Impact of Methanol–Gasoline Fuel Blends on the Performance and Exhaust Emissions of a SI Engine

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Abstract

In this study, the effect of Methanol (M5, M7.5, M10, M12.5, M15) on the performance and combustion characteristics of a spark ignition engine (SI) were investigated. In the experiment, an engine with four-cylinder, four stroke, multi-point injection system (Ford, Zetec-E) was used. Performance tests were conducted for brake torque, brake power, brake thermal efficiency, volumetric efficiency, equivalence air-fuel ratio, and brake specific fuel consumption and exhaust emissions (CO, CO_2, HC, NO_x) were analyzed under wide open throttle operating conditions and variable engine speed ranging from 1500 to 5000 rpm. The experimental results showed that the performance of engine was improved with the use of methanol. It was also shown that CO and HC emissions were reduced with the increase of methanol content while CO_2 and NOx were increased.

Keywords: Methanol, Gasoline, Engine performance, Exhaust emissions

1. INTRODUCTION

The majority of the energy used today is obtained from the fossil fuels. Due to the continuing increases in the cost of fossil fuels, demands for clean energy have also been increasing. Therefore, alternative fuels sources are sought. Some of the most important fuels are biogas, natural gas, vegetables oil and its esters alcohols and hydrogen.

In alcohols, methanol and ethanol are used most often as fuels and fuel additives. Methanol can be produced from natural gas, gasification of coal or biomass .However, coal is not preferred as a feedstock because conversion process is complex and costly than using other feedstock in commercial methanol production [1]. Methanol has much higher octane number than gasoline [2]. This allows to Methanol engines to have much higher compression ratios, and so increasing thermal efficiency. Compared with gasoline, the lower boiling point, faster flame propagation speed, high oxygen content (50 % wt), and simple chemical structure of methanol all help to reduce the CO and hydrocarbon (HC emissions) [3-10]. Nevertheless, as significant disadvantage of methanol relative to gasoline is that it has lower energy content and higher Reid vapor pressure [11].

Many researchers have focused on ethanol-gasoline blended fuels. Brinkman et al. [12] measured the octane number of methanol–gasoline blends. They found that the research and motor octane numbers increased with increasing methanol amount in the fuel blend. Shenghua et al. [4] operated a three-cylinder SI engine with several fractions of methanol (10%, 15%, 20%, 25% and 30%) in gasoline under the full load condition. They saw that the engine power and torque decreased, while the brake thermal efficiency improved with the methanol fraction increase in the fuel blend. Bilgin and Sezer [13] studied the effect of methanol addition to leaded and unleaded gasoline on the engine performance. They stated that the maximum brake mean effective pressure (bmep) was obtained from M5 fuel blend. Abu-Zaid et al.[6] researched the performance of an SI engine when using 3%, 6%, 9%, 12%, 15% methanol blended gasoline, and reported that the maximum power output and the minimum brake specific fuel consumption were obtained from M15 fuel blend. Hu et al. [14] stated that start of combustion advanced and rapid burning phase became shorter with the methanol addition to gasoline. The maximum cylinder gas pressure (Pmax) of the methanol–gasoline fuel blends became higher compared to pure gasoline under the same engine speed and throttle opening. In a similar study, Yanju et al. [15] tested three typical methanol–gasoline fuel blends M10, M20, and M85 in an SI engine. They stated that with the increase of the

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methanol fraction in gasoline, the CO emission decreases and the reduction is 25% for M85, and the low methanol ratio fuel blends have no significant effect on reducing the NO_x emission while M85 gives an 80% reduction. Liu S. et al. [4] stated that when methanol–gasoline fuel blends being used, the engine emissions of carbon monoxide (CO) and hydrocarbon (HC) decrease, nitrogen oxides (NO_x) changes little prior to three-way catalytic converter (TWC).

In this work, engine performance and exhaust emission with different methanol–gasoline were investigated. Experiments were performed at different engine speeds which were 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250, 3500, 4000, 4500, and 5000 rpm and wide open throttle.

2. EXPERIMENTAL PROCEDURE AND EQUIPMENT

2. 1. Engine and Equipment

In this study, the experiment were performed on MVH 418, 1796 cc, four cylinder, sixteen valves, four stroke spark ignition gasoline engine that equipped with variable valve timing (VVT) system. The engine specification is given in Table 1.

Table 1. Specification of test engine

Company	FORD Power Product
ENGINE Model	MVH 418
No. of Cylinder	4
Capacity (cc)	1796
Compression Ratio (mm)	10.0 : 1
Cylinder Bore (mm)	80.6
Stroke (mm)	88.0
Maximum Power (kW)	85 (kW) at 5500 rpm
Maximum Torque (Nm)	160 (Nm) at 4400 rpm
Average dry Weight (kg)	116

Table 2. Main characteristics of dynamometer

Company	SAJ TEST PLANT PVT. LTD.
Model	AWM 50 LC
Type	Hydraulic
Max Power (H.P.)	150
R.P.M.	4000 To 7500
Calibration Arm Length (mm)	509.84
Ratio (kg : Nm)	01:05
Weight (kg)	180
FSD (Nm)	280

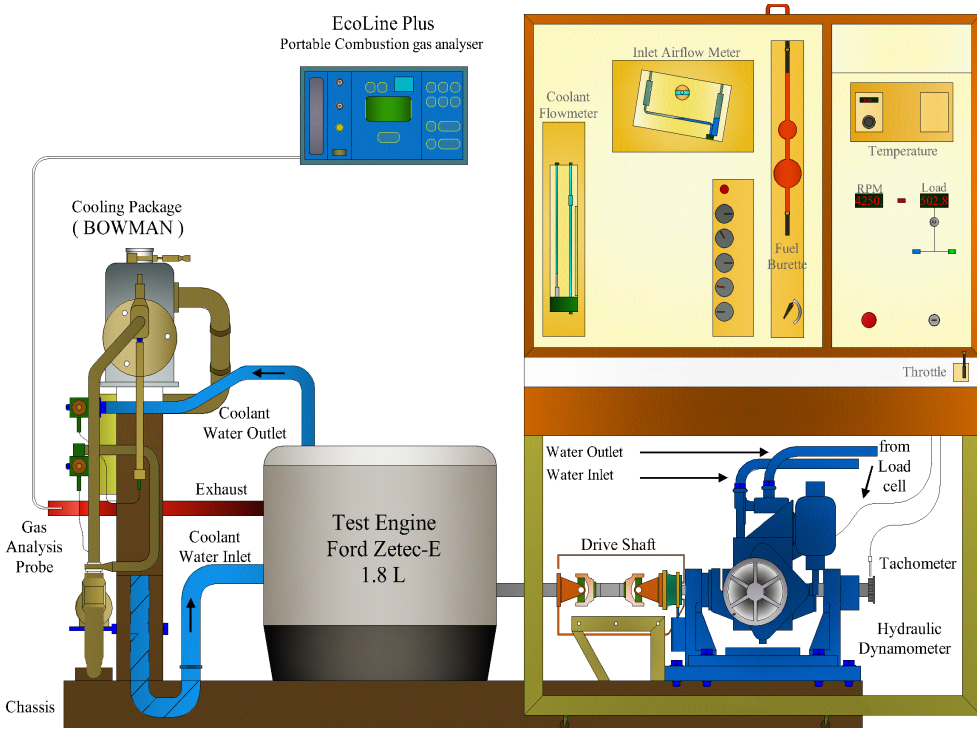

Fig. 1. The schematic diagram of experimental setup

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Table 3. Properties of different methanol-gasoline blended fuels

Property item	accuracy	G	M5	M7.5	M10	M12.5	M15
Density(g/cm³)	0.001 (g/cm³)	0.7682	0.7715	0.7723	0.7737	0.7744	0.775
LHV (kJ/kg)	1 (kJ/kg)	43313	42610	42246	41815	41725	41597
RVP (kPa)	0.1 (kPa)	59.2	83.1	83.5	83.3	83.1	83
MON	0.1	81.6	83.8	84.3	84.4	84.5	84.6
RON	0.1	85.3	87.3	87.9	88	88.1	88.2
Anti-Knock	–	83.45	85.55	86.1	86.2	86.3	86.4
Oxygen(g/cm³)	–	0	1.98	2.98	3.97	4.97	5.96

The engine was coupled to a hydraulic dynamometer (AWM 50 LC) was manufactured by SAJ TEST PLANT PVT. LTD. The dynamometer characteristics is given in Table 2.

The dynamometer is equipped with an instrument cabinet fitted with a Load cell and switched for a load control. The Load cell accuracy is 0.1 N. Fuel consumption was measured by using a calibrated burette and stopwatch with an accuracy of 0.01 s. Air consumption was measured using by orifice plates with corner taps. The concentration of exhaust emissions (HC, CO, CO_2 and NO_x) were measured by using EcoLine Plus portable combustion gas analyser. The accuracy of measurement for CO, CO_2, HC and NO_x is 0.1 %V, 0.01 %V for CO and 1 ppm respectively. Engine performance and exhaust emissions were measured in the Motor and propulsion Laboratory of Department of mechanical engineering of Tarbiat Modares University. The schematic layout of the experimental setup is shown in Fig. 1.

2. 2. Fuels

Six different fuel samples were experimentally investigated during this study. Base gasoline was obtained from the Tehran Oil Refinery Company (TORC). Methanol with the purity of 99.9% was obtained from Merck chemicals. The base gasoline (G) was mixed with methanol (M) to get five test mixtures (5%, 7.5%, 10%, 12.5%, and 15%). The fuel blends were prepared just before starting the experiment to ensure that the fuel mixture is homogeneous. The fuel properties are shown in Table 3.

2. 3. Procedure

The engine was started and allowed to warm up. Engine tested were performed at 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250, 3500, 4000, 4500, and 5000 rpm engine speed at wide open throttle. Before running the engine to a new fuel blend, it was allowed to run for a sufficient time to consume the remaining fuel from the previous experiment.

3. RESULT AND DISCUSSION

3. 1. Brake Torque

The effect of methanol–gasoline blends on the brake

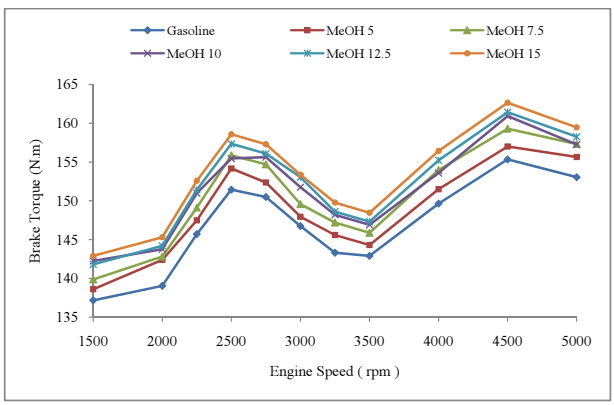

Fig. 2. The effect of addition methanol on the brake torque

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torque is shown in Fig. 2. From Fig. 2, the brake torque increases in methanol percentage for all engine speed. Because of existence of oxygen in methanol chemical component, increase of methanol, produce lean mixtures that decrease equivalence air-fuel ratio (Φ) to a lower value and due to presence of oxygen entered the combustion chamber makes the burning more efficient. The main cause of increase brake torque to 2500 rpm and decrease of the same to 3500 rpm and then, its increase to 4500 rpm is related to the fact that Variable Valve Timing System has been used in this engine.

3. 2. Brake Power

The comparison of brake power for fuel tests is shown in Fig. 3. The brake power increased with the increasing of the methanol content for all engine speeds. The brake power can be attributed to the increase of the indicated mean effective pressure for higher methanol content blends. The heat of evaporation of methanol is higher than that gasoline, this provide air-fuel charge cooling an increases the density of the charge, and thus higher power output obtained.

3. 3. Volumetric Efficiency

The volumetric efficiency of the engine is,

$$\eta_v = \frac{2\dot{m}_a}{\rho_{a,i} V_d N}$$

Where $\dot{m}_a$ is mass air flow rate, $\rho_{a,i}$ is density of the intake air, V_d is displacement volume, and N is engine speed. Fig. 4 shows the relationship between the volumetric efficiency (çv) and the percentage of methanol in the fuel blends. It is obvious from Fig. 4 that as the methanol percentage increases, volumetric efficiency increases, since the amount of air introduced into the engine cylinder increases.

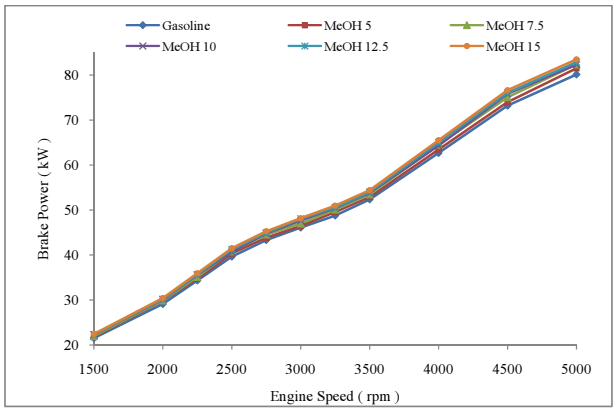

Fig. 3. The effect of addition methanol on the brake power

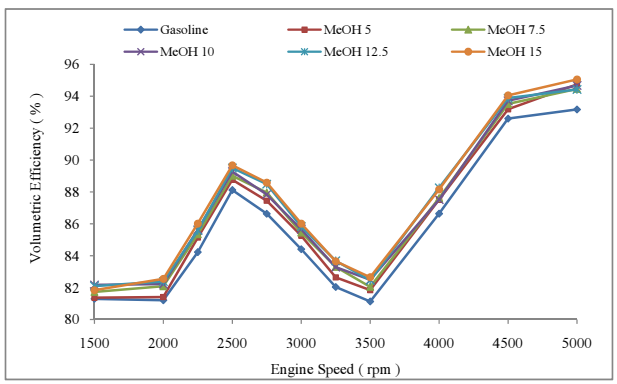

Fig. 4. The effect of addition methanol on the volumetric efficiency

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3. 4. Brake Thermal Efficiency

The thermal effciency of the engine is,

$$\eta_{th} = \frac{P_b}{LHV \times \dot{m}_f}$$

Where P_b is the brake power, LHV is Lower Heat Value of fuel, and $\dot{m}_f$ is the fuel consumption rate . Fig. 5 presents the effect of using methanol–gasoline blends on brake thermal efficiency. As shown in this figure, the brake thermal efficiency increases as the methanol percentage increases. The maximum brake thermal efficiency (çth) was approximately 32.5% when 15% methanol was in the fuel blend. As the methanol percentage increases in the fuel blend, the indicated work increases. As can be seen in Fig. 5, as the engine speed increases reaching 2250 rpm, the brake thermal efficiency increases reaching its maximum value. Thermal efficiency and bsfc have reverse behavior. Because of this, maximum of the thermal efficiency occurs in the speed of the engine which has the least bsfc.

3. 5. Brake Specific Fuel Consumption

The brake specific fuel consumption (bsfc) is the fuel flow rate per unit power output and is defined as

$$\eta_{th} = \frac{P_b}{LHV \times \dot{m}_f}$$

Where P_b is the brake power. The effect of using methanol–gasoline blends on brake specific fuel consumption (BSFC) as can be seen in Fig. 6. As shown in this figure, the bsfc decreases as the

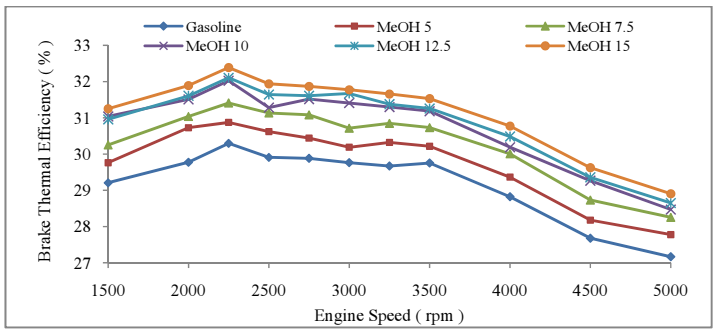

Fig. 5. The effect of addition methanol on the brake thermal efficiency

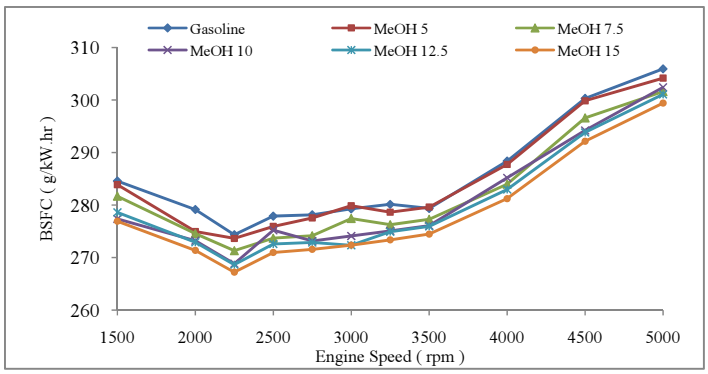

Fig. 6. The effect of addition methanol on the brake specific fuel consumption

Table 4. Stoichiometric Air-Fuel Ratio of methanol-gasoline blends (vol%)

Methanol%	0	5	7.5	10	12.5	15
$(A/F)_{st}$	14.7	14.2865	14.0797	13.8729	13.6661	13.4594

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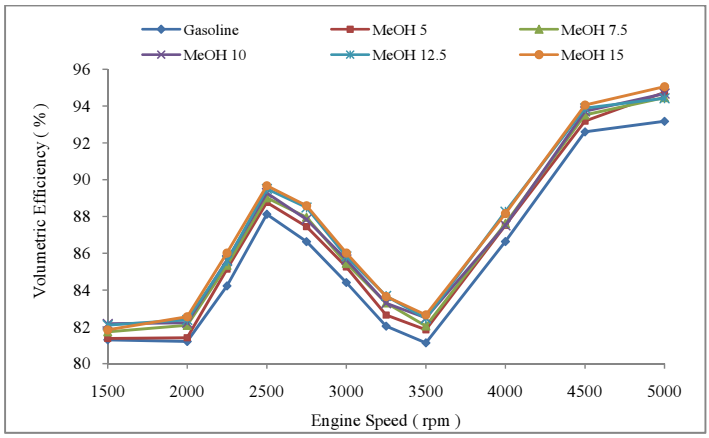

Fig. 7. The effect of addition methanol on the equivalence air-fuel ratio

methanol percentage increases. This is a normal consequence of the behavior of the engine brake thermal efficiency shown in Fig. 5. On the other hand, as the engine speed increases to 2250 rpm the bsfc decreases. This is due to increase in brake thermal efficiency.

3. 6. Equivalence Air-Fuel Ratio

The Equivalence Air-Fuel Ratio is defined as ,

$$\Phi = \frac{(A/F)_{st,blend}}{(A/F)_{actual,blend}}$$

$(A/R)_{st}$. is stoichiometric air–fuel ratios and $(A/R)_{act}$ is actual air–fuel ratios of the test fuels. The effect of methanol–gasoline blends on equivalence air-fuel ratio is shown in Fig. 7. It is obvious from Fig. 7 the equivalence air-fuel ratio decreases as the methanol increases. This is due to the decrease in the stoichiometric air-fuel ratio of the fuel blend (as can be seen in Table 4) and the increase of actual air-fuel ratio of the blends as a result of the oxygen content in methanol.

3. 7. CO Emission

The effect of the methanol–gasoline blends on CO emission for different engine speeds is shown in Fig.8. It can be seen that when methanol percentage increases, the CO concentration decreases. This can explained by the enrichment of oxygen owing to the methanol, in which an increase in proportion of oxygen will promote the further oxidation of CO during the engine exhaust process. Another significant reason of this reduction is that methanol (CH_3OH) has less carbon than gasoline (C_8H_{18}). At the 2250 rpm fuels showed lower CO emissions. It can attributed to the enriched O_2 in the combustion chamber

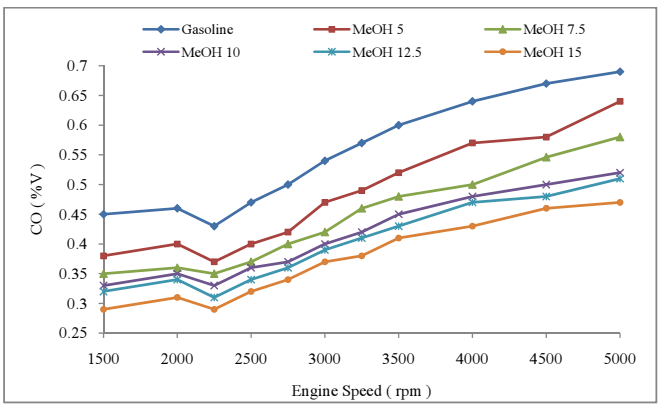

Fig. 8. The effect of addition methanol on CO emission

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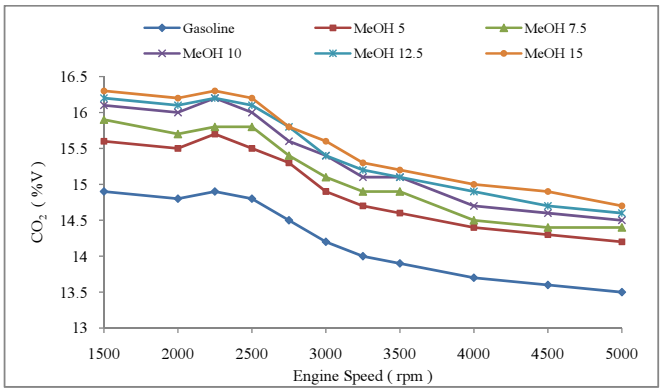

Fig. 9. The effect of addition methanol on CO2 emission

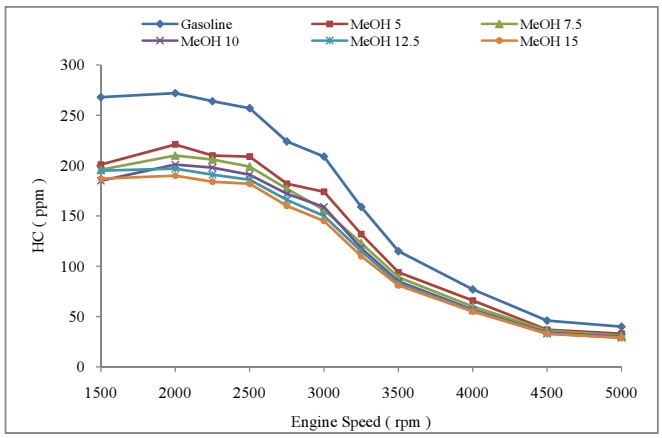

Fig. 10. The effect of addition methanol on HC emission

accompanied by sufficient turbulence created by increased mean piston speed.

3. 8. CO_2 Emission

The effect of the methanol–gasoline blends on CO_2 emission for different engine speeds is shown in Fig. 9. It can be seen that when ethanol percentage increases, the CO_2 concentration increase. The increase in CO_2 concentration is due to improve combustion.

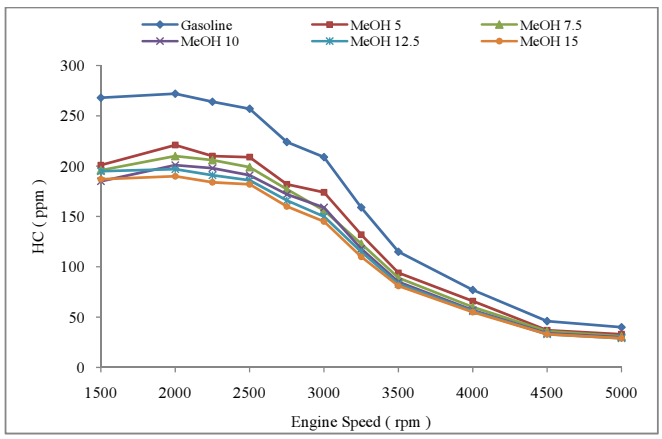

Fig. 11. The effect of addition methanol on NOx emission

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3. 9. HC Emission

The effect of the methanol–gasoline blends on HC emission for different engine speeds is shown in Fig. 10. It can be seen that when methanol percentage increases, the HC concentration decreases. The concentration of HC emission decreases with increase of the relative air-fuel ratio, the reason for the decrease of HC concentration is similar to that of CO concentration described above.

3. 10. NO_x Emission

The effect of the methanol–gasoline blends on NO_x emission for different engine speeds is shown in Fig. 11. It can be seen that when methanol percentage increases, the NO_x concentration increase. When combustion process is closer to stoichiometric, flame temperature increases, therefore, the NO_x emission is increased.

4. CONCLUSION

In this study, it was seen that when engine was fueled with methanol–gasoline blend, engine performance parameters such as brake torque, brake power, brake thermal efficiency, volumetric efficiency increases with increasing methanol amount in the blended fuel while bsfc and equivalence air-fuel ratio decreased.

Since the latent heat of evaporation of ethanol is higher than that of gasoline, during compression process, the fuels containing methanol will absorb more heat from combustion chamber and eventually, the pressure of the combustion chamber will be decreased accordingly. Relying on above statements, during the compression process, the pressure of such combustion chamber will be decreased compared with when pure gasoline is used in combustion.

On the other hand, due to presence of oxygen entered the combustion chamber during expansion process and after combustion of fuel and upon improvement of combustion, the pressure of the expansion process will be increased as well. Hence, the work of compression process, which is a negative work, will be decreased and that of the expansion process that is a positive work, will be increased for that reason. Consequently, upon increase of enclosed area in the pressure-volume curve, the work done by the engine will be increased in case of use of the fuel containing methanol and finally, the indicated mean effective pressure will be increased as well. Therefore, brake power will be increased.

Using methanol–gasoline blends lead to a significant reduction in exhaust emissions by about 24.9% and 23.7% of the mean average values of HC and CO emissions, respectively, for all engine speeds. On the other hand CO_2 and NO_x emissions increases by about 7.5% and 17.5% respectively.

5. ACKNOWLEDGEMENTS

The authors wish to thank the Motor and Propulsion Laboratory of Tarbiat Modares University for providing of laboratory and Tehran Oil Refinery Company (TORC) for providing us base gasoline.

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