Journal of Mechanical Engineering and Sciences
ISSN (Print): 2289-4659; e-ISSN: 2231-8380
Volume 11, Issue 2, pp. 2734-2742, June 2017
© Universiti Malaysia Pahang, Malaysia
DOI: https://doi.org/10.15282/jmes.11.2.2017.14.0248

Effect of ethanol addition on the performance and exhaust emissions of a spark ignition engine

Mega Nur Sasongko* **and Widya Wijayanti**

Mechanical Engineering Department, Brawijaya University,
Jln. MT. Haryono 167, Malang 65145, Indonesia
*Email: megasasongko@ub.ac.id
Phone: Telp: +62 341 587710; Fax: +62 341 551430

ABSTRACT

The depletion of fossil fuel availability and increase of pollution due to the use of fossil fuels have forced the researcher to find a renewable-friendly energy source. One of the potential replacements is alcohol based fuel. This present study investigated experimentally the influence of ethanol addition on the engine performance, in terms of effective power, brake specific fuel consumption, and exhaust emissions of a gasoline spark ignition engine. The engine used in the research was a 4-stroke single cylinder, indirect injection system with engine capacity of 124.8cc, and compression ratio of 9.3:1. The experiments were conducted at eight different engine speeds ranging from 1500 rpm to 5000 rpm and 10 types of gasoline-ethanol mixtures (E10 to E100). The result showed that the effective power decreased with the increase of ethanol in the fuel blends for all variations of engine speed. Leaning effect of ethanol addition in the blend fuel caused the CO emissions to decrease greatly as well as the HC emissions. On average, gasoline engine fueled by pure ethanol reduced the CO emission level by more than 60 % in volume compared to the engine with gasoline fuel. On average, the maximum power of the engine with fuel blend was obtained at engine speed of around 2500 to 3000 rpm. For higher ethanol content on the fuel blend, the optimum shift to the lower engine speed. It can be concluded that engine operation with ethanol content on the fuel performed better in the lower engine speed.

Keywords: Ethanol; gasoline-ethanol fuel; spark ignition engine; engine performance; emissions.

INTRODUCTION

The decreasing fossil fuel reserves and environmental degradation caused by pollution from the burning of fossil fuels are forcing the researcher to develop new renewable energy sources that are more benign for the environment. Ethanol is an alternative fuel that has been developed to be a substitute for fossil fuels. The main advantages of ethanol as a fuel is that it can be produced from renewable energy sources such as sugarcane, cassava, waste biomass materials, and corn. Furthermore, burning ethanol is cleaner than fossil fuels so as to reduce environmental pollution and greenhouse emissions. Currently, alcohol based fuel is found to be the main focus for internal combustion engine research [1-8]. Ethanol could be used as a blending fuel in gasoline and diesel engines [9-11]. Furthermore, ethanol also acts as fuel additive to improve the engine performance [12]. Some researchers proved that ethanol has several advantages over gasoline such as the reduction of CO and HC emissions burning and better anti-knock characteristics, which allow the use of a higher compression ratio of the engine [13-15]. Research by Al-Farayedhi [16] on the SI engine showed that the addition of ethanol in gasoline can reduce emissions of CO gas, especially in the rich combustion conditions for the extra oxygen already contained in ethanol (available oxygen contained). Another result of the study showed that the addition of 10% ethanol in gasoline-ethanol mixtures could also reduce emissions of NOx. The addition of ethanol, according to a research by Miers [17], can also reduce hydrocarbon emissions since the addition of ethanol gasoline can lower the evaporation temperature. Another advantage of using ethanol is that ethanol has a higher octane number which can be designed so that the motor fuel has higher compression ratios to obtain greater thermal efficiency. Turner [10] researched on motor gasoline by using 85% ethanol fuels. Motor fuel performance testing was carried out on the design of a high compression ratio. The results showed that the knocking limit can be increased significantly because of the high octane number of ethanol in the range of RON 105. This resulted in the thermal efficiency of motor fuel to increase 3 to 4%. Mustafa [18] did a research on the effect of compression ratio on the performance and combustion emissions of internal combustion engine spark plug. The results showed that the specific fuel consumption of gasoline-ethanol mixtures tend to be higher than using pure gasoline. Furthermore, an increase in compression ratio engine resulted in increased engine performance [19, 20].

In order to accelerate the conversion of fossil fuel with environmentally-friendly fuels, especially ethanol fuel, the retrofit technique on the motorcycle engine in the market is one way to realise the goal. So far, ethanol has been used in small proportion blend fuel such as from 5% to 10%. There is a lack of data on the performances of blend fuel with higher percentage of ethanol on the spark ignition engine. The present research aims to retrofit the gasoline motor cycle with ethanol-gasoline fuel in a wide range of percentage of ethanol on the blend fuel (0 – 100 %). Since the stoichiometric mixtures between gasoline and ethanol are different, the use of ethanol in the gasoline engine requires some modifications to the engine. Hopefully, the present experiment could be used as a reference to improve the engine performance of spark ignition engine with higher ethanol blend fuel.

METHODS AND MATERIALS

Experimental Apparatus

The schematic of the experimental setup is shown in Fig 1. Experiments were performed on a commercial motorcycle without any modification on the engine. The specification of the engine used in this study was a gasoline engine 4 stroke single-cylinder with engine capacity of 124.8cc and compression ratio of 9.3: 1. Details of the engine specification are shown in table 1. The engine was an indirect injection system. The motor shaft was coupled to a dynamometer to measure the torque and power of the engine. An engine brake dynamometer was produced by a local manufacturer with maximal load capacity of 20 kW and maximum speed of 7000 rpm. The Electronic Control Unit (ECU) of the motor cycle could not be reprogrammed to accommodate the parameter study. Therefore, the system was replaced by a modified ECU System to be programmed (ECU Juken 3) and set according to the motor operating parameters of the test. With this modified ECU, the ignition system, injection time, and amount of supply of fuel into the combustion chamber can be adjusted with a mixture of gasoline-ethanol fuel.

Figure 1. Photograph of experimental setup.

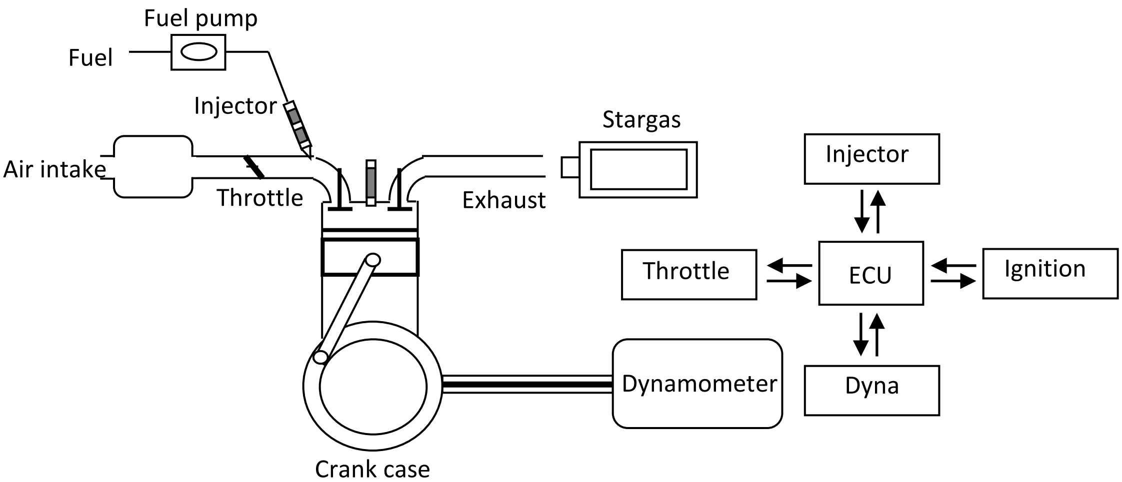

Figure 2. Schematic of experimental setup.

Stargas exhaust gas analyser (type 898) was used to measure the concentration of CO, CO2, O2, and HC. This gas analyser can perform automatic calibration at every analysis while the level of accuracy in the analysis of gas concentrations was low. The exhaust gas for the analysis was tapped from the exhaust pipe, approximately 1 m away from the exhaust.

Table 1. Specification of the SI engine.

Description	Value
Engine Type	Gasoline
Displacement, cc	124.8
Number of cylinder	1
Compression ratio	9.3:1
Bore, mm	52.4
Stroke, mm	57.9
Max. power, PS/rpm	9.6/5700
Max. torque, kgf.m/rpm	1.08/5500

Experimental Procedure

The experiments were conducted at eight different engine speeds ranging from 1500 rpm to 5000 rpm, by 500 rpm increments and a fixed compression ratio of 9.3:1. The fuel used in this experiment was unleaded gasoline (E0) and 10 types of gasoline-ethanol mixtures (E10 to E100). E indicates the volumetric percentage amount of ethanol in the fuel. In order to produce the blend fuel, gasoline and ethanol (99% purity) were mixed manually at different proportions based on the volume ratio. Then, the evaluations of the properties of blend fuel such as density and heating value were carried out. The data can be seen in table 2. Engine torque, fuel consumption, and pollutant emissions of the engine were tested for each fuel type and engine speed. A total of 88 experiments were conducted. At each experiment, the engine was allowed to reach a stable condition and then the measurements were recorded in a few minutes. In this study, the ECU could adjust the frequency of injection of fuel every minute and the percentage of injector openings in each injected fuel (duty cycle). The adjustment of ECU ensured that the mixture of fuel and air was always in the stoichiometry condition (excess air equal to 1) for each different type of fuel.

Table 2. Properties of gasoline-ethanol blends.

Gasoline-ethanol	ρ density (kg/l)	LHV (kcal/kg)
E0	0,735	10509
E10	0,740	10102,9
E20	0,745	9696,8
E30	0,750	9290,7
E40	0,755	8884,6
E50	0,760	8478,5
E60	0,765	8072,4
E70	0,770	7666,3
E80	0,775	7260,2
E90	0,780	6859,1
E100	0,785	6448

RESULTS AND DISCUSSION

Figure 2 shows the effect of gasoline-ethanol blends for different percentages of ethanol from 10% to 100% on the effective power of the engine between 1500 rpm and 5000 rpm engine speed. As shown in this figure, the effective power tends to decrease with the increase of the volumetric amount of ethanol in the fuel blends for all variations of engine speed. The heating value of ethanol was about 35% less than that of gasoline. The increase in the percentage of ethanol resulted in the low energy content of gasoline-ethanol blend (Table 2). As a result, the addition of ethanol in the fuel blend decreased the power of the engine. The maximum power of the engine was obtained at engine speed around 2500 to 3000 rpm. At the engine speed higher than 3000 rpm, the effective power decreased with the increasing engine speed. The value of volumetric efficiency was inversely proportional to the engine speed. Consequently, the volumetric efficiency decreased with the increasing engine speed. This condition was caused by the choked flow phenomenon and occurred when the flow rate of the fuel could not increase with further increase in the pressure drop at the inlet. As a result, once a choked flow phenomenon occurred, the volumetric efficiency will significantly decrease and the power will also decrease [21]. The experimental result of the engine speed at maximum engine power agreed with the investigation observed by Phuangwongtrakul [4]. However, the relationship between power and ethanol percentage in the fuel showed a different tendency with a previous research by [10]. The present experiment was performed at a lower compression ratio compared to the previous research.

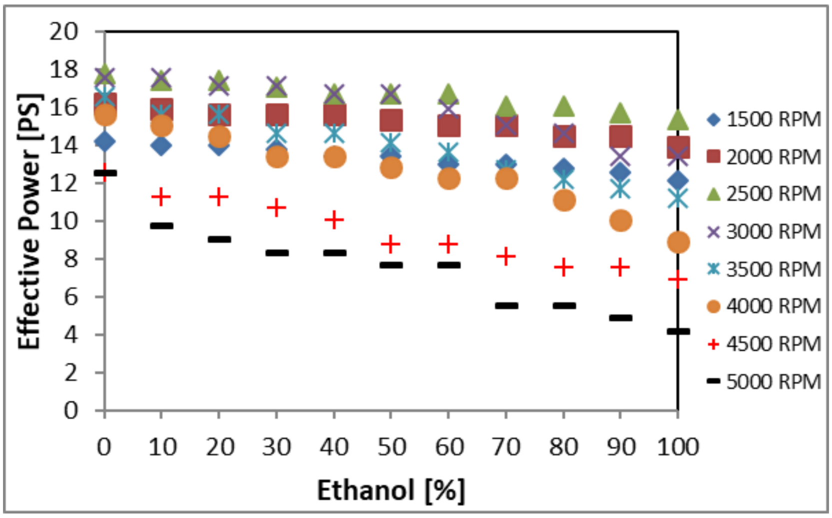

Figure 2. The effect of percentage of ethanol on the effective power for different engine speeds.

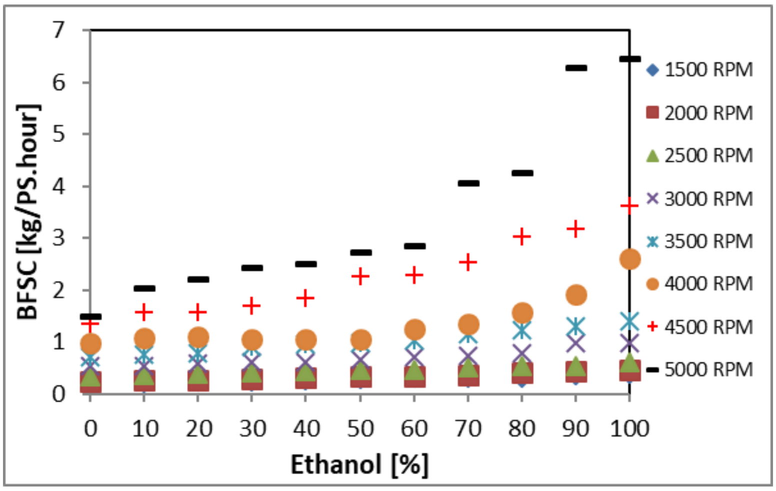

Figure 3. The effect of percentage of ethanol on the brake specific fuel consumption for different engine speeds.

Figure 3 depicts the dependence of brake specific fuel consumption (BSFC) on the percentage of ethanol for different engine speeds from 1500 to 5000 rpm. The BSFC was measured at constant engine speed and torque. As shown in the figure, ethanol addition caused the increment of BSFC. Even an increase in BSFC would be enlarged with the increase of the engine speed. This could be explained with the effect of heating value of fuel blend on the BSFC. Heating value indicates the amount of energy produced by a complete combustion of fuel per unit mass. Ethanol has a lower heating value than that of gasoline; therefore, in order to produce the same energy, engine fuelled ethanol needs more mass of fuel compared to gasoline engine. Engine with blend fuel requires more to produce the same power compared to pure gasoline at the same working condition [22].

Figure 4 displays the effect of ethanol addition on the CO emissions of the spark ignition engine. For all of the engine speed ranges of the experiment, the combustion produced very low CO emissions. CO emissions were lower than 0.07% by volume for all speed ranges. With the increase in ethanol contents, the CO emissions decreased. On average, motorcycle fuelled by pure ethanol has a reduced CO emission level by more than 60% of volume compared to an engine with gasoline fuel. The concentration of CO emission was produced by the level of incomplete combustion. Incomplete combustion mainly occurs when the combustion takes place in fuel-rich conditions [23]. The oxygenated characteristic of ethanol can reduce the incidence of incomplete combustion due to insufficient amount of oxygen in the air-fuel mixture. In the case of engine fuelled by pure ethanol, the presence of CO emissions in the exhaust gas may be caused by the reduction of combustion temperature which resulted in incomplete combustion [24].

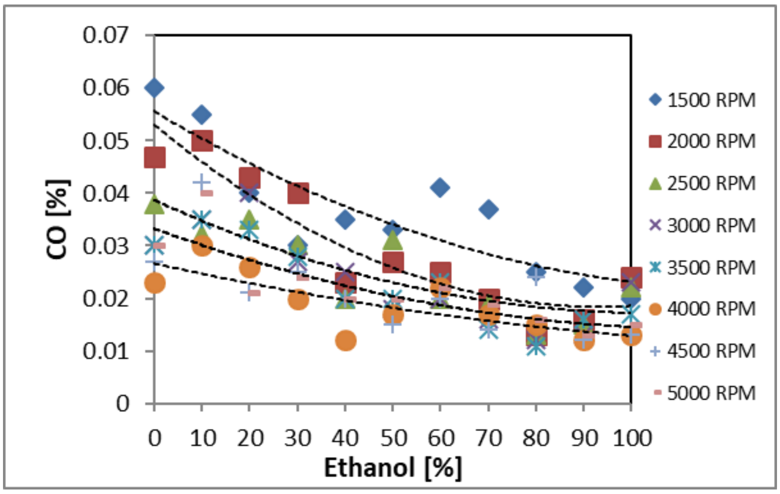

Figure 4. The effect of ethanol addition on the CO emission for different engine speeds.

Figure 5 represents the variations of HC emission with respect to the ethanol concentration in the fuel for different engine speed ranges. The tendency of HC emission is similar to the CO emission. HC emission was reduced significantly with the increasing ethanol addition. Reduction in the HC emission indicated that the combustion performed with better conditions. The main reason for this tendency was caused by the leaning effect. Ethanol can be tread as a partially oxidised hydrocarbon due to oxygen atom contained in ethanol [5]. Addition of ethanol in the fuel blend could increase the number of oxygen atoms for the combustion process (leaning effect). The emission of HC existed due to insufficient air in the air fuel mixture while combustion occurred in the incomplete processes. When some portion of ethanol was added in the blend fuel, it can provide more oxygen for the combustion process and improve the completion of combustion. Due to the leaning effects, the HC emissions will decrease greatly as well as the CO emissions [24].

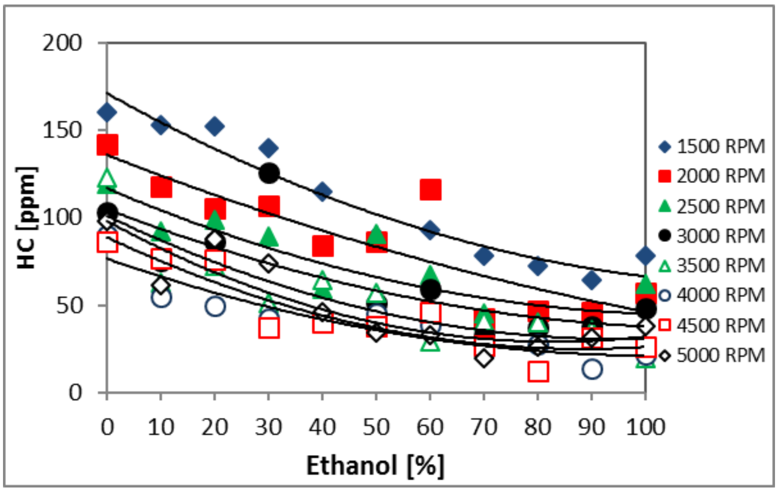

Figure 5. The effect of ethanol addition on the HC emission for different engine speeds.

CONCLUSIONS

This present experiment investigated the influence of ethanol addition on the performance and exhaust emissions of a spark direct injection engine. The results could be summarised as follows:

i) The effective power tends to decrease when the volumetric amount of ethanol in the fuel blends for all variations of engine speed increase. The maximum power of the engine was obtained at engine speed around 2500 to 3000 rpm.
ii) Since ethanol has a lower heating value than that of gasoline, ethanol addition in the blend fuel caused the increment of Brake Specific Fuel Consumption.
iii) The CO emissions decreased with the increase of ethanol in the fuel. On average, motorcycle fuelled by pure ethanol reduced the CO emission level by more than 60% of volume compared to the engine with gasoline fuel.
iv) Leaning effect of ethanol addition in the fuel blend caused the HC emissions to decrease significantly.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from Ministry of Research, Technology and Higher Education Republic of Indonesia through the PUPT project number 137/ SP2H/LT/DRPM/III/2016

REFERENCES

[1] Wang C, Janssen A, Prakash A, Cracknell R, Xu H. Splash blended ethanol in a spark ignition engine–effect of ron, octane sensitivity and charge cooling. Fuel. 2017;196:21-31.
[2] KR Patil ST. The effect of injection on the performance and emmision of direct injection ci engine running diethyl ether-diesel blends. International Journal of Automotive and Mechanical Engineering. 2016;13:2773-87.
[3] Akasyah M, Mamat R, Abdullah A, Aziz A, Yassin H. Effect of ambient temperature on diesel-engine combustion characteristics operating with alcohol

fuel. International Journal of Automotive and Mechanical Engineering. 2015;11:2373-82.
[4] Phuangwongtrakul S, Wechsatol W, Sethaput T, Suktang K, Wongwises S. Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol–gasoline blended fuels. Applied Thermal Engineering. 2016;10:869-79.
[5] Awad OI, Mamat R, Ali OM, Sidik N, Yusaf T, Kadirgama K, et al. Alcohol and ether as alternative fuels in spark ignition engine: A review. Renewable and Sustainable Energy Reviews. 2017.
[6] Bhaskar K, Sendilvelan S, Muthu V, Aravindraj S. Performance and emission characteristics of compression ignition engine using methyl ester blends of jatropha and fish oil. Journal of Mechanical Engineering and Scienes. 2016;10:1994-2007.
[7] Rashid AK, Mansor A, Radzi M, Ghopa WAW, Harun Z, Mahmood WMFW. An experimental study of the performance and emissions of spark ignition gasoline engine. International Journal of Automotive and Mechanical Engineering. 2016;13:3540-54.
[8] Saifuddin N, Refal H, Kumaran P. Performance and emission characteristics of micro gas turbine engine fuelled with bioethanol-diesel-biodiesel blends. International Journal of Automotive and Mechanical Engineering. 2017;14:4030-49.
[9] Balki MK, Sayin C, Canakci M. The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. Fuel. 2014;115:901-6.
[10] Turner D, Xu H, Cracknell RF, Natarajan V, Chen X. Combustion performance of bio-ethanol at various blend ratios in a gasoline direct injection engine. Fuel. 2011;90:1999-2006.
[11] Yüksel F, Yüksel B. The use of ethanol–gasoline blend as a fuel in an si engine. Renewable Energy. 2004;29:1181-91.
[12] Hund G, Laverty K, Mahy H, Szabo C, Woods L. 200 proof transportation: The potential for ethanol as an alternative fuel. University of Washington, Global Commercialization of Environmental Technologies. 2003.
[13] Al-Hasan M. Effect of ethanol–unleaded gasoline blends on engine performance and exhaust emission. Journal of Energy Conversion and Management. 2003;44:1547-61.
[14] Bata RM, Elord A, Rice RW. Emissions from ic engines fueled with alcohol–gasoline blends: A literature review. Transactions of the ASME. 1989;111:424-31.
[15] Park C, Choi Y, Kim C, Oh S, Lim G, Moriyoshi Y. Performance and exhaust emission characteristics of a spark ignition engine using ethanol and ethanol-reformed gas. Fuel. 2010;89:2118-25.
[16] Al-Farayedhi AA, Al-Dawood A, Gandhidasan P. Effects of blending crude ethanol with unleaded gasoline on exhaust emissions of SI engine. SAE paper No. 20-01-2857; 2000.
[17] Wallner T, Miers SA. Combustion behavior of gasoline and gasoline/ethanol blends in a modern direct-injection 4-cylinder engine. SAE paper 2008-01-0077; 2008.

[18] Koç M, Sekmen Y, Topgül T, Yücesu HS. The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine. Renewable Energy. 2009;34:2101-6.
[19] Balki MK, Sayin C. The effect of compression ratio on the performance, emissions and combustion of an si (spark ignition) engine fueled with pure ethanol, methanol and unleaded gasoline. Energy. 2014;71:194-201.
[20] Costa RC, Sodré JR. Compression ratio effects on an ethanol/gasoline fuelled engine performance. Applied Thermal Engineering. 2011;31:278-83.
[21] Pulkrabek W, Willard,. Engineering fundamental of the combustion engine. New Jersey: Pearson Persntice Hll; 2004.
[22] Barakat Y, Awad EN, Ibrahim V. Fuel consumption of gasoline ethanol blends at different engine rotational speeds. Egyptian Journal of Petroleum. 2016;25:309-15.
[23] Heywood JB. Internal combustion engine fundamentals: Mcgraw-Hill New York; 1988.
[24] Elfasakhany A, Mahrous A-F. Performance and emissions assessment of n-butanol–methanol–gasoline blends as a fuel in spark-ignition engines. Alexandria Engineering Journal. 2016;55:3015-24.