EFFECT OF GASOHOL BLENDS ON A FOUR CYLINDER, PORT FUEL INJECTION ENGINE PERFORMANCE

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ABSTRACT

This paper investigates the effect of using unleaded gasoline–ethanol blends on SI engine performance. A four stroke, four cylinder SI engine (type FORD, 16 V ZETEC) was used for conducting this study. Performance tests were conducted for equivalence air fuel ratio, fuel consumption, volumetric efficiency, brake thermal efficiency, brake power, engine torque and brake specific fuel consumption, using unleaded gasoline–ethanol blends with 50% and 100% throttle opening position and variable engine speed ranging from 1000 to 3000 rpm. The results showed that blending unleaded gasoline with ethanol increases the brake power, torque, volumetric, fuel consumption and brake specific fuel consumption. The addition of ethanol between 0-100 percent to the unleaded gasoline is achieved in the experiments without any problems during engine operation

Keywords: Ethanol, fuel blends, performance, test

1. Introduction

Alcohols have been suggested as an engine fuel almost since automobile was invented [1]. Ethanol which is a colorless liquid with mild characteristic odor and can be produced from coal, natural gas and biomass, have high octane rating and can be used as one of the realistic alternative fuels. As fuel, it is renewable and having a higher octane rating than gasoline with similar storage and dispensing and can be mixed with conventional fuels (diesel fuel or gasoline) [2].

It is known as the most suited fuel for spark-ignition (SI) engines [3, 4] and can be used in SI engines as pure or by blending with gasoline [4, 5, 6] Ethanol can be blend with gasoline at low concentrations without any modification to be used in SI engine [7]. Ethanol–gasoline blends (gasohol) can be used as fuel in order to substitute some part of gasoline in engine applications [2]. It was reported that using gasoline–ethanol blends including ethanol at low concentrations could improve engine performance and exhaust emissions [3, 4, 7, 8]; such as increasing the octane rating, which is particularly important in unleaded fuel, and reduce carbon monoxide (CO) emissions from the engine [9].

Gasahol gain importance within these recent years as alternative fuel due to this high octane number, especially with ethanol which has low carbon [10]. This led the gasohol (a mixture of 10% alcohol with 90% gasoline) to be a commercial fuel in over 35 countries of the World including the USA, Canada and France [9]. Alternative renewable fuels such as bioethanol-gasoline blended fuels are becoming essential due to increasing oil prices, environmental concerns and their potential to preserve the agricultural activity. Ethanol–gasoline blends which has high octane rating can be used as fuel in order to substitute some part of gasoline in engine applications as it has higher heat of vaporization compared to gasoline, which means that freezes the air allowing more mass to be drawn into the cylinder and increases the power output [11]. Besides that, ethanol has antiknock properties that improves engine efficiency and gives higher compression ratios [2].

Based on Oklahoma consumers' survey 2002, majority responders perceived that ethanol-blended gasoline is better for the environment than gasoline [12] as the usage will result the reduction of CO and UHC emissions [13]. Gasohol (a mixture of 10% alcohol with 90% gasoline) as the gasoline alternative fuel is already a commercial fuel in over 35 countries of the World including the USA, Canada and France. In Brazil, cars with modified engines have been running for years on this [9]. As in China; petroleum scarcity and corn overstock, the blends (ethanol fuel (E100)) were applied on small motorcycles SI engine based on the research of LPG fuel application in the motorcycles [14].

2. Properties of Ethanol–Gasoline Blended Fuels

Heating value of ethanol is lower than that of gasoline (Table 1) thus heating value of the blended fuel will decrease with the increasing content of the ethanol [7], therefore, more fuel is needed (by mass) to obtain same power when blended fuels are used instead of gasoline. However, ethanol addition to gasoline makes the engine operation leaner and improves engine combustion and performance [8].

Table 1: Some Properties of Gasoline and Ethanol [20]

	Gasoline	*Ethanol*
Chemical formula	C_4-H_{12}	C_2H_5OH
Molecular weight	100-105	46
Oxygen (mass %)	0-4	34.7
Net lower heating value (MJ/kg)	43.5	27
Latent heat (kJ/L)	223.2	725.4
Stoichiometric air/fuel ratio	14.6	9
Vapor pressure at 23.5^{o}C (kPa)	60-90	17
MON	82-92	92
RON	91-100	111

Hsieh et al., 2002 [7] used various blend rates of ethanol–gasoline fuels such as E0, E5, E10, E20, and E30 which were classed into its group with ASTM standard analysis. The ''E'' designates ethanol and the number next to E designates the volume percentage of ethanol in the total fuel blend. Pure ethanol has a RON at E105 therefore; the RON increases monotonically with the increase of ethanol content [15].

3. Engine Performance

Palmer (1986) [16] indicated that 10% ethanol addition increased the engine power output by 5%, and the octane number can be increased by 5% for each 10% ethanol added. Abdel-Rahman and Osman (1997) [17] had tested 10%, 20%, 30% and 40% ethanol of blended fuels in a variable-compression-ratio engine and found that the increase of ethanol content increased the octane number, but decreased the heating value. Under various compression ratios of engine, the optimum blend rate was found to be 10% ethanol with 90% gasoline. Later, Hsieh et al (2002) [7] investigated the engine performance and pollutant emission produced by commercial SI engine using ethanol–gasoline blended fuels with various blended rates (0%, 5%, 10%, 20%, 30%) which were set according to standard ASTM methods. The outcomes showed that by increasing the ethanol content, the heating value of the blended fuels was decreased, the octane number of the blended fuels increased while better combustion can be achieved and higher torque output can be acquired.

The usage of ethanol–gasoline blends in finding the effect of air–fuel ratio on SI engine performance showed that torque output improved significantly [18]. With 60% ethanol and 40% gasoline blend used to test the performance, the fuel consumption, and the exhaust emissions, a new carburetor was redesigned to apply successfully gasoline–alcohol mixtures as a motor fuel. Experimental results indicated that the torque output consumption of the engine increased slightly [19]. Similar results produced by Yücesu et al., 2006 [10], which investigated the effect of compression ratio on engine performance and exhaust emissions with different ethanol-gasoline fuel blends examined at stoichiometric air/fuel ratio, full load and minimum advanced timing for the best Mean Brake Torque (MBT) in a single cylinder, four stroke, with variable compression ratio and spark ignition engine. In all compression ratios, the better engine performance was obtained by using blends up to the 60% ethanol. With increasing compression ratio, the engine torque increased and so as the temperature of end gas area which caused detonation.

When Cowart et al. 1995 [20] used methanol M85 and ethanol E85 as fuels, the engine performance increased via engine torque and power. Recently, Wei et al., 2008 [21] explored the use of varies methanol-gasoline blends to investigate the affects on engine power, thermal efficiency, and emissions in three-cylinder, port fuel injection engine. It was found that the experiment produced the similar results as mentioned earlier.

4. Description of Experiment

4.1 Engine and Equipment

The experiments were conducted on a four cylinder, four stroke spark ignition engine (type Ford 16 V Zetec 1800cc). The engine has a swept volume of 1795 cm^3; bore 80.6 mm and stroke 88 mm, a compression ratio of

10:1 and a maximum power of 77 kW at 5950 rpm. The engine was coupled to an eddy-current dynamometer, which is equipped with an instrument cabinet (column mounted) fitted with a torque gauge, electric tachometer and switches for the load remote control.

4.2 Fuels

Two different fuel samples were experimentally investigated during this study. Unleaded gasoline was obtained from PETRONAS petrol station. Ethanol, with a purity of 99%, was used in preparing the blends. The unleaded gasoline was blended with ethanol to get 10 test blends ranging from 0% to 100% ethanol. The fuel blends were prepared just before starting the experiment to ensure that the fuel mixture is homogenous and to prevent the reaction of ethanol with water vapor. The fuel types properties are shown in Appendix A

4.3 Procedures

The engine was started and allowed to warm up for a period of 20–30 min. The air–fuel ratio was adjusted to yield maximum power on unleaded gasoline. Engine tests were performed at 1000, 1500, 2000, 2500, and 3000 rpm engine speed at 50 % and 100 % throttle opening position. The lowest desired speed is maintained by the load adjustment. The required engine load was obtained through the dynamometer control. Before running the engine to a new fuel blend, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment.

For each experiment, three runs were performed to obtain an average value of the experimental data. The variables that were continuously measured include engine rotational speed (rpm), torque, BMEP, exhaust temperature, air flow, fuel flow etc. The parameters, such as fuel consumption rate, equivalence air–fuel ratio, volumetric efficiency, air consumption, brake power, brake specific fuel consumption, brake thermal efficiency, density, stoichiometric air–fuel ratio and lower heating value (LHV) of the fuel blends, were estimated using the following equations. The fuel consumption is estimated by measuring the fuel consumed per unit time and the calculated values of the density for different fuel blends through Eqs. (1) and (2):

$$\dot{m}_f = \frac{3.6 Q_f \rho_b}{t} \qquad (1)$$

$$\rho_b = \sum \rho_i \upsilon_i \qquad (2)$$

The volumetric efficiency is defined as follows

$$n_v = \frac{\dot{m}_a R_a T_o}{30 P V_s N} \qquad (3)$$

Where

$$\dot{m}_a = (AFR)_{act} \dot{m}_f \qquad (4)$$

The equivalence air-fuel ratio is defined as

$$\phi = \frac{(AFR)_{st.b}}{(AFR)_{act}} \qquad (5)$$

Where

$$(AFR)_{st.b} = \sum (AFR)_{st.i} \upsilon_i \qquad (6)$$

The brake power is calculated by measuring the engine speed and the engine torque and is given by Eq. (7). The specific fuel consumption is defined as the ratio of the fuel consumption to the brake power, as shown in Eq. (8). The brake thermal efficiency is defined as the ratio of the brake power to the heat input for each blend, as shown in Eq. (9)

$$B_p = \frac{NT}{9549.29} \qquad (7)$$

$$BSFC = \frac{\dot{m}_f}{B_p} \qquad (8)$$

$$\eta_{b.th} = \frac{3600 B_p}{\dot{m}_f (LHV)_b} \qquad (9)$$

Where

$$(LHV)_b = \sum \left(\frac{\rho_i \upsilon_i}{\rho_b} \right) (LHV)_i \qquad (10)$$

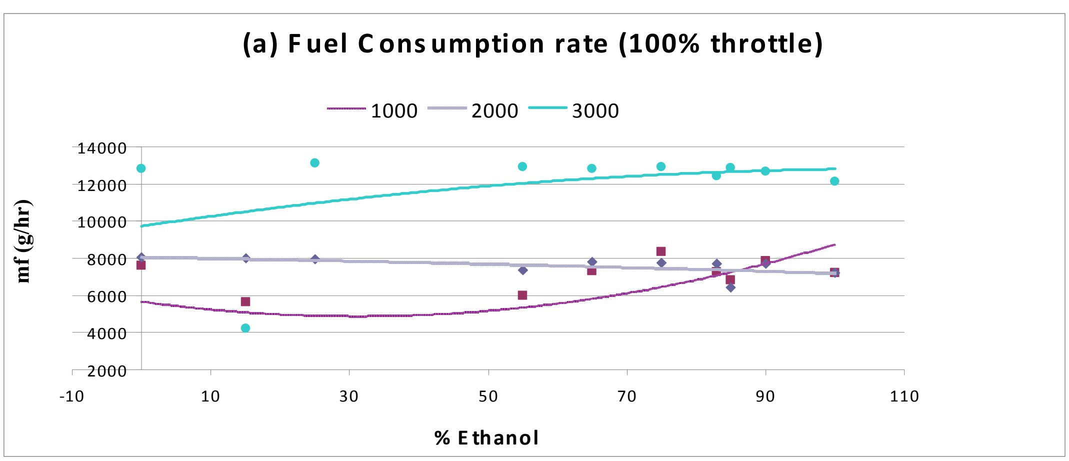
5. Result and Discussion

The effects of ethanol addition to unleaded gasoline on SI engine performance at half and full throttle opening at variable engine speeds were investigated. For the start, various blend rates of ethanol–gasoline fuels (E0, E15, E25, E55, E65, E75, E83, E85, E90, and E100) have been prepared by volume. The ''E'' designates ethanol and the number next to E designates the volume percentage of ethanol. The E15 means that 15% ethanol (99.9% purity) was blended with 85% gasoline.

Originally, fuel injection strategy controlled by the ECU is set based on the use of pure gasoline with the stoichiometric air – fuel ratio approximately 14.7. However, the blended fuel should have stoichiometric air–fuel lower than 14.7. Together with the amount of intake air remains constant and the engine speed also the throttle valve opening are kept the same, the fuel supply is reduced to achieve the 14.7 stoichiometric air–fuel ratio when ethanol is added; Resulting air–fuel mixture of the ethanol–gasoline blended fuel go leaner. Which, as known, ethanol contains an oxygen atom in its basic form, thus 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".

5.1 Fuel Consumption

The effect of the ethanol–unleaded gasoline blends on the fuel consumption is shown in **Fig. 1**. From **Fig. 1**, the m_f increases as the E% increases for all engine speeds. This behavior is attributed to the LHV per unit mass of the ethanol fuel, which is distinctly lower than that of the unleaded gasoline fuel. Therefore, the amount of fuel introduced into the engine cylinder for a given desired fuel energy input has to be greater with the ethanol fuel. However for engine speeds of 1000 rpm, slightly decreases until 50% gasohol blended that show the relative increase of mf is approximately 50-60%, respectively for both throttle load. This increase in m_f could be explained by the fact that as the engine speed increases, the air velocity increases and the pressure decreases at the injector. Consequently, the pressure drop between the pressure at the injector and the pressure (atmospheric) inside the float chamber increases, which causes more fuel consumption.



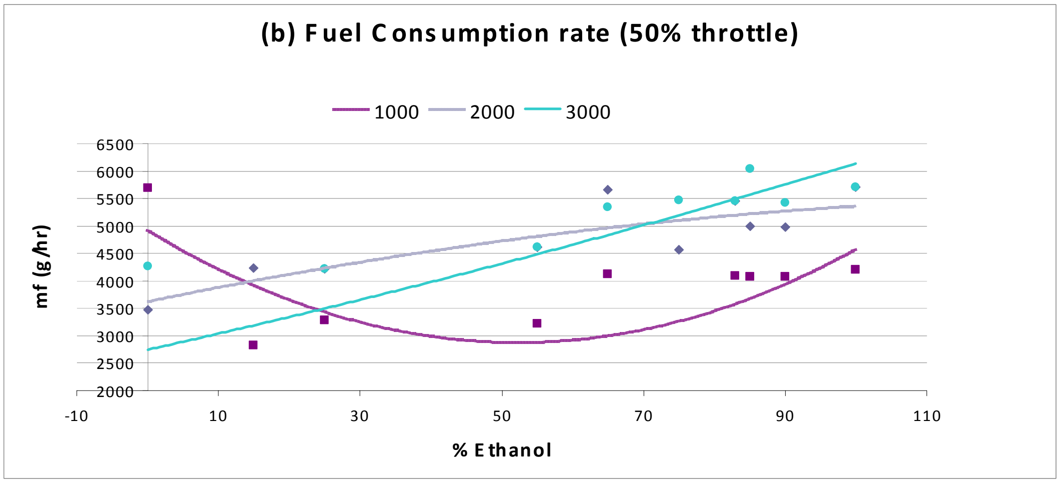


Fig.1. The effect of gasohol blends percentage on the fuel consumption rate.

5.2 Brake Specific Fuel Consumption (BSFC)

From the experimental results, the brake specific fuel consumption (bsfc) defined as the ratio of the rate of fuel consumption (g/hr) and the brake power (kW), have been calculated by using eq. (8) in order to understand the variations of fuel consumption in the test engine by using different gasohol blended fuels. **Fig. 2** indicates the variations of the bsfc for different blended fuels under various engine speeds and two throttle valve openings. The bsfc increases significantly at all engine speeds (1000, 2000, 3000 rpm) with both throttle valve openings 50% and full throttle valve openings (100%). 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.

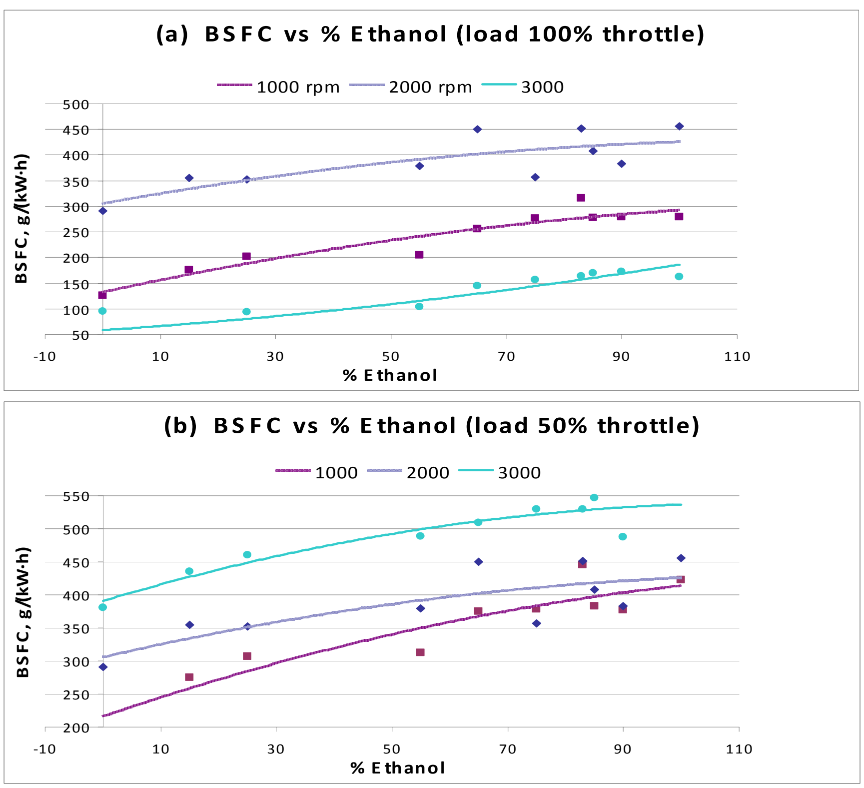


Fig. 2. The effect of gasohol blend percentage on the brake specific fuel consumption (bsfc)

5.3 Brake Torque (T_b)

Fig. 3 shows the torque against the ethanol ratio under 50% and wide opens throttle (WOT) operating conditions. It shows that for 50% open throttle the engine torque increases slightly for all blended and all engine speed. Whereas, under WOT (100% load), the engine torque decreases for all blended especially for 2000-3000 rpm that decreased significantly for all blended. That is because the SI engine is in a λ open-loop control under WOT conditions. Although the same volume of fuel blends is injected, the energy that bring into the cylinder decreases for all blended. The laminar flame of ethanol propagates faster than that of gasoline, [22] the combustion process occurs near top dead center (TDC), and the combustion heat is released in a shorter time and a smaller volume; as a result, the isometric effect is improved.

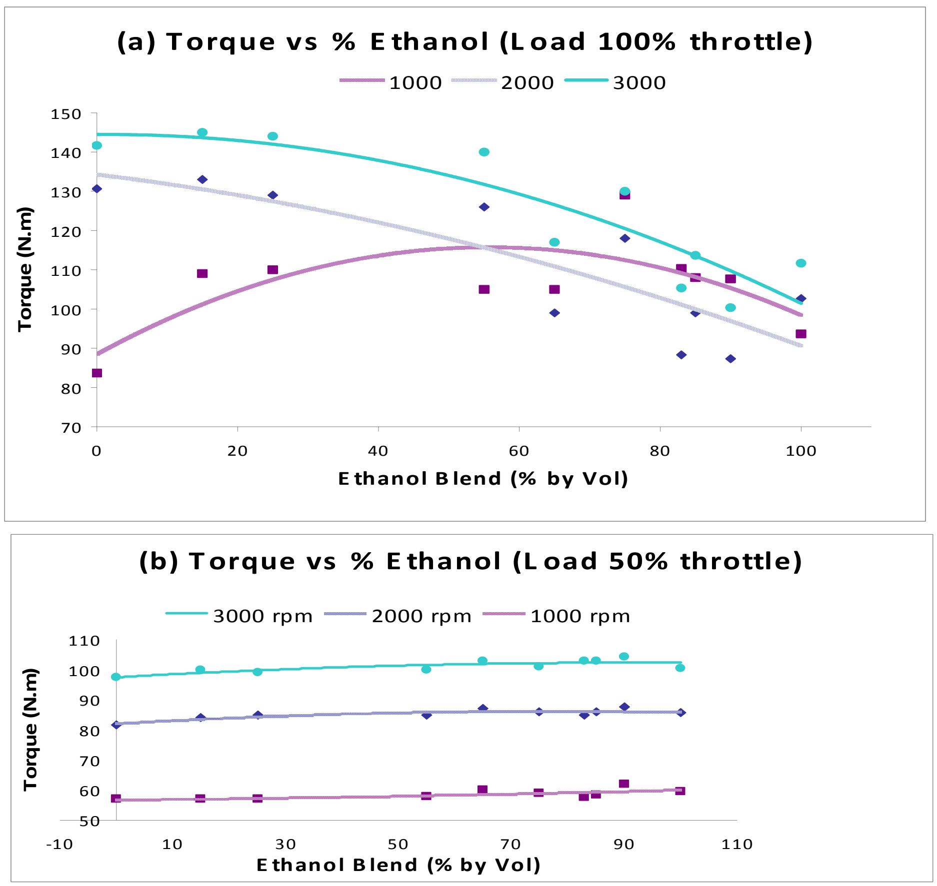


Fig. 3. The effect of gasohol blends percentage on the brake torque.

Moreover, it can be seen from the total combustion reaction formulas of gasoline (substituted by isooctane) and ethanol with air, as shown in eqs 11 and 12. For the same amount of heat release, ethanol has 49% more triatomic molecules in the combustion products than gasoline. This means that the burnt gas heat capacity of ethanol is larger than that of gasoline; thus, the combustion temperature of ethanol is lower than that of gasoline as shown in **Fig. 4**. The cooling heat loss via radiation and conduction is reduced, and, consequently, the thermal efficiency is improved [23]. Another research results show that for alcohols with boiling points lower than that of water, a significant amount of moisture, generated during combustion is absorbed by the droplet. Absorption of this moisture prolongs droplet life and reduces flame temperature [24].

Gasoline:

$$C_8H_{18} + 12.5(O_2 + 3.785N_2) \rightarrow 8CO_2 + 9H_2O + 47.31N_2 + 5.128\ MJ \qquad (11)$$

Ethanol:

$$4.167C_2H_5OH + 12.5(O_2 + 3.785N_2)$$
$$\rightarrow 8.333CO_2 + 12.5H_2O + 47.31N_2 + 5.333\ MJ \qquad (12)$$

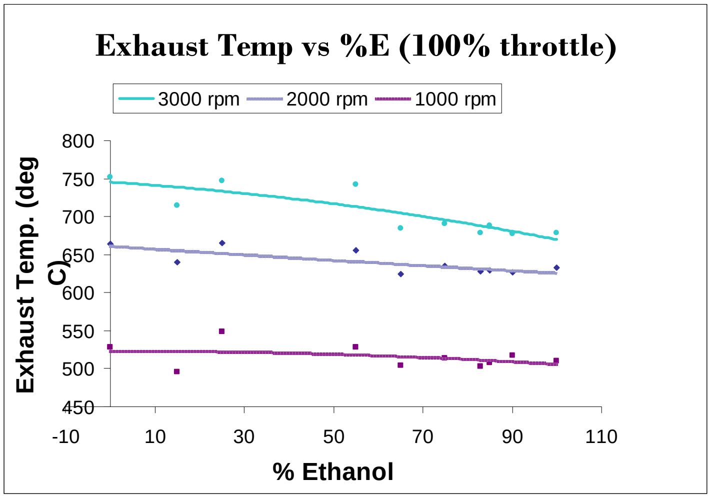


Fig. 4. The effect of gasohol blends percentage on the exhaust temperature.

Generally, the brake torque has a significant dependence on the volumetric efficiency and only a slight dependence on the engine speed. As a consequence, the influence of engine speed on T_b is similar to its influence on the volumetric efficiency

5.4 Brake Power (P_b)

The brake power is proportional to the product of the engine torque and speed, which the effect of ethanol–unleaded gasoline blends on brake power is illustrated in **Fig. 5**. It is clear that P_b increase as the E% increases for all engine speeds as half open throttle (50%). However P_b decreases for full open throttle (100%). This behavior agrees with that of the volumetric efficiencies shown in Figs. 6. However, as Eq. (7) shows, the brake power is proportional to the product of the engine torque and speed, which suggests that P_b increases as the engine speed increases.

Fig. 5. The effect of gasohol blends percentage on the brake power.

5.5 Volumetric efficiency (η_v)

Fig. 6 shows slightly increase in the volumetric efficiency as the percentage of ethanol in the fuel blends increases especially in full open throttle (100%). This is due to the decrease of the charge temperature at the end of the induction process (T_a). This decrease is attributed to the increase in the charge temperature by an amount T_h as a result of the heat transfer from the hot engine parts and the residual gases in the charge. At the same time, the charge temperature drops by an amount T_v due to vaporization of the fuel blend in the inlet manifold and engine cylinder. Therefore, the total change in the charge temperature (ΔT) could be expressed as shown in equation 13 [25]:

$$\Delta T = T_h - T_v \text{ and } T_a = T_h + \Delta T \quad (13)$$

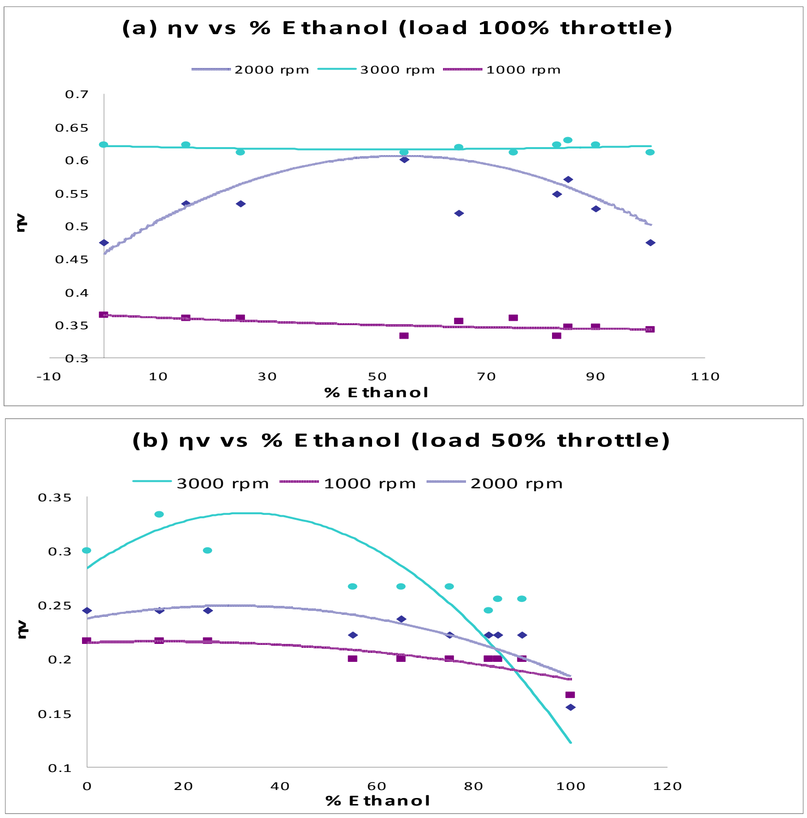


Fig. 6. The effect of gasohol blends percentage on the volumetric efficiency.

It has been reported by Holger and Bernd [25] that as the E% in the fuel blend increases, the volatility and the latent heat of the fuel blend increases. Meanwhile, with increasing volatility and latent heat of the fuel blend, the drop of the charge temperature T_v increases. At the same conditions, the total heat capacity of the charge increases, since the specific heat of the ethanol fuel is higher than that of the unleaded gasoline fuel, and this led to decreases in the charge temperature T_v. Therefore, increasing the ethanol in the fuel blend has two contradicting effects on T_v. Therefore, T_v changes with E% in the fuel blend as ΔT. This means that T_v changes with the E% in the fuel blends.

The effect of engine speed on η_v can also be explained from **Fig. 6**. As the engine speed increases to 3000 rpm, η_v increases, as the amount of air introduced to the engine cylinder was increased. However, further increase in the engine speed gave declining value of η_v, where the amount of air decreased as a result of the choking in the induction system.

6. Conclusion

The engine performances of a commercial SI engine have been investigated by using gasohol blended fuels. Experimental results indicated that using gasohol blended fuels, the torque output and fuel consumption of the engine slightly increase; as a result of the leaning effect caused by the ethanol addition. Whereas, the engine power varies with the cyclic injected energy, and the addition of ethanol improved the brake thermal efficiency; however, the improvement depended slightly on the ethanol ratio.

From the results of the study, the following conclusions can be deduced:
1. Using ethanol as a fuel additive to unleaded gasoline causes an improvement in engine.
2. Ethanol addition results in an increase in brake power, volumetric efficiency, fuel consumption and the brake specific fuel consumption for 3000 rpm.
3. The addition of ethanol between 0-100 percent to the unleaded gasoline is achieved in the experiments without any problems during engine operation.

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