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JAPTT

Journal homepage: https://publisher.uthm.edu.my/ojs/index.php/japtt/index

e-ISSN: 2821-286X

Journal of Automotive Powertrain and Transportation Technology

Influences of Biopetrol-Ethanol Fuel on Performance and Emission in Internal Combustion Engine

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DOI: https://doi.org/10.30880/japtt.2022.02.01.006
Received 20 February 2022 ; Accepted 25 April 2022 ; Available online 19 June 2022

Abstract: The purpose of this study is to experimentally investigate the engine performance and pollutant emission of a commercial SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20%, and 30%). Fuel properties of ethanol–gasoline blended fuels were first examined by the standard ASTM methods. Results showed that by increasing the ethanol content, the heating value of the blended fuels is decreased, while the octane number of the blended fuels increases. It was also found that with the increment of ethanol content, the Reid vapor pressure of the blended fuels initially increases to a maximum at 10% ethanol addition, and then decreases. Results of the engine test indicated that using ethanol–gasoline blended fuels, torque output and fuel consumption of the engine slightly increase; CO and HC emissions decrease dramatically as a result of the leaning effect caused by the ethanol addition; and CO2 emission increases because of the improved combustion. Finally, it was noted that NOx emission depends on the engine operating condition rather than the ethanol content.

Keywords: Biopetrol-ethanol, fuel, performance, emission, internal combustion engine

1. Introduction

1.1 Ethanol

When mixed with unleaded gasoline, ethanol increases octane levels, decreases exhaust emissions, and extends the supply of gasoline. Ethanol in its liquid form, called ethyl alcohol, can be used as a fuel when blended with gasoline or in its original state. It can also be used as a raw material in various industrial processes. Ethanol is made by fermenting almost any material that contains starch or sugar. Grains such as corn and sorghum are good source but potatoes, sugar cane, Jerusalem artichokes, and other farm plants and plant wastes are also suitable. About 2 billion gallons of ethanol are produced annually in the United States. Each bushel of corn processed yields 2.5 to 2.7 gallons of ethanol along with several valuable co-products. The first ethanol-blended gasoline in the 1970s was 10 percent ethanol by volume (E-10), while a blend of 85 percent by volume (E-85) was introduced in the 1990 [1-4]. Ethanol is an alternative energy source. It is an alcohol made by fermenting corn or other similar biomass material. There are three primary ways that ethanol can be used as a transportation fuel:

- As a blend of 10 percent ethanol with 90 percent unleaded gasoline called "E-10 Unleaded";
- As a component of reformulated gasoline, both directly and/or as ethyl tertiary butyl ether (ETBE);
- As a primary fuel with 85 parts of ethanol blended with 15 parts of unleaded gasoline called "E-85."

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In ancient times ethanol was known as an intoxicating drink. In the United States, ethanol is produced mainly by the fermentation of corn. It is the same alcohol used in beverage alcohol but meets fuel-grade standards. Ethanol that is to be used as a fuel is “denatured” by adding a small amount of gasoline to it. This makes it unfit for drinking. During the late 1800s, ethanol was used in the United States for lamp fuel and sales exceeded 25 million gallons per year. At the request of large oil companies, the government placed a tax on ethanol during the Civil War. This tax almost destroyed the ethanol industry [4,5]. In 1906 the tax was lifted and alcohol fuel did well until competition from oil companies greatly reduced its use. Ethanol use and production has increased considerably during the 1980s and 1990s. Growth in use of “E-10 Unleaded” gasoline has taken place because the fuel performs well in automotive engines and is competitively priced with “conventional” gasoline. Other reasons for increased production and use of ethanol, especially in the Midwest include:

- Ethanol reduces the country’s dependence on imported oil, lowering the trade deficit and ensuring a dependable
- source of fuel should foreign supplies be interrupted.
- Farmers see an increased demand for grain which helps to stabilize prices.
- The quality of the environment improves. Carbon moNOxide emissions are reduced, and lead and other
- carcinogens (cancer causing agents) are removed from gasoline.
- car owners benefit from increased octane in gasoline, which reduces engine “knock” or “pinging.” Ethanol-
- blended fuels also absorb moisture and clean the fuel system.

1.2 Other Bioalcohols

Methanol is currently produced from natural gas, a non-renewable fossil fuel. In the future it is hoped to be produced from biomass as biomethanol. This is technically feasible, but the economic viability is still pending. The methanol economy is an alternative to the hydrogen economy, compared to today's hydrogen production from natural gas. Butanol (C4H9OH) is formed by ABE fermentation (acetone, butanol, and ethanol) and experimental modifications of the process show potentially high net energy gains with butanol as the only liquid product. Butanol will produce more energy and allegedly can be burned "straight" in existing gasoline engines (without modification to the engine or car), and is less corrosive and less water-soluble than ethanol, and could be distributed via existing infrastructures. DuPont and BP are working together to help develop butanol. Ecoli strains have also been successfully engineered to produce butanol by modifying their amino acid metabolism [5-7].

2.0 Experimental Apparatus and Method

Experimental apparatus includes three major systems:

- Engine system,
- Power measurement system,
- Exhaust measurement system.

The engine system used in this experiment is a commercial engine, New Sentra GA16DE, which is a 1600 cm³ multi-point injection gasoline engine with cylinder bore and stroke being 76.0 and 88.0 mm, respectively, the ports arrangement being D.O.H.C., and the compression ratio being 9.5. The signals of fuel injectors can be acquired and adjusted by the CONSULT, which is an engine tester and diagnostic tool. The fuel injection rate can be adjusted ±25% in the open-loop control. Results of the open-loop control related to the ethanol–gasoline blended fuel will be reported in the near future. However, in this experiment, the closed-loop control is chosen instead of the open loop control. In the closed-loop control, the on-board central unit controls the fuel injection strategy with feedback signal from the oxygen sensor placed in the exhaust pipe. By using closed-loop control, we can investigate the effect of ethanol addition on the engine performance and pollutant emission under the original fuel injection strategy [8,9]. The engine output power is metered by the eddy-current dynamometer made by BORGHI & SAVERI (FE60-100-150 Series). In the experiment, the concentration of CO, CO_2 and HC in the exhaust gas are measured on-line by the analyzer of UREX-5000-4T with pre-calibration. The AFR and air–fuel equivalence ratio (λ) can be calculated simultaneously by the UREX-5000-4 T according to the compositions of the exhaust. The ZFR-2000 infrared detector measures the concentration of NOx. The online sampling of exhaust gas is taken in the extension section of the exhaust pipe without the catalytic converter, as illustrated in Figure 1. Due to the pulsed characteristics of the engine, 10 measurements taken to average the data for each operating condition [9,10].

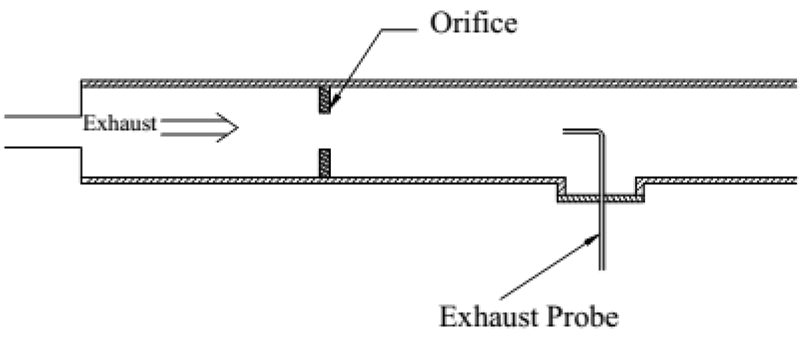

Fig. 1 - Illustration of the emission measurement location [4]

The selected operation conditions for this experiment are as follows: the engine speeds are at 1000, 2000, 3000 and 4000 rpm; throttle valves are at 0%, 20%, 40%, 60%, 80% and 100% (wide open throttle, WOT) opening. With these operation conditions, we can have a full understanding of the effects of the ethanol addition on the engine performance and pollutant emission. Engine operating conditions (throttle valve opening, engine speed, and fuel type), torque output, fuel consumption rate, intake air quantity and concentrations of NOx, CO, CO2 and HC emissions are recorded for further analysis [11,12].

2.1 Properties of Ethanol–gasoline Blended Fuels

Various blend rates of ethanol–gasoline fuels (E0, E5, E10, E20, E30) have been prepared and then sent to the China Petroleum Corp. for ASTM standard analysis. The ‘‘E’’ designates ethanol and the number next to E designates the volume percentage of ethanol. The E5 means that 5% ethanol (99.9% purity) was blended with 95% gasoline by volume.

From the results of the ASTM analysis, some of the combustion-related properties have been summarized in Table 1. Table 1 shows the variations of Reid vapor pressure (RVP), research octane number (RON) and the heating value as a function of different blend rates of ethanol–gasoline blended fuels. Table 1 indicates that, by increasing the ethanol content, the RVP increases to reach a maximum at E10, and then decreases. Pure ethanol has a RON at ≈ 105. Therefore, the RON increases monotonically with the increase of ethanol content, as shown in Table 1. The heating value of ethanol is lower than that of gasoline [11,12]. Table 1 further indicates that the heating value of the blended fuel will decrease with the increase of the ethanol content. Table 1 also presents the variations on distillation temperatures of different ethanol–gasoline blended fuels, including the initial boiling temperature (IBP), 10%, 50%, 90% distillation temperatures and final distillation temperature. It can be observed that the IBP, 10%, 90% and final distillation temperatures are almost independent of the ethanol content, while the 50% distillation temperature is decreased with the increase of ethanol content until 10% ethanol addition. Since the boiling temperature of ethanol is about 75°C, and the boiling temperature of gasoline is 25–230°C, it is suspected that the decrease of the 50% distillation temperature could be related to the evaporation of ethanol [13,14].

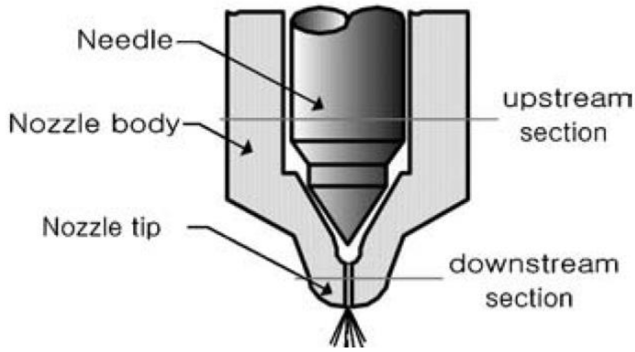

Fig. 2 - A cross-sectional view of an injector [18]

Table 1 - Properties of different ethanol/gasoline blended fuels (E0, E5, E10, E20, E30) [4]

Property item	Test fuel					Method
	E0	E5	E10	E20	E30	
Density (kg/l at 15.5°C)	0.7575	0.7591	0.7608	0.7645	0.7682	ASTM D4052
RON (octane number)	95.4	96.7	98.1	100.7	102.4	ASTM D2699
RVP (kPa at 37.8°C)	53.7	59.3	59.6	58.3	56.8	ASTM D5191
Sulfur (wt%)	0.0061	0.0059	0.0055	0.0049	0.0045	ASTM D5453
Washed gum (mg/100 ml)	0.2	0.2	0.2	0.6	0.2	ASTM D381
Unwashed gum (mg/100 ml)	18.8	18.6	17.4	15	14.4	
Lead content (g/l)	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025	ASTM D3237
Corrosivity (3 h at 50°C)	1a	1a	1a	1a	1a	ASTM D130
Distillation temperature (°C)						ASTM D86
IBP	35.5	36.5	37.8	36.7	39.5	
10 vol%	54.5	49.7	50.8	52.8	54.8	
50 vol%	94.4	88.0	71.1	70.3	72.4	
90 vol%	167.3	167.7	166.4	163.0	159.3	
End point	197.0	202.5	197.5	198.6	198.3	
Heating value (cal/g)	10176	9692	9511	9316	8680	
Carbon (wt%)	86.60	87.70	86.70	87.60	86.00	
Hydrogen (wt%)	13.30	12.20	13.20	12.30	13.90	
Residue (vol%)	1.7	1.5	1.5	1.5	1.5	
Color	Yellow	Yellow	Yellow	Yellow	Yellow	Visual

2.2 Engine Test of Ethanol–Gasoline Blended Fuels

Ethanol contains an oxygen atom in its basic form; it therefore can be treated as a partially oxidized hydrocarbon. When ethanol is added to the blended fuel, it can provide more oxygen for the combustion process and leads to the so-called ‘‘leaning effect’’. Owing to the leaning effect, CO emission will decrease tremendously; HC and NOx emissions will also decrease under same operating conditions. In this section, the effects of the blended fuels on the engine performance and pollutant emission are the main issues and will be discussed in detail [14,15].

3.0 Results

3.1 Torque Output

Figure 2 shows the torque output of the test engine using different blended fuels under various throttle valve openings. The figure is divided into 4 plots, which stand for the torque output at the engine speeds of 1000, 2000, 3000 and 4000 rpm, respectively. For a fixed engine speed, a higher throttle opening can provide more fuel for burning, i.e. more energy input. Therefore, the torque output is increased with the increase of the throttle valve opening. It also seems that the torque output of the engine is quite insensitive to the variation of the blend rate of ethanol–gasoline fuels. However, the torque output of pure gasoline (E0) is slightly lower than those of E5–E30, especially for low throttle valve openings (e.g., 20%) or high engine speeds (e.g., 4000 rpm) [15-20].

The original fuel injection strategy controlled by the ECU is set based on the use of pure gasoline. The stoichiometric air–fuel ratio for pure gasoline is 14.7 approximately, and that for the blended fuel should be < 14.7. The amount of intake air remains constant, when the engine speed and the throttle valve opening are kept the same. However, according to the control base of gasoline, the ECU must reduce the fuel supply to achieve the stoichiometric air–fuel ratio being 14.7 when ethanol is added. This ultimately makes the air–fuel mixture of the ethanol–gasoline blended fuel go leaner. The oxygen in ethanol gives an additional assistance to achieve lean burning in the engine. Therefore, the added ethanol will produce the leaning effect to increase the air–fuel equivalence ratio (λ) to a higher value, and make the burning closer to be stoichiometric. Its final result is that better combustion can be achieved and higher torque output can be acquired as a consequence.

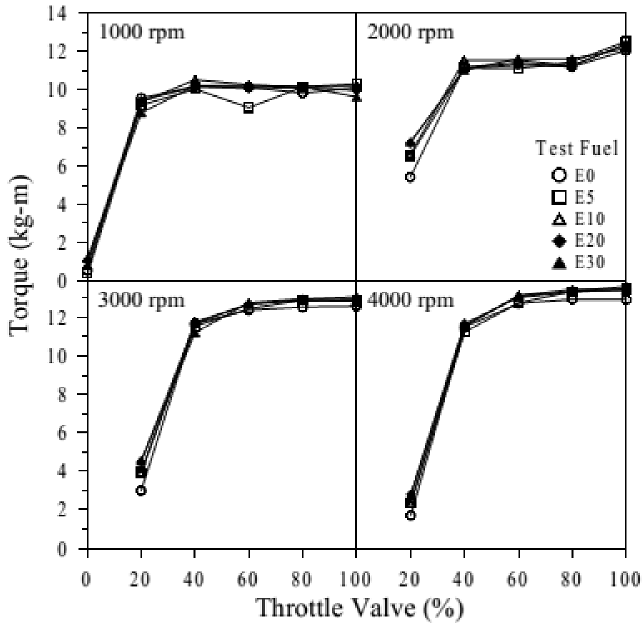

Fig. 2 - Torque output of the engine using different blended fuels under various operating conditions [4]

3.2 Fuel Consumption

From the experimental results, brake specific fuel consumption (bsfc) was calculated to understand the variations of fuel consumption in the test engine using different ethanol–gasoline blended fuels. The bsfc (g/kJ) is defined as the ratio of the rate of fuel consumption (g/sec) and the brake power (kW).

Figure 3 indicates the variations of the bsfc for different blended fuels under various engine speeds and throttle valve openings. In Figure 3, the curve of E0 represents the original fuel injection strategy controlled by the ECU. The bsfc remains constant at low engine speeds (1000, 2000 rpm) with throttle valve openings >20%, or at high engine speeds (3000, 4000 rpm) with higher throttle valve openings (above 40%). The theoretical AFR of gasoline is 1.6 times that of ethanol, therefore the bsfc should be increased with the increase of ethanol content. However, the fuel injection strategy tends to operate the engine at fuel-rich condition, and the ethanol addition produces leaning effect to enhance the combustion of fuel, these factors make no difference on the bsfc between using pure gasoline and using ethanol–gasoline blended fuels, as observed from Figure 3.

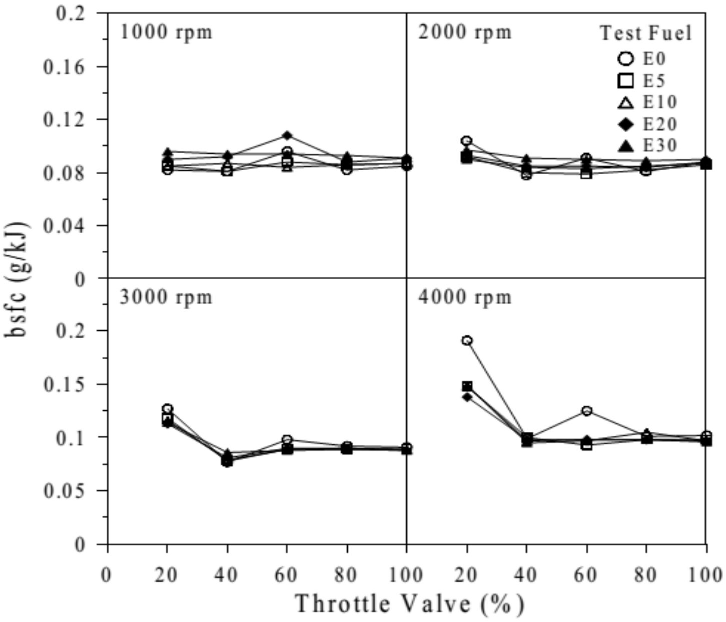

Fig. 3 - Brake specific fuel consumption (bsfc) of the engine using different blended fuels under various operating conditions [4]

3.3 Pollutant Emissions

Considering the typical torque outputs for a passenger car, we control torque outputs between 11 and 14kg m to evaluate pollutant emissions from the engine in this part of experiment. Figure 4 presents the correlations between the pollutant emissions (concentrations of CO, CO_2, HC and NO_x emissions) and the equivalence ratio in the range of 11–14 kg m torque output. Figure 4 shows two sets of experiment performing under 3000 and 4000 rpm engine speed respectively. The equivalence ratio (λ) is defined based on the air–fuel ratio, and is calculated directly by the UREX-5000-4T analyzer while taking measurements. Here, $\lambda < 1$ and $\lambda > 1$; respectively, denote fuel-rich and fuel-lean operations.

For an engine speed of 3000 rpm, Figure 4 shows that the concentration of CO emission decreases by increasing the equivalence ratio, as λ approaches 1. It is noted that the increase of λ is associated with the increase of ethanol content. This indicates that the engine tends to operate in leaner conditions, closer to stoichiometric burning, as the ethanol content is increased. The combustion process is more complete when it is closer to stoichiometric burning; therefore, the concentration of CO emission decreases. The variation of CO emission for the case of 4000 rpm is similar to that of 3000 rpm, except that the CO concentration of the former is higher due to the shorter combustion time at a higher engine speed. In Figure 4, the variation of the CO2 concentration is contrary to that of the CO concentration. When the engine condition goes leaner, the combustion process is more complete and the concentration of CO2 emission gets higher. It would be expected that CO2 concentrations at 4000 rpm are lower than those at 3000 rpm. Furthermore, the concentration of HC emission decreases with the increase in the equivalence ratio. The reason for the decrease of HC concentration is similar to that of CO concentration described above. Considering the NOx emission, Figure 4 shows that the NOx concentration gets higher as the equivalence ratio approaches 1. As the equivalence ratio approaches 1, the combustion process is closer to stoichiometric and produces a higher flame temperature, therefore the NOx emission is increased, particularly by the increase of thermal NOx. However, it is important to address that in this series of engine test, the influence of the ethanol addition on NOx emission is insignificant as $\lambda < 1$ shown in Figure 4.

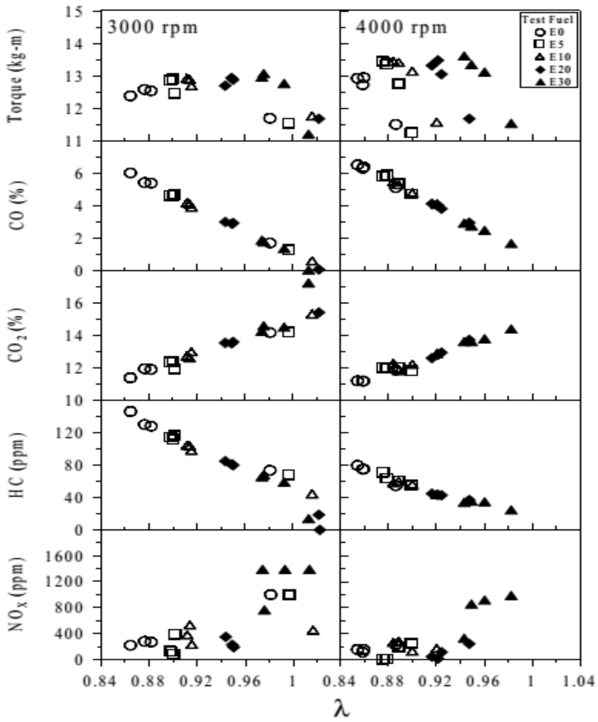

Fig. 4 - Correlations between the equivalence ratio and the concentrations of CO, CO2, HC and NOx emissions at 3000 and 4000 rpm with torque output of 11–14 kg m [4]

3.4 Overall Engine Performances

To investigate the influence of different blended fuels on the torque output and pollutant emissions, results of the engine test at 3000 rpm with throttle valve opening of 40%, 60%, 80% and 100% are selected for comparison, as shown in Figures 5–9. The case of pure gasoline (E0) was chosen as the basis of the comparison.

Figure 5 presents the influence of the blended fuels on the increase of engine torque output. It can be observed from the figure that at lower throttle valve openings, the torque output is either increased or decreased by adding the ethanol content. However, at higher throttle valve openings (60%, 80%, and 100%), the increase of torque output grows with the ethanol content ranging from 2% to 4%.

Figure 6 shows the influence of the blended fuels on the reduction of CO emission. It is found that the reduction of CO emission grows as the ethanol content increases. This indicates that the addition of ethanol can reduce the concentration of CO emission efficiently. The concentration of CO emission can be reduced up to 90% depending on the operating condition of the engine. Figure 7 further shows the increase of CO2 emission by the additional ethanol. It is obvious that the concentration of CO2 emission increases as the ethanol content in the blended fuel increases. However, the variations of CO2 emission are not as obvious as those of CO emission. The increase of CO2 emission grows from 5% to 25% depending on the operating condition and the ethanol content.

Figure 8 represents the influence of the blended fuels on the reduction of HC emission. It is shown that by increasing the ethanol content, the concentration of HC emission decreases from 20% to 80% in comparison with pure gasoline. Figure 9 finally indicates the influence of the blended fuels on the reduction of NOx emission. From this figure, there is no clear correlation between the fuel type and the emission reduction ability. It is therefore noted that the NOx emission depends on the engine operating condition rather than the ethanol content.

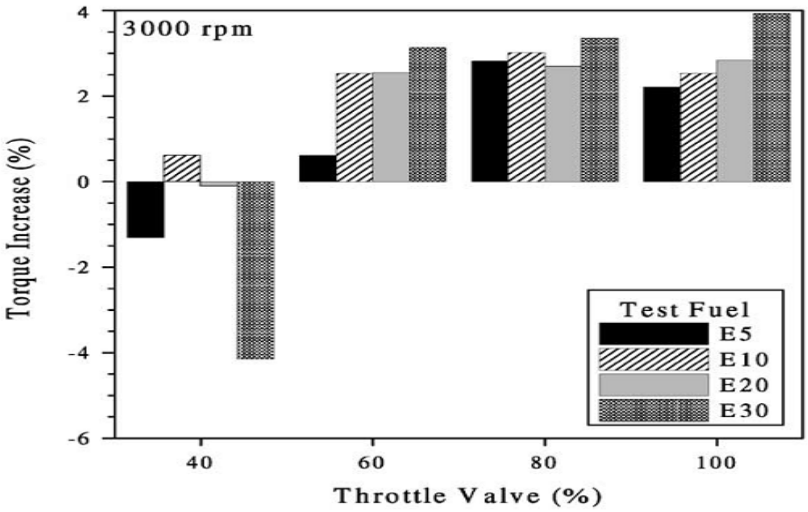

Fig. 5 - Influence of the blended fuels on the increase of engine torque output (relative to pure gasoline) at 3000 rpm [4]

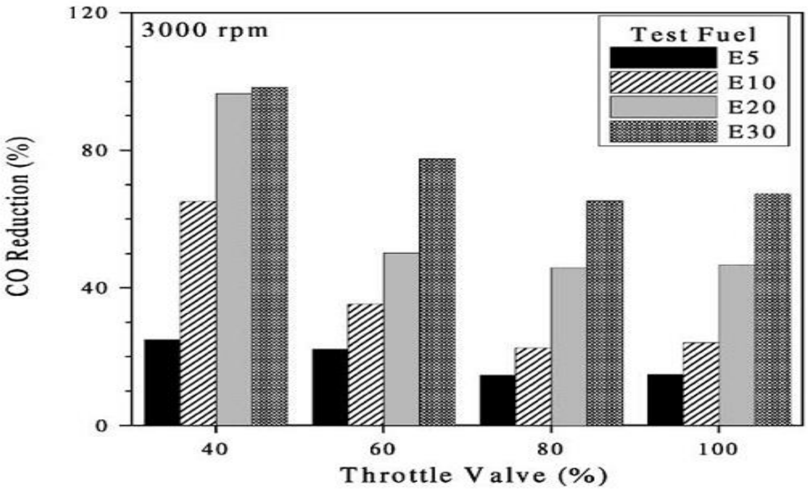

Fig. 6 - Influence of the blended fuels on the reduction of CO emission (relative to pure gasoline) at 3000 rpm [4]

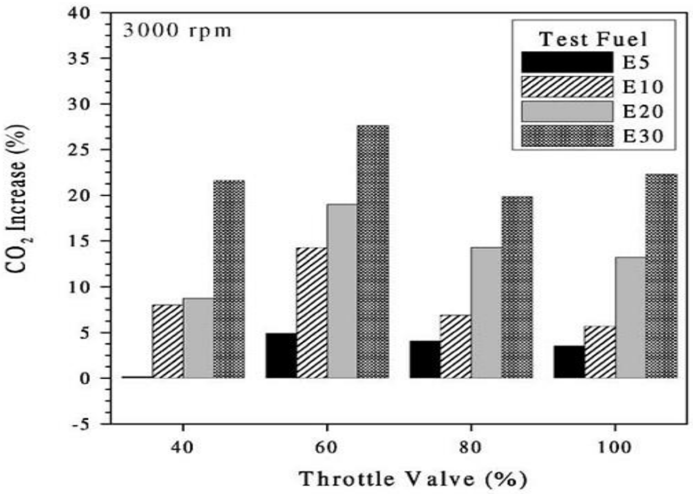

Fig. 7 - Influence of the blended fuels on the increase of CO2 emission (relative to pure gasoline) at 3000 rpm [4]

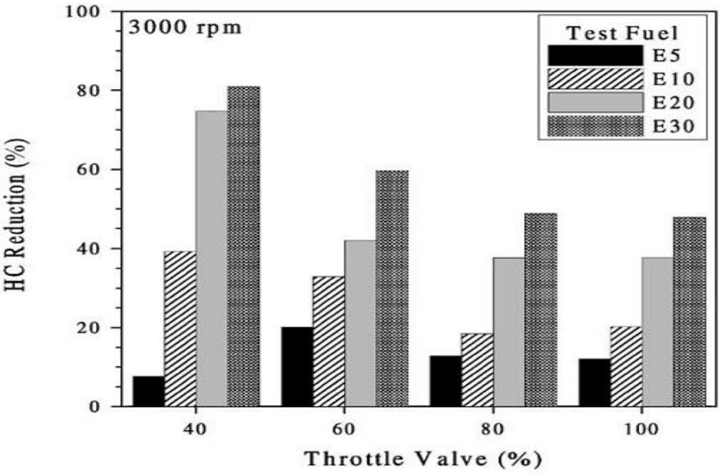

Fig. 8 - Influence of the blended fuels on the reduction of HC emission (relative to pure gasoline) at 3000 rpm [4]

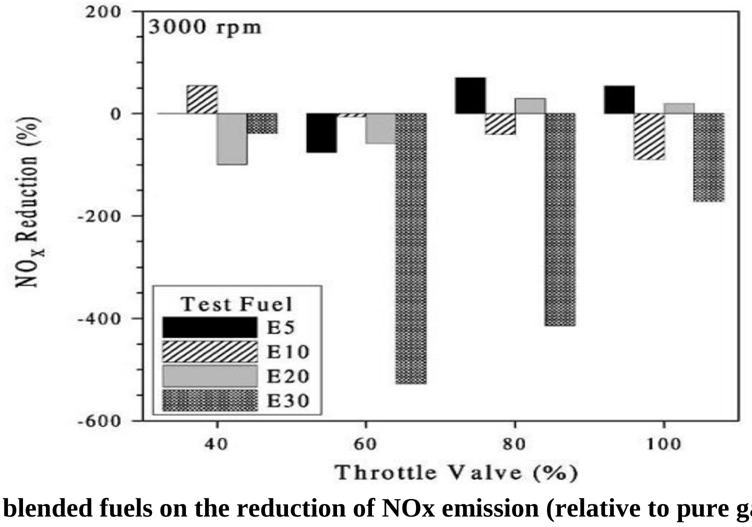

Fig. 9 - Influence of the blended fuels on the reduction of NOx emission (relative to pure gasoline) at 3000 rpm [4]

Conclusion

The engine performance and pollutant emission of a commercial SI engine have been investigated by using ethanol–gasoline blended fuels. Experimental results indicated that using ethanol–gasoline blended fuels, the torque output and fuel consumption of the engine slightly increase; CO and HC emissions decrease dramatically as a result of the leaning effect caused by the ethanol addition; and CO_2 emission increases because of the improved combustion.

In this study, it revealed that using ethanol–gasoline blended fuels, CO and HC emissions may be reduced 10–90% and 20–80%, respectively, while CO2 emission increases 5–25% depending on engine conditions. It was noted that NOx emission is closely related to the equivalence ratio, such that NOx emission reaches a maximum near the stoichiometric condition ($\lambda = 1$); and that NOx emission depends on the engine operating condition rather than the ethanol content. Finally, in order to present a complete picture on the utilization of the ethanol–gasoline blended fuels in engines, the extensions of this study, such as the engine test under the open-loop control of fuel injection and measurements on the emission of aldehyde, also have been done and will be reported in the near future.

Acknowledgement

The authors would like to thank the Ministry of Education Malaysia for supporting this research under Fundamental Research Grant Scheme (FRGS) Vot K218, K 224 and also Research Fund Universiti Tun Hussein Onn Malaysia (H802) and GPPS vot. U749).

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