterioration at 2500 rpm. Hydrous ethanol is a mixture of ethanol and water, and Eh95, Eh90 and Eh85 represent 5%, 10% and 15% water contents in ethanol by volume, respectively. To achieve a relative air/fuel ratio of approximately one ($\lambda \approx 1$) for all four fuel types, the hole diameter of a main jet was modified. The experimental engine speeds to test the fuel performance were maintained at 2000 and 2500 rpm. The engine loads were varied from 500 W up to 2000 W using electric lamps. The performance parameters are the specific fuel consumption (Bsfc) and fuel conversion efficiency (η_f), while the focus of the deterioration of engine oil at 2500 rpm is on the oil condition, wear condition and contamination. The findings revealed that, in comparison with anhydrous ethanol, Bsfc of hydrous ethanol fuels were higher and increased with increase in water content. η_f increased with increase in power output (P_{out}). The experimental results also showed that the deterioration levels of the engine oil were within the requirements, indicating that all four fuels are compatible with the generator.

Keywords*:* hydrous ethanol, anhydrous ethanol, engine oil, engine oil performance, deterioration.

1. Introduction

Biofuel is an oxygenated fuel whose molecule contains oxygen atoms. The oxygen atoms make biofuel combustible under the lean combustion condition and enhance the combustion process efficiency. Most commercially available biofuels are sugarcane molasses-based, cassava-based or corn starch-based, while the conventional biodiesel is produced from legumes and palm oil. According to [1, 2], the benefits of promotion and use of locally produced ethanol and biodiesel are: (1) less reliance on the imported fossil fuels; (2) strengthening the energy and agricultural sectors, in addition to the creation of employment and elevation of income; (3) lower greenhouse gas emissions (GHG), e.g. hydrocarbon, particulate matters, carbon monoxide (CO); and (4) the completion of the carbon neutral cycle, thereby lowering the severity of global warming, despite higher carbon dioxide (CO_2) emissions of biofuels relative to fossil-based fuels. The lower GHG emissions are attributable to oxygen contained in biofuels, which in turn lessen the negative impacts on human health and the environment.

An agricultural country in the Southeast Asian region, Thailand is able to grow numerous fuel crops, e.g. sugar cane and cassava, and thereby is capable of producing its own ethanol fuels. In general, anhydrous ethanol is better received by motorists than hydrous ethanol since the former contains a higher ethanol content than the latter. However, the distillation process of anhydrous ethanol is more complicated and costlier. Thus, it makes good economic and environmental sense to promote the use of hydrous ethanol.

R. Munsin et al. [3] investigated the effect of hydrous ethanol (up to 40% water in ethanol) on the performance and emission of a small SI engine using an electronic control unit (ECU) to control the engine speeds and loads. The addition of 20–40% water to ethanol resulted in incomplete combustion, thereby increasing CO and HC emissions while reducing NOx. The authors reported that the combustion temperatures at the spark plug decreased with increase in the water content of ethanol. Moreover, the lower combustion temperatures of hydrous ethanol reduced the formation of NOx.

The objectives of this research are to investigate the effects of water content in three hydrous ethanol fuels, i.e. Eh95, Eh90, and Eh85, on the SI carburetor engine generator performance; and to determine the hydrous ethanol that exhibits the lowest level of engine oil deterioration.

2. Materials and methods

Typically, small engine generators are of carburetor system. Thus, this research work employed an SI carburetor engine generator to examine the effects of water content in three hydrous ethanol fuels on the generator performance and to determine which hydrous ethanol least contributes to the engine oil deterioration.

2.1 Engine

Table 1 presents the specifications of the SI carburetor engine generator (Kwai Thong's K009 EP 2500 Es model).

Table. 1 Engine Specifications

Engine Type	Air-cooled, 4-stroke, Single cylinder, OHV
Bore x Stroke	68 x 54 mm
Displacement	196 cm^3
Compression Ratio	8.5:1
Carburetor Type	Butterfly
Max output / Rated output	2000 W / 1800 W
Fuel Tank Capacity	15 liters
Lubricant Oil Tank Capacity	0.6 liter
Lubricating Oil Life Time	100 hrs or 6 months
Ignition system	Transistorized Magneto Ignition
Fuel use	Gasoline

2.2 Fuel

Between ethanol and gasoline, the heating value of ethanol is approximately 1/2 time lower than that of gasoline. However, an oxygen content of 34.7 wt% in ethanol promotes combustion efficiency as well as high combustion temperature whereas gasoline contains no oxygen. The heat of vaporization of ethanol is higher than that of gasoline, and a lower C/H atom ratio of ethanol reduces the adiabatic flame temperature. Ethanol normally has a higher octane number (ON) than does gasoline. It follows that the higher the octane number, the more compression the fuel can withstand before detonating. In addition, the laminar flame propagation speed of ethanol is higher than that of gasoline, the characteristic which quickens the combustion process and thus improves the engine thermal efficiency [4].

E100 (C_2H_5OH, ethanol 99%), Eh95 ($C_2H_{6.1}O_{1.05}$, water content 5% by volume), Eh90 ($C_2H_{6.2}O_{1.1}$, water content 10% by volume) and Eh85 ($C_2H_{6.3}O_{1.15}$, water content 15% by volume) were fuel tested. Table. 2 shows some properties of ethanol compared hydrous ethanol, the most value decrease according the concentration of water is increased except density and oxygen fraction increased.

Table. 2 The physical-chemical properties of four ethanol fuels

Fuel properties	E100	Eh95	Eh90	Eh85
Density (kg/m^3)	790	810	814	826
LHV (MJ/kg)	28.67	26.79	25.55	23.24
$(A/F)_S$	9.0	8.8	8.6	8.5
Carbon mass (%)	52.14	51.14	50.18	49.25
Hydrogen mass (%)	13.13	13.09	13.06	13.02
Oxygen mass (%.)	34.73	35.77	36.76	37.73
Self-ignition (^{o}C)	423	420	-	-
Heat of vapori-zation (kJ/kg)	923	992.1	-	-
Vapor pressure (kPa)	15.9	15.4	-	-
Research ON	108.6	106	-	-
Motor ON	89.7	87	-	-

2.3 Experiment and procedure

Theoretically, the hole diameters of a carburetor main jet calculated by the elementary carburetor equation for E100, Eh95, Eh90 and Eh85 are 1.01, 1.02, 1.03 and 1.03 mm, respectively. However, the main jet diameters of commercially available carburetors have a 0.10 mm increment. Thus, a commercially available main jet with a hole diameter of 1.10 mm was selected for all four fuels. Since ethanol fuel possesses the characteristic of lean mixture, which is closest to the theoretical values, was employed in the experiments.

The relative air/fuel ratio (λ), measured with an oxygen sensor at the exhaust, was maintained at approximately one ($\lambda \approx 1$) by adjusting the generator choke valve. In addition, the engine speeds were maintained at 2000 and 2500 rpm. The engine loads were varied from 500 W to 2000 W using electric lamps. A clamp meter was utilized to monitor the electricity load supplied to the lamps. The engine revolution (rpm) was measured by a tachometer, and a high precision weight loss meter set was used to measure the fuel consumption.

The effects on the generator performance of the four ethanol fuels were investigated at different engine speeds of 2000 and 2500 rpm. The performance is evaluated based on the specific fuel consumption (Bsfc) and fuel conversion efficiency (η_f). The deterioration of engine oil in the generator powered by the four fuel types was examined only at 2500 rpm after operating the engine for a continuous period 40 hours. Fig. 1 illustrates the schematic of the experimental setup.

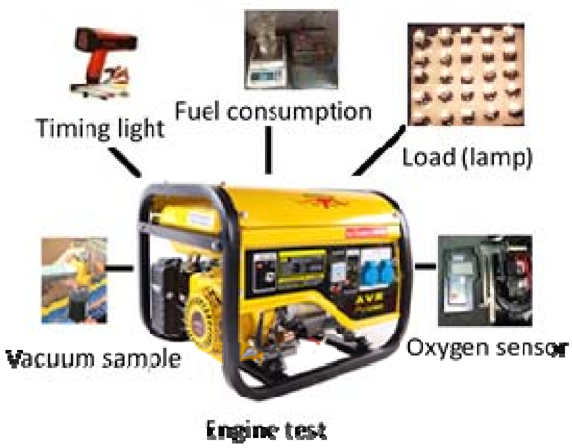

Fig. 1 The schematic of the experimental setup

The performance of the generator powered by the four ethanol fuels is assessed based on the specific fuel consumption (Bsfc) and fuel conversion efficiency (η_f), whose respective equations are given by Equations (1) and (2) [5].

$$Bsfc = \frac{\dot{m}_f}{P} \tag{1}$$

Where P is the electric power output, and $\dot{m}_f$ is the mass flow rate of fuel.

$$\eta_f = \frac{1}{BsfcQ_{LHV}} \tag{2}$$

Where Q_{LHV} is the fuel lower heating value.

2.4 Deterioration of engine oil Heading

The engine oil used was of multi-grade SAE 10W-30 4T oil. The deterioration of engine oil in the generator running on the four ethanol fuels was investigated at the maximum load of 2000 W and constant engine speed of 2500 rpm. The generator was operating 40 hours continually for each ethanol fuel type according to ASTM D6709-13 [6]. The sampling of the engine oil for each ethanol type was carried out at the end of the 40-hour period for further analysis by a certified laboratory, FOCUSLAB.

3. Results and discussion

The experimental results indicate that the relative air/fuel ratio (λ) varies in a range of 1.00 to 1.04 for the engine speeds under investigation (i.e. 2000 and 2500 rpm). In Fig. 2, at 2000 rpm, the maximum electric power output is 1206 W or approximately 60% of the possible maximum electric power output of the generator, while at 2500 rpm (Fig.3), the maximum electric power output is 1866 W or about 93 % of the possible maximum electric power output. The deterioration levels of engine oil in terms of wear condition, oil condition and contamination, illustrated respectively in Figs. 4-6, were focused on fine element.

3.1 Performance

Figure 2 shows Bsfc and η_f of E100, Eh95, Eh90 and Eh85 at 2000 rpm in relation to the electric power output. The fuel consumption (Bsfc) of all four fuels trended downward with increase in the power output; and rose with increase in the water content. In comparison with E100, Bsfc of Eh95, Eh90 and Eh85 at 2000 rpm were higher on average by 10%, 24% and 37% respectively. The fuel conversion efficiency (η_f) trended upward relative to the electric power output; and decreased with increase in the water content. η_f of Eh95, Eh90 and Eh85 at 2000 rpm were lower than that of E100 on average by 3%, 8% and 8%, respectively.

Figure 3 shows Bsfc and η_f of E100, Eh95, Eh90 and Eh85 at 2500 rpm relative to the electric power output. The fuel consumption (Bsfc) of all four fuels trended downward with increase in the power output. Bsfc increased with increase in the water content. In comparison with E100, Bsfc of Eh95, Eh90 and Eh85 at 2500 rpm were higher on average by 9%, 20% and 34% respectively. The fuel conversion efficiency (η_f) trended upward relative to the electric power output, and decreased with increase in the water content. η_f of Eh95, Eh90 and Eh85 at 2500 rpm were lower than that of E100 on average by 2%, 5% and 6%, respectively.

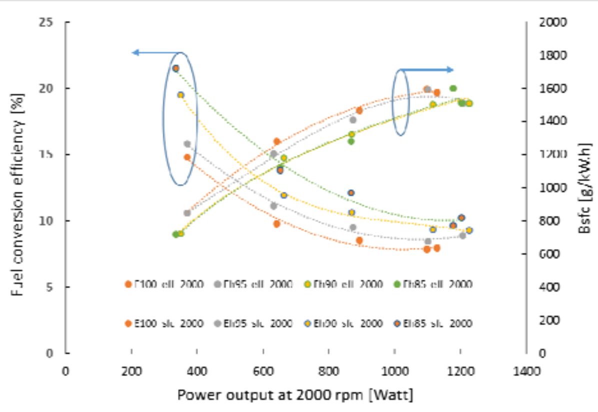

Fig. 2 Bsfc and η_f relative to power output at 2000 rpm.

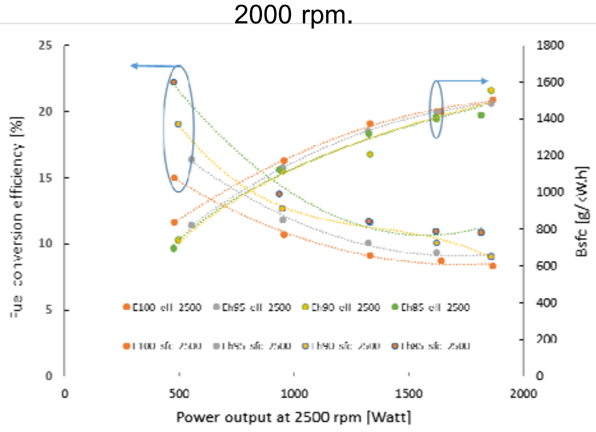

Fig. 3 Bsfc and η_f relative to power output at 2500 rpm.

In comparison with E100, the three hydrous ethanol fuels have higher Bsfc but lower η_f. This is probably because the heating value per mass of hydrous ethanol is reduced with increase in water content and some energy from the combustion of hydrous ethanol is lost to vaporization [7]. As the combustion duration increases, the peak pressure occurs later in the expansion stroke and thereby reduces the expansion work transfer of gasses in the cylinder to the piston [8].

3.2 Deterioration

The particle counts in the analysis of oil properties and contamination by FocusLab follow the NAS1638 and ISO4406 standards. The deterioration levels of engine oil in this research are assessed based on its wear condition, oil condition and contamination. The three criteria are interconnected as a poor measurement in one of the three criteria leads to poor measurements of the rest.

In Fig. 4 which illustrates the wear condition, with E100 fuel, fine elements of iron, aluminum and copper are found in great quantity. The fine iron in the engine oil came mainly from the cylinder wall, camshaft lobes and crankshaft journals. The fine aluminum was the product of wear (scuffing) on the piston skirt as the piston repeatedly traveled along the length of a cylinder, while the fine copper came from bushings and bearings, e.g. crankshaft journal bearings, connecting rod bearings, camshaft bushings, and piston wrist pin bushings. Molybdenum values at 10, 20, 30 and 40-hour operating periods of all four ethanol fuels were relatively similar except for that of Eh85 at the 40-hour operation time (i.e. 65.5 ppm) which exceeds that of a new engine oil of 54 ppm. The severity levels of the engine oils powered by the four fuels with respect to wear are normal.

As seen in Fig. 5, the oil condition running on Eh85 for the 40-hour operation time exceeds the Upper Caution limit since the viscosity at 100°C of the engine oil is higher than 11.9 cSt. due probably to poor cooling. In addition, nitration of the engine oil running on Eh85 for 40 hours was relatively high, but not exceeding 6.6 Abs. Nitration induces high acidity, causes sediment and accelerates the oxidation process.

Thus, the severity level of the engine oil running on Eh85 with regard to the oil condition is at the caution level.

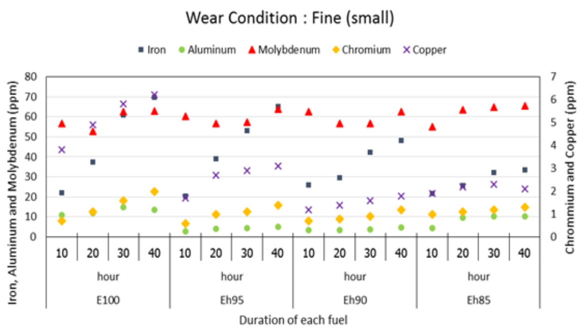

Fig. 4 Wear condition (fine element)

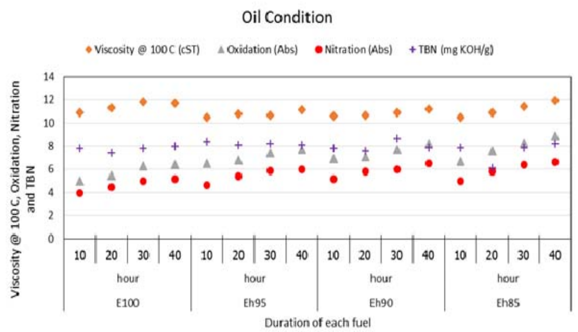

Fig. 5 Engine oil condition

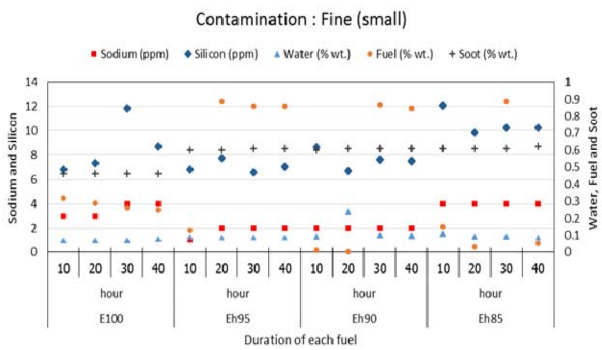

Fig. 6 Contamination in engine oil (fine element)

Figure 6 illustrates the fine element contamination in the engine oil, i.e. silicon and water percent. The silicon in the engine oils running on E100 and Eh85 exceed that of a new engine oil of 10 ppm, while the water percent of the engine oil running on Eh90 for the 20-hour operating time is higher than 0.2 %wt. The severity levels of the engine oils powered by the four fuels in terms of fine element contamination are normal.

4. Conclusion

This paper has investigated the performance of the SI engine generator running on E100, Eh95, Eh90 and Eh85. In addition, it has examined the effects that the four ethanol fuels have had on the engine oil deterioration at 2500 rpm. The findings are as follows:

- The fuel consumption (Bsfc) increases with increase in water content. For instance, Bsfc of the generator running on Eh85 at 2000 and 2500 rpm are on average 37% and 34% higher than those running on E100.
- The fuel conversion efficiency (η_f) decreases with increase in water content. For example, η_f of the generator running on Eh85 at 2000 and 2500 rpm are on average 8% and 6% lower than those running on E100.
- Based on the engine oil deterioration levels, all four fuel types can be used with the generator. However, due to high nitration in the engine oil running on Eh85 and thus high acidity, a frequent change of engine oil is recommended.

5. Acknowledgements

The authors would like to express sincere appreciation to Kwaithong Co., Ltd. (Thailand) for the experimental generator engines and to FOCUSLAB for the support on engine oil analysis.

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