AEC – 013

The Investigation of Wear and Emission on Spark Ignition Engine Using Ethanol Fuels

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Abstract

This paper investigates the electrical power output, emission, wear and deterioration of engine oil in a small spark ignition engine equipped with a power generator set using E100 (anhydrous ethanol), EW95 (5% water content in anhydrous) and EW85 (15% water content in anhydrous), and the engine oil multi-grade SAE 10W30 4T. The engine was tested at a speed of 2000 rpm, 25% to 100% electrical load and λ about 1. It was found that the increased water content affects the electrical power output to decrease. The emission of CO and NOx tended to decrease. On the other hand, HC and CO2 had upward trends. In addition, all three fuels did not cause wear and deterioration of engine oil, over the normal limits, although the viscosity of the EW85 at 40 hours will have the value to level of caution. This study indicates that hydrous ethanol can be used instead of the more expensive anhydrous ethanol for small spark ignition engines.

Keywords: anhydrous ethanol; hydrous ethanol; SI engine.

1. Introduction

As global warming pollution and demand for hydrocarbon fuels continues to rise, conditions have caused a start in using ethanol instead of fossil fuel by introducing some agricultural crops, such as cassava, sugarcane and others for the production of sugar as a raw material for ethanol production. In the ethanol production first step there will be a water mixture, the so-called "Hydrous Ethanol", and through the dehydration process a colorless and homogeneous liquid free from suspended matter and consisting of at least 99.5% ethanol by volume at 15.6 ^{o}C is produced [1, 2]. In the process of water separation, up to 37% energy is used [3]. Hydrous ethanol is an azeotrope with a boiling point of 78.1 ^{o}C. The water is approximately 5% by volume and cannot be further purified by distillation. In general, a molecular sieve is used to remove the remaining water in ethanol. And to avoid higher prices in the process of water separation, hydrous ethanol has been used by motor vehicles since 2009 in Brazil [4]. In Thailand, the main raw materials are molasses and cassava, with ethanol produced from molasses providing 80%, and ethanol production is expected to increase every year [5]. Commercial hydrous ethanol production will produce a water mixture with 5-8% water, and this passes into the dehydration process using molecular sieves to make ethanol at 99.5-99.8% and this is mixed with gasoline as the fuels E10, E20 and E85 used in the current conventional vehicles.

Ethanol fuel has a high-octane number so anti-knock occurs at higher compression ratios, and it has a high latent heat of evaporation, which makes the temperature of the intake manifold lower and gives high flammability. This has a positive influence on the engine performance and increases the compression ratio. In addition, ethanol clearly indicates combustion stability, so that thermal efficiency is improved even for lean operation [6, 7]. One of the most important properties of ethanol is the oxygenated atoms in their molecular compounds which provide significant reduction in the CO and HC emission, but it may adversely affect NO_x emission [8]. The oxygen content has a positive effect on the environment, but it is necessary to make some modification to the engine [9]. For emission, carbon dioxide (CO_2) increases, while hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxide (NO_x) decrease compared to gasoline [10]. Fuel consumption reduces when the compression ratio increases [11, 12]. At high generator load, to export comparable power, more fuel is injected into the combustion chamber; the fuel–air mixture is more homogeneous as a result while the HC, CO and CO_2 emissions are comparable [13]. The increase of water content in ethanol may increase the possibility of water contamination in the lubricant, leading to lubricity failure and a proportion of water from 20% to 40% will result in incomplete combustion [14].

From this research we found that 20% water in ethanol will cause incomplete combustion. This paper investigates the performance, emission, wear and deterioration of engine oil on a small spark ignition engine equipped with a generator set using E100 (anhydrous ethanol), EW95 (hydrous ethanol), EW85 (15% water by volume content in anhydrous ethanol) and used the engine oil multi-grade SAE 10W30 4T.

2. Materials and method

For comparison, the fuel consumption of the engine is generally written in the form of specific fuel consumption (sfc). A measurement of the engine's efficiency per cycle can be written in the form of the fuel conversion efficiency (η_f).

$$sfc = \frac{\dot{m}_f}{P} \quad (1)$$

$$\eta_f = \frac{1}{sfc\, Q_{LHV}} \quad (2)$$

where $\dot{m}_f$ is the mass flow rate of fuel and P is the electrical power output and Q_{LHV} is the low heating value of fuel.

2.1 Engine test and fuels test

The engine used in the test is a spark ignition engine equipped with a power generator set is shown in Table 1, with the modified hole size of the main jet being 1.10 for use with all three fuels. Some properties of the tested fuel are shown in Table 2. It shows that when the water content in ethanol increases, it adds to the density, percentage of oxygen and latent heat of vaporization. On the other hand, the percentage of carbon and hydrogen, the lower heating value, the stoichiometric mixture, the self-ignition temperature, octane number and laminar flame speed are all reduced. The fuel used in the tests consisted of anhydrous ethanol (E100), hydrous ethanol (EW95) and 85% ethanol blended water 15% by volume (EW85).

2.2 Experimental method

A preliminary test of the spark ignition engine equipped with power generator set used fuel E100, EW95 and EW85 and varied the generator load from 500 watts to 2000 watts. It was seen that the average engine speed was 2006, 1907 and 1912 rpm, respectively. The engine speed reduced when the generator load increased. The average air/fuel ratio (λ) for fuel lean mixtures were 1.25, 1.35 and 1.39 respectively. In addition, the values of specific fuel consumption, fuel conversion efficiency, CO, CO_2, HC and NO_x had an unstable trend.

This research was carried out in rooms maintained at a temperature about 26 °C, $\lambda \cong 1$ and engine speed was maintained at 2000 rpm by adjusting the choke valve, idle speed screw and idle mixture screw, while changing the generator load to 25%, 50%, 75% and 100%. The hole diameters of the carburetor main jet calculated for E100, EW95 and EW85 are 1.01, 1.02 and 1.03 mm, respectively (original size 0.80 mm). However, the main jet diameters of commercially available carburetors have a 0.10 mm increment. Thus, a commercially available main jet with a main jet hole of 1.10 mm was selected for all fuels, since ethanol fuel possesses the characteristic of lean mixture and the mixture ratio closest to the theoretical values was employed in the experiments. The schematic diagram of the experimental apparatus is shown in Fig. 1.

Table. 1 The properties of test fuels

Parameter	Description
Engine Type	4-stroke, Overhead valve, Single cylinder
Displacement (cm^3)	196
Compression Ratio	8.5:1
Fuel supply / Fuel	Carburetor butterfly / gasoline
Ignition system	
Lubricating oil life time	100 hrs. or 6 months
Generator	
Generator output	AC 220 V and DC 12V 8.3 A
Rated frequency (Hz)	50/60
Rated / Maximum output (W)	1800/2000

Table. 2 The properties of test fuels

Fuel properties	E100 [7]	EW95 [4, 9]	EW85
Density (kg/m^3) at 15 °C	790	810	826
Carbon mass (%)	52.2	50.6	48.7
Hydrogen mass (%)	13.1	13	13
Oxygen mass (%)	34.7	36.4	39.7
Lower heating value (MJ/kg)	26.7	25	23.24
Stoichiometric air/fuel ratio	9	8.7	8.4
Self-ignition temperature (°C)	464	420	NA
Latent heat of vaporization (kJ/kg)	920	993	NA
Research octane number (RON)	108.6	106	NA
Motor octane number (MON)	89.7	87	NA
Laminar flame speed (m/s)	≅ 0.58[a]	0.42	NA

The high precision weight loss meter set was used to measure the fuel consumption, the engine loads were varied from 500 W to 2000 W using electric lamps. Volt and amp meter were utilized to monitor the power electricity load supplied to the lamps. The exhaust gas including CO, HC, NOx and CO2 were measured with automotive gas analyzer model Koeng KEG-500. CO, HC and CO2 were measured by the method of non-dispersive infrared (NDIR), NOx was measured by electrochemical cell, the technical specification of gas analyzer. For the deterioration of engine oil in terms of wear condition, oil condition and contamination on standard test method in according to ASTM D6709-13 [15], the sampled engine oil to analyze the engine oil by FOCUSLAB.

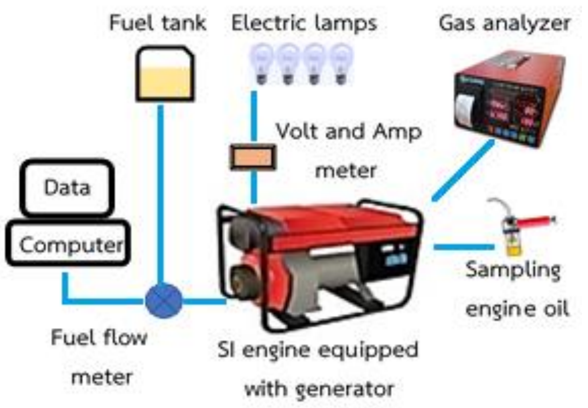

Fig. 1 Schematic diagram of the experimental apparatus

3. Results and Discussion

3.1 Performance and exhaust emission

The specific fuel consumption (sfc) and fuel conversion efficiency (ηf) vary with generator load, as shown in Fig. 2. The sfc tends to decrease and ηf tends to increase as the generator load increases. The sfc of EW85 is more than EW95 and E100 in order. This is due to the lower heating value of fuel as the proportion of water increases; the stoichiometric air/fuel ratio decreases, so the engine needs more fuel to supply the same energy demand. Therefore, the fuel conversion efficiency decreases as the proportion of water increases, with the value for EW85 being less than EW95 and E100 in order. As the generator load increases, the specific fuel consumption decreases due to the engine power rising at the same engine speed, leading to increased fuel conversion efficiency.

The electric power output (P_o) of the SI engine is shown in Fig. 3. The power tends to increase as the generator load increases. This is due to a more homogeneous fuel-air mixture; the combustion temperature increases leading to the incylinder pressure increasing [13], which causes more electric power output. The latent heat of vaporization of the fuel decreases as the water content increases, causing the intake temperature to decrease, which is not beneficial to the mixture, leading to the in-cylinder pressure decreasing, as shown in Fig.2. The EW85 produces less power than the EW95 and E100 in order at all generator loads.

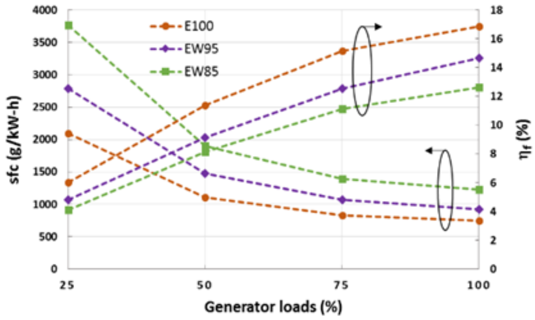

Fig. 2 Variation sfc and η_f varies with generator loads.

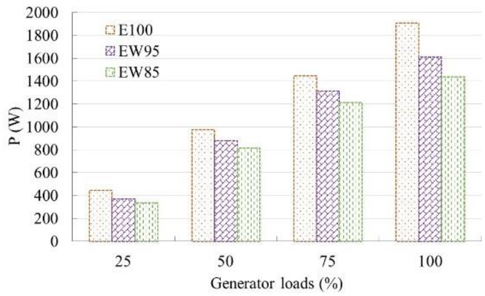

Fig. 3 The electric power output of fuels at various generator loads

The CO emission tends to decrease as the generator load increases. CO for EW85 is lower than EW95 and E100 in order at all generator loads. The CO emission results from the incomplete combustion of the combustion period, due to the influence of the combustion temperature and the homogeneous mixture of air and fuel. At low load and low combustion temperature, a homogeneous poor mixture of fuel with air, results in high CO, but at higher load and higher combustion temperature and a more homogeneous fuel mix with air leads to complete combustion, so that CO emission decreases. CO for EW85 is lower, due to a proportion of oxygen that is higher than EW95 and E100 in order; oxygen present in the fuel molecules contributes to the oxidation of CO into CO2.

CO2 emission tends to decrease as the generator load increases. CO2 for EW85 is higher than EW95 and E100 in order, due to the proportion of oxygen being higher the carbon is lower, according to the specific fuel consumption of each fuel, as shown in Fig. 4. As a result, CO2 is higher.

The HC emission tends to decrease as the generator load increases. HC for EW85 is lower than EW95 and E100 in order, as shown in Fig. 5. HC production, primarily caused by unburned mixtures, is located around the periphery of the reaction regions, as the presence of carbon and hydrogen are less, leading to reduced unburned HC formation and significantly to CO. When the load increases, the more homogeneous fuel mixture leads to improved combustion, resulting in HC decrease. The NOx emission tends to increase as the generator load increases. Formation of NOx increases due to higher combustion temperature, higher peak pressure, higher flame speed and high spark timing [16]. NOx for EW85 is lower than for EW95 and E100 respectively, due to lower combustion temperature, lower peak pressure, lower flame speed and lower spark timing, according to the in-cylinder pressure of each fuel.

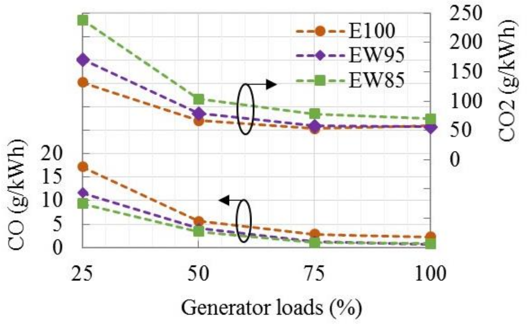

Fig. 4 Comparison of CO and CO2 emissions of fuels at various generator loads.

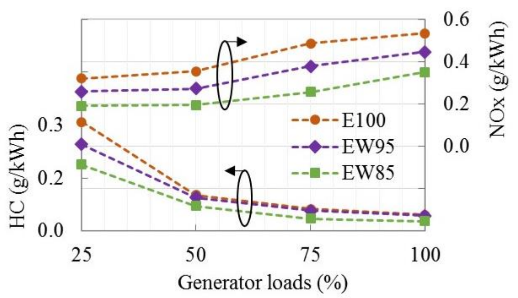

Fig. 5 Comparison of HC and NOx emissions of fuels at various generator loads.

The HC emission tends to decrease as the generator load increases. HC for EW85 is lower than EW95 and E100 in order. HC production, primarily caused by unburned mixtures, is located around the periphery of the reaction regions, as the presence of carbon and hydrogen are less, leading to reduced unburned HC formation and significantly to CO. When the load increases, the more homogeneous fuel mixture leads to improved combustion, resulting in HC decrease. The NOx emission tends to increase as the generator load increases. Formation of NOx increases due to higher combustion temperature, higher peak pressure, higher flame speed and high spark timing [16]. NOx for EW85 is lower than for EW95 and E100 respectively, due to lower combustion temperature, lower peak pressure, lower flame speed and lower spark timing, according to the in-cylinder pressure of each fuel.

3.2 Wear and Deterioration

Wear of the engine can be analyzed from the engine oil used, checking the deterioration of the engine oil, and the oil change period. In this research, SAE 10W30 4T multi-grade engine oil was used and E100, EW95 and EW85 as fuel, at generator load of 2000 W (100% load), engine speed about 2000 rpm for each fuel, operating 40 hours continuously. Engine oil samples were collected every 10 hours and new oil added to replace the amount of suction. The wear metal debris analysis for the particle size was determined by a rotating disc electrode, RDE for fine particle size (smaller than 8 microns) using the Rotrode filter spectroscopy method, and RFS for large metal particles (8-150 microns). Detected metal particles are Iron, Chromium, Lead, Copper, Tin, Aluminum, Nickel, Silver, Molybdenum and Titanium. Fig. 6 shows a comparison of wear for fuels at the same conditions together with the table wear limits for the metal type. Particles of metal were detected and with a rather high value, including aluminum (Al), copper (Cu) and iron (Fe). Other metal particles were less, so are not shown here.

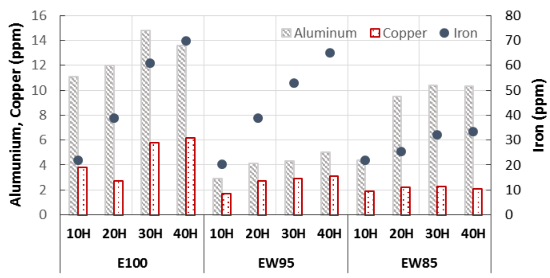

Fig. 6 Comparison wear particles of Al Cu and Fe for each fuel in 40 hours.

Li
Al
Co
Ir

The small wear particles of all three fuel types were increasing with time, specifically particles of Al and Fe, apparent trends, likely reduced and less than E100. However, the wear of metal particles for three fuel types is within the normal wear limits. The analysis of oil condition and contamination was performed by the Fourier transform infrared spectroscopy (FTIR) method. The verifying of oil condition, including viscosity at 40 °C and 100 °C, oxidation, nitrate, TAN which represents the acidity value with an increase indicating the oxidation of engine oil, and TBN which represents the alkalinity value, which indicates the ability of the engine oil to resist corrosive acids. The contamination in engine oil, including water, fuel, glycol, soot, vanadium, sodium and silicon was measured. From the test results, the deterioration and contamination of engine oil have a relatively high value, including viscosity at 100 °C, oxidation, water and silicon, while others have relatively low values as shown in Fig. 7. A comparison of oil condition and contamination for fuel E100, EW95 and EW85 at the same condition together with the table limits of engine oil deterioration, contamination as shown in table 3, found that the oxidation and water had a higher value as the proportion of water increases, but is still within the limit. The viscosity at 100 °C of the three fuels is quite high, especially the EH85, which is equal to 11.9 cSt, which is at the level of caution, but they still do not exceed the limits of the deterioration of engine oil. The silicon value at 30 and 40 hours is equal to 10.2 ppm, which is higher than the U-Caution level, but still lower than the danger level (not over 30 ppm). This may be caused by water contamination leading to oxidation increases, which will result in the faster deterioration of engine oil.

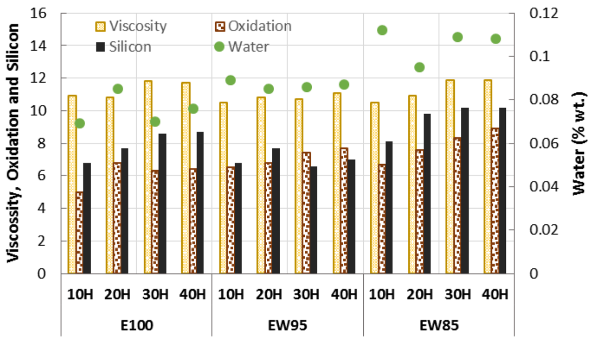

Fig. 7 Comparing the condition and contamination of engine oil for each fuel in 40 hours.

Table. 3 The limit value of wear oil condition and contamination

Limit value	U-Caution	U-Warming
Wear	> 40	> 60
Aluminum (ppm)	> 40	> 60
Copper (ppm)	> 100	> 200
Iron (ppm)		
Oil condition and contamination		
Viscosity (cSt)	> 11.9	> 13.5
Oxidation (Abs)	> 12.8	> 14.4
Water (% wt.)	> 0.2	> 0.5
Silicon (ppm)	> 10	> 30

4. Conclusion

The focus of this study was to evaluate the effect of the proportion of water in ethanol without causing incomplete combustion on the combustion characteristic performance and deterioration of engine oil on SI engine equipped with a generator. Based on the experimental results, when the proportion of water in the fuel increase can be summarized there are three topics as follows. (1) Performance and emission: The heating value of fuels and air-fuel ratio theory are decreasing, as a result ηf and Po are lower, sfc is more. The CO decreased due to a molecular mass of carbon reduced. However, it becomes more CO2, the HC increases, and the NOx decrease. (2) Deterioration: All three types of fuel can be used without wear and degradation of engine oil not exceed the normal limits. But be careful in the use of E85 fuel due to the contaminant levels is above the level of caution, as a result of more oxidation. Moreover, the effects of mixing on the carburetor system of the engine occur only at 25% of the generator load. In this case, the E100 is best for the engine compared to the EW95 and EW85, respectively. In terms of economics, the E100 is 37 percent more expensive than the EW95. And although more than CO2 emissions, that's a gas plant photosynthesis to grow according to the carbon cycle and does not cause wear or degradation of engine oil. Therefore, it should encourage the use of fuel hydrous ethanol (EW95).

Limit Oil Condition and Cotamination

	(TNO)	U-Caution	U-Warning
Viscosity (cSt)	10.4	>11.9	>13.5
Oxidation (Abs)	6.4	>12.8	>14.4
Water (% wt.)	0.085	>0.2	>0.5
Silicon (ppm)	7	>10	>30

5. Acknowledgement

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