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The Effects of Ethanol-Gasoline, Methanol-Gasoline and Ethanol-Methanol-Gasoline Blends on Engine Performance, Combustion Characteristics, and Exhaust Emissions

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---*ABSTRACT*---

An experimentally study were carried out to investigate the effect of methanol and/or ethanol blends with gasoline on the combustion characteristics,engine performance and pollutant emissions. The blends including up to 15% by volume of alcohol and pure gasoline were used as test fuels in a four stroke, single cylinder, spark ignition (SI) engine. Experiments were performed at similar operating conditions under wide open throttle (WOT) operating conditions with varying engine speeds between 1200 and 1800 rpm. The test results showed that the average change in engine brake power, brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), volumetric and combustion efficiencies within all engine speed and all blends rates by 4.63%, 4.91%, 1.46%, 13.5% and 0.27% for methanol-ethanol-gasoline blends, respectively. The calculated average reduction for all speeds and all blends rate in CO, HC, and NOx emissions were found as 7.56%, 16.02% and 8.17% for methanol-ethanol-gasoline blends, respectively. The results demonstrated that the pure gasoline has minimum cylinder pressure than blended fuel and increasing the rate ethanol and/or methanol in blends resulted in an increase of the maximum cylinder pressure. It was found that the alcohol content increases in the fuel blend caused also the higher the heat release rate (HRR) and thus the shorter the combustion duration. In addition, the ignition timing for the alcohol blends advanced to achieve maximum brake torque (MBT) conditions

KEYWORDS: *Performance; Pollutant emissions;Gasoline; Ethanol; Methanol; Blends; Spark-ignition engine*

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I. INTRODUCTION

Developing alternative fuels for internal combustion engines is one of most attractive research topic for scientist and engineers.The use of alcohol and their blends as fuels has been a popular subject of research sincethe 1970s[1-5]. Currently, alcohols are the most popular additives as octane boosters and as a partially oxidized fuel in gasoline fuel. In literature, there are several recent studies on the usage of ethanol andmethanol blending with gasoline in SI engines[6-18].

In some studies, the effects of methanol blends with gasoline on the performance and exhaust emissions of SI engines were investigated [6,9,14]. M. Abu-Zaid et al.[6]found that the methanol mixture has a significant impact on improving the performance of SI engines and also increases the octane number. Bilgin and Sezer [9]concluded that M5 fuel blend was given the maximum brake mean effective pressure (BMEP). Shenghua et al. [14]concluded that the methanol ratio increase in the gasoline blends decreased the engine power, and torque while the BTE increased. In other some studies, the effects of ethanol blends with gasoline on engine performance and exhaust emissions were investigated [10,13,15]. Koc et al. stated that the engine torque, power, and BSFC increases, while the emissions of CO, NOx and HC decreases with the higher ethanol concentration in the blends compared with the gasoline. Schifter et al. [15]investigated the effect of ethanol-gasoline blends containing up to 20vol% ethanol on engine performance and exhaust emissions.They found that ethanol in the blends of 20 vol% was slowed down the rate of burning and the cyclic variation was increased.Another study reported that the use of hydrous ethanol cause higher BSFC and higher thermal efficiency than the gasoline-ethanol blend for the range of all operating speeds[10].The effects of methanol and/or ethanol blended gasoline on engine performance and exhaust emissions have investigated in a number of studies [19-22]. In a limited number of studies, the effect of ethanol and methanol blends with gasoline on the combustion characteristics of SI engines have investigated [15,20].The effects of adding at low ratios of methanol and ethanol to gasoline on thecombustion characteristics, engine performance and exhaust-gas emissions were experimentally investigated[19].Their results showed that the ethanol-gasoline blends have higher BSFC compared with pure gasoline. They also found that the combustion pressure rise was noted to occur later than gasoline fuel, and the lowest peak heat release rate was obtained in the gasoline study.Balki et al.[20]revealed that the engine torque, BSFC, BTE and combustion efficiency increased, the emissions in CO, HC, and NOx also decreased when using alcohol blended gasoline instead of pure gasoline.Moreover,the cylinder pressure and heat release rate (HRR) occurred earlier.Turner et al. [21]investigated the effect of ethanol-methanol-gasoline blends on NOx and CO_2 emissions. They found that dual fuel blends can reduce the CO_2 and NOx emissions than pure gasoline.Elfasakhany [22] investigated experimentally the effects of different ternary blendsonthe performance and pollutant emissions of an SI engine.He found that the torque, brake power, and volumetric efficiency was increased, while exhaust emissions of HC and COwere decreased at using ethanol-methanol-gasoline fuel blends, compared to other blended fuels.

It can be realized from the literature that several studies were conducted on the use of ethanol or methanol and their blends with gasoline as fuel in SI engines.However, there are very few studies[23,22,24,21]on the usage of methanol-ethanol-gasoline blends in SI engines. Even, there was no study on the effect of methanol-ethanol-gasoline blends on combustion characteristics. For this reason, the effects of methanol-ethanol-gasoline blends containing up to 15 vol% alcohol on combustion characteristics were experimentally investigated in an SI engine without any modification in this study. For this purpose, the effects of the methanol and/or ethanol blends with gasoline on engine performance (volumetric efficiency, combustion efficiency, torque, and brake power), combustion characteristics (cylinder pressure, HRR and mass fraction burned) and the exhaust emissions (CO, NOx, and HC) were examined. In addition, the results obtained with methanol-ethanol-gasoline blends were also compared with the results of pure gasoline and the commonly used methanol–gasoline and ethanol-gasoline blends

II. EXPERIMENTAL METHODS

Some properties of methanol, ethanol, and gasoline were given in Table 1. The octane number of methanol and ethanol has higher than gasoline. This allows operates the engine in higher compression ratios, and so obtaining higher thermal efficiency. Compared with gasoline, methanol and ethanol contain oxygen, the oxygen content enhances the combustion process and that leads to decrease the CO and UHC emissions and increase the CO_2 emissions. The methanol and ethanol compared to gasoline have a higher heat of evaporation, this causes a lower combustion temperature, hence decreases brake power and torque; but the higher volumetric efficiency cause to improve fuel combustion and, in turn, increase brake power and torque. Nevertheless, as a significant disadvantage of methanol and ethanol has lower energy content according to gasoline. This causes higher BSFC.

The methanol-gasoline, ethanol-gasoline, methanol-ethanol-gasoline blends, and gasoline were tested as fuels in the experiments. The methanol and ethanol purchased from MERCK at 99% purityfor preparing blends were used. The methanol, ethanol and methanol-ethanol blends with gasoline were prepared with a concentration of 5%, 10% to 15% alcohol to 95%, 90%, and 85% gasoline on a volume basis in this study. The properties of the selected blends were listed in Table 2.The schematic layout of the experimental setup was shown in Fig. 1. The specifications of the test enginewerealso summarized in Table 3.The experiments were conducted under WOTconditions, and at this throttle position, the engine speeds were varied (1200-1800 r/min) in therange of 200 r/min to evaluate the engine exhaust emissions and performance. The experiments for the combustion characteristics were done at a moderate engine speed of 1500 rpm.The spark was optimized to MBT spark timing in all engine tests. Performance, combustion, and emission data were measured under stoichiometric conditions. The portable TESTO 350 XL Flue Gas Analyzer and the K-TEST exhaust gas analyzer were used to measure the pollutant emissions of HC, CO, and NOx.The measurement details in HC, CO, and NOx emissions were given in Table 4.

In this study, brake power (Bp) obtained at the crankshaft was calculated by the following expression:

$$B_P = \frac{2\pi NT}{60X1000} \quad 1$$

where Bp is the brake power (kW); N is the engine speed(rpm); T is the engine torque (N-m).
BTE was computed by

$$\eta_{b,th} = \frac{B_P}{\dot{m}_f\ LHV_f} \quad 2$$

where $\eta_{b,th}$ is brake thermal efficiency (%); $\dot{m}_f$ is fuel rate into the cylinder(kgs^{-1}). LHV_f is the lower heating value of the fuel ($kJkg^{-1}$).
BSFC can be defined as the ratio between the fuel massconsumption rate per brake power output and is expressed as

$$BSFC = \frac{3600x\dot{m}_f}{B_P} \quad 3$$

where BSFC is the brake specific fuel consumption($gkW^{-1}hr^{-1}$).
The volumetric efficiency (η_v) of four stroke engine was defined by

$$\eta_v = \frac{120\dot{m}_a}{\rho_a V_d N} \quad 4$$

where $\dot{m}_a$ is air induction rate into the cylinder(kgs^{-1}), ρ_a is inlet manifold air density at standard temperature and pressure(kgm^{-3}). V_d is the volume displacement of the engine (m^{-3}).
The combustion efficiency (η_c) can be calculated with using the exhaust emission values by the following formula;

$$\eta_c = \frac{H_R - H_P}{\dot{m}_f LHV_f} \quad 5$$

where η_c is combustion efficiency (%);H_P is enthalpy of exhaust gases (products); H_R is enthalpy of fuel and air(reactants).
The measurements were repeated for at least three times and the averaged values were consideredas final results to minimize the experimental uncertainties. The uncertainties in the calculated results and measurement accuracies were given in Table 5.The uncertainty of the calculated variables (Equations 1-5) was performed using the Root Sum Square (RSS) method [25].

III. RESULTS AND DISCUSSIONS

3.1. Engine performance and combustion characteristics

The effects of lower alcohol (5% to 15%, methanol and/or ethanol) blends with gasoline on the performance, emission and combustion characteristics of a single cylinder, SI engine wereobserved at WOT condition and variable speeds from 1200 to 1800 rpm.Figure 2 shows the variations in the brake power with theengine speed for the test fuels. This figure shows that the brake power increases with engine speed. In addition, as the methanol and/or ethanolratio in the blend increases, the power increases slightly. The average change in brake power within all engine speed and all blends rates by 3.34% for methanol blends, 4.52% for ethanol blends and 4.63% for methanol-gasoline blends, respectively. The higher increase in brake power using ethanol, methanol and methanol-ethanol blends with gasoline by 8% (G85E15;1800 rpm), 7.45% (G85M15;1800 rpm) and 6.18% (G85M5E10;1800 rpm) respectively as compared to gasoline. Previous studies reported similar trends. For example, Elfasakhany [22] found that the average change in the brake power for all blends rate (3-10%) at 3400 rpm were 8.52% for ethanol-gasoline, 6.28% for methanol-gasoline and 5.6% for methanol-ethanol-gasoline blends compared to pure gasoline. Figures 3 and 4 present the effect of using methanol-gasoline, ethanol-gasoline and methanol-ethanol-gasoline blends on BTE andBSFC, respectively. As shown in Figure 3, the BTE increases slightly as the methanol and / or ethanol content increases.The average change in BTE within all engine speed and all blends rates by 2.55% for methanol blends, 0.71% for ethanol blends and 1.46% for methanol-ethanol-gasoline blends, respectively.These trends agreed with the results of reported by Balki et al.[20]. They explained the reason of the having higher BTE of the alcohol-gasoline blends as the oxygen content and the heat of vaporization of alcohol. As shown in Table 2, the oxygen content of the G85M15, G85E15 and G85M5E10 blends have calculated 16.14%, 15.8%,and 15.91%, respectively.Figure 4 shows thatBSFC dramatically increases as the percentage of alcohol increases because the methanol and ethanol have relatively lower calorific values than gasoline. The average change in BSFC within all engine speed and all blends rates by 3.93% for methanol blends, 3.17% for ethanol blends and 4.91% for methanol-ethanol-gasoline blends, respectively.Ethanol and methanol contain an oxygen atom; Because of this, they have lower stoichiometric fuel-to-air ratios and heating valuesthan gasoline as shown in Table 2.As a result, when ethanol and/or methanol blends with gasoline are used instead of pure gasoline, more fuel is required to achieve the same performance.There is a consensus in the results of studies in the literature agreed that alcohol-gasoline mixtures increase BSFC.Figure 5 and 6 shows the effect of using methanol-gasoline, ethanol-gasoline and methanol-ethanol-gasoline blends on volumetric efficiency and combustion efficiency, respectively.The volumetric efficiency decreased with an increased engine speed for all fuel blends due to the residual gases in the charge andthe hot engine parts. As shown in Figure 5, volumetric efficiency increases significantly when using analcohol-gasoline blend.The heat of vaporization of methanol and ethanol are higher than that of gasoline; therefore, this reduces the intake air temperature and thus increases the density of inlet air and consequently the volumetric efficiency.The average change in volumetric efficiency within all engine speed and all blends rates by 13.06% for methanol blends, 7.69% for ethanol blends and 13.5% for methanol-gasoline blends, respectively.The higher increase in volumetric efficiency achieved by using ethanol, methanol and methanol-ethanol blends with gasoline by 22.12% (G85M15;1800 rpm), 16.30% (G85E15;1800 rpm) and 20.59% (G85M10E5;1800 rpm) respectively as compared to gasoline.The observations agreed with the experimental results in literature[7,23,15].As can be seen in figure 6, the combustion efficiency is very little higher than pure gasoline for all blends. The average change in combustion efficiency for methanol-gasoline, ethanol-gasoline, and methanol-ethanol-gasoline blends compared with gasoline calculated as 0.29%, 0.25% and 0.27, respectively, at within all engine speed and all blends rates. Primarily presence of oxygen can be considered as areason for increments in combustion efficiencies further it is validated by thehigher blending of methanol and/or ethanol.

3.2. Combustion Characteristics

Figure 7-9 shows the variations of the cylinder pressure, MFB, and HRR with crank angle for the pure gasoline and various alcohol blends with gasoline. It can be seen from these figures that the pure gasoline has minimumcylinder pressurethan blended fuel. The maximum cylinder pressure for puregasoline is 6.28 MPa. However, the same figuresshow thatincreasing the methanol percentage (5%, 10%, and 15%)results in anincrease of the maximum pressure to avalue of 6.36, 6.50 and 6,66 MParespectively.Figures 8 shows that increasing the ethanol percentage (5%, 10%, and 15%) results in an increase of the maximum pressure to a value of 6.29, 6.47 and 6,57 MPa, respectively.The maximum cylinder pressure for G90M5E5, G85M5E10, and G85M10E5 are 6,45 MPa, 6,53 MPa, and 6,50 MPa respectively.It can be also seen from figure 7-9, the minimum HRR occurs for pure gasoline. Adding of methanol, ethanol, and methanol-ethanol to gasoline caused the maximum HRR occurs more early than pure gasoline. This is because the flame speed increases to some extent thereby with the addition of alcohol.Figures 7-9 clearly shows that the MFB curve and pressure traces as a function of the crank angle. The higher alcohol content in the fuel blend causes the higher the heat release rate and thus the shorter the combustion duration. The maximum heat release rate for pure gasoline is 13,55 J/deg. The maximum heat release rate increased to 13,55 J/deg, 13,60 J/deg and 13,49 J/deg for methanol, ethanol, and methanol-ethanol blends, respectively.In addition, the ignition timing for the alcohol blends advanced about 1.5 degrees to achieve MBT conditions

3.3. Exhaust emissions

Figures 10–12 show the effect of gasoline and various alcohol-gasoline blends on HC, CO,and NOx emissions, respectively. As shown in Figures10-12, the addition of methanol and/or ethanol to gasoline significantly reduced the emissions of HC,CO, and NOx.CO and HC emissionsare products of incomplete combustion of fuel. The methanol, ethanol and methanol-ethanol blends with gasoline have wide flammability range and oxygen content to compare with pure gasoline. This allows blends to burn more completely. This increases the combustion efficiency and reduces CO and HC emission. The calculatedaverage reduction for all speeds and all blendsin CO emissions was 31.55%, 21.34% and 31.4% for methanol-gasoline blends, ethanol-gasoline blends, and methanol-ethanol-gasoline blends, respectively.The calculated average reduction for all speeds and all blends in HC emissions was 17.56%, 16.02% and 16.37% for methanol-gasoline blends, ethanol-gasoline blends, and methanol-ethanol-gasoline blends, respectively. These trends agreed with the previous studies. Yuksel and Yuksel stated that the CO and HC emissions for ethanol gasoline blends operation reduced by approximately 80 and 50%, respectively compared to gasoline fuel.Shanmugam et al. stated that a decrease in CO emission by 13% and HC emissions by 19% for 10 vol% ethanol-gasoline blends. Yanju et al. [26]concluded that the CO emission decreases with increasing methanol ratio in gasoline, and the reduction was 25% for M85. Elfasakhany[23]showed that the emissions of HC and CO with the addition of 3 vol.% ethanol and methanol to gasoline decreased by about 10% and 17%, respectively when compared with pure gasoline. NOx emissions in the exhaust are related tooxygen concentration,combustion temperature, and also time. The charge temperature at the end of intake stroke decreases due to the high latent heat of vaporization of the methanol and/or ethanol, and this cause in a low combustion temperature, so NOx formation is significantly reduced. The calculated average reduction in NOx emissions for all speeds and all blends was 7.68%, 5.85% and 8.17% for methanol-gasoline blends, ethanol-gasoline blends, and methanol-ethanol-gasoline blends, respectively.Many studies in the literature have shown that NOx emission decreases related with increasing ratio of alcohols[27,28,26,29]. Yanju et al [26] claimed that with increasing fraction of methanol in gasoline, the NOx emission decreases and the reduction is 80% for M85. Zervas et al.[29]stated that ethanol added to gasoline reduced NOx emissions. They explained this reduction in NOx emissions as the addition of oxygenated compounds.Lin et al. [27]reported a considerable reduction of NOx emissions by 35%, 86% and 77%, respectively, with blends containing 3%, 6% and 9% ethanol.Turner et al. indicated a reduction in NOx emissions when the ethanol ratio in the blend was increased to 85%.In contrast, some studies have shown that alcohol blends increase NOx emissions[30,31]. For example, Shanmugam et al. [31] showed that a net increase in NOx emission by 16%, with 10 vol% ethanol-gasoline blends. Another study revealed an increase in NOx concentration when ethanol was added[30]. Otherwise, few kinds of literature[32,33] also found no any significant change in NOx emission with adding alcohol to gasoline. For example, Jia et al.[33] revealed that the gasoline blends containing %10 ethanol were not caused by a significant change in NOx emission as compared with the gasoline. Similarly, Jeuland et al [32] also indicated that no significant change in NOx emissions for ethanol-gasoline blends.

IV. CONCLUSIONS

In this study, the effects of the gasoline blends containing up to 15 vol%methanol and/or ethanol on the combustion characteristics,performance, and exhaust emissions of a single cylinder SI engine have been studied. The results of this experimental study can be summarized as follows:

1. The engine reached to maximum brake power at 1800 rpm for all test fuels, and the highest increase in brake power has been obtained from the methanol-gasoline blends. The alcohol fuels have alsoshown in the better engine performance at higher engine speeds.
2. Adding of methanol and methanol to gasoline has slightly increased the combustion efficiency, while significantly increased the BSFC. On the other hand, the methanol-gasoline blends have more significantly increased BSFC than ethanol-gasoline and methanol-ethanol-gasoline blends.The increase in BSFC in the average basis within all engine speed and all blends rate for methanol-gasoline, ethanol-gasoline, and methanol-ethanol-gasoline blends compared with the gasoline case have been found as 3.93%, 3.17%, and 4.91%.
3. The combustion efficiencies have obtained to be higher for the methanol-gasoline studies when compared to the gasoline, ethanol-gasoline and methanol-ethanol-gasoline studies.
4. It has been found that the pure gasoline has minimum cylinder pressure than blended fuel. In addition, increasing the rate of methanol and/or ethanol in blends has resulted in an increase of the maximum cylinder pressure.
5. The addition of methanol, ethanol,and methanol-ethanol to gasoline has been caused the maximum heat release rate occurs more early than pure gasoline. The higher alcohol content in the fuel blend has been caused also the higher the HRR and thus the shorter the combustion duration. In addition, the ignition timing for the alcohol blends have been advanced to achieve MBT conditions
6. The emissions of CO, HC and NOx have reduced with the addition of alcohol to gasoline due to improved combustion. When methanol-gasoline, ethanol-gasoline and methanol-ethanol-gasoline blends used in the engine compared to the gasoline study.The reductions in the emissions of CO, HC and NOx in average basis were by 31.55%, 17.56%, and 7.68%; 21.34%, 16.02%, and 5.85%; 31.4%, 16.37%, and 8.17%, respectively.
7. The desirable results for the pollutant emissions and the engine performance (higher brake power) were obtained with methanol gasoline, methanol-ethanol-gasoline and ethanol gasoline mixtures respectively.
8. Studies in the literature and above study reveals that alcohol-gasoline blends provide environmentally safer emission and improve engine efficiencies output depending on operating conditions and the nature of the engine.

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TABLE CAPTIONS

Table 1. Comparison of Fuel Properties [22,34]
Table 2. Calculated properties of alcohol-gasoline blends
Table 3. Specifications of test engine
Table 4. Uncertainties in the exhaust measurements
Table 5. Measured and calculated uncertainties in engine test

Table 1. Comparison of Fuel Properties [22,34]

Property	Methanol	Ethanol	Gasoline
Molecular Weight (kg/kmol)	32.041	46.068	95-120
Oxygen Content (wt%)	49.93	34.72	-
Density (g/cm^3)	796	790	760
Latent heat of vaporization at 20 ^{o}C (kJ/kg)	1147	873	307
Stoichiometric air/fuel ration (AFR)	6.5	9.0	14.6
Lower heating value (kJ/kg)	20050	26950	43000
Motor Octane Number (MON)	92	89	80-91
Research Octane Number (RON)	106	107	92-99

Table 2. Calculated properties of alcohol-gasoline blends

Blends	Gasoline,%	Methanol,%	Ethanol,%	CV(kJ/kg)	Oxygen,%	AFRs
G95M5	95	5	-	41852,5	14,95	14,20
G90M10	90	10	-	40705	15,52	13,79
G85M15	85	15	-	39557,5	16,14	13,39
G95E5	95	-	5	42197,5	14,85	14,32
G90E10	90	-	10	41395	15,31	14,04
G85E15	85	-	15	40592,5	15,80	13,76
G85M10E5	85	10	5	39902,5	16,02	13,51
G85M5E10	85	5	10	40247,5	15,91	13,64
G90M5E5	90	5	5	41050	15,41	13,92

Table 3. Specifications of test engine

Type	1 cylinder, four strokes, water cooled
Cylinder bore and stroke, mm	87.5;110
Compression ratio	6-10
Cylinder volume, cm^3	661
Maximum power	4.5 kW at 1800 rpm
Spark variation range	0-70 deg bTDC
Dynamometer	Eddy current, water cooled, with loading unit
Speed range, rpm	1200-1800
Air flow transmitter	Pressure Transmitter, Range (-) 250 mm WC
Fuel flow transmitter	DP Transmitter, Range 0-500 mm WC
Sofware	Engine soft (Labview)
Piezo sensor	Make PCB, Range 350 bar
Data acquisition device	NI USB-6210

Table 4. Uncertainties in the exhaust measurements

	Range	Accuracy	Resolution	Measurement Principle
CO	0-500 ppm	± 2 ppm (0-39.9 ppm) ± 5% of mv (40-500ppm)	0.1 ppm	electrochemical cells
NO	0-3000 ppm	± 5 ppm (0-99 ppm) ± 5% of mv (100-1999.9 ppm) ± 10% of mv (2000-3000 ppm)	1 ppm	electrochemical cells
NO_2	0-500 ppm	± 5 ppm (0-99.9 ppm) ± 5% of mv (100-500 ppm)	0.1 ppm	electrochemical cells
HC	0-5000 ppm	±0.5% of ind value	1 ppm	NDIR(Non-dispersive infrared)

Table 5. Measured and calculated uncertainties in engine test

Measurements	**Accuracy**
Torque	<±0.3%
Speed	±1 rpm
$\dot{m}_h$	<±0.2%
$\dot{m}_y$	<±0.25%
Calculated Parameters	**Uncertainty**
Power (kW)	<±1%
BSFC (gr/kWh)	<±1%
$\eta_{b,to}$	<±1%
η_v	<±0.5%
η_c	<±0.1%

FIGURE CAPTIONS

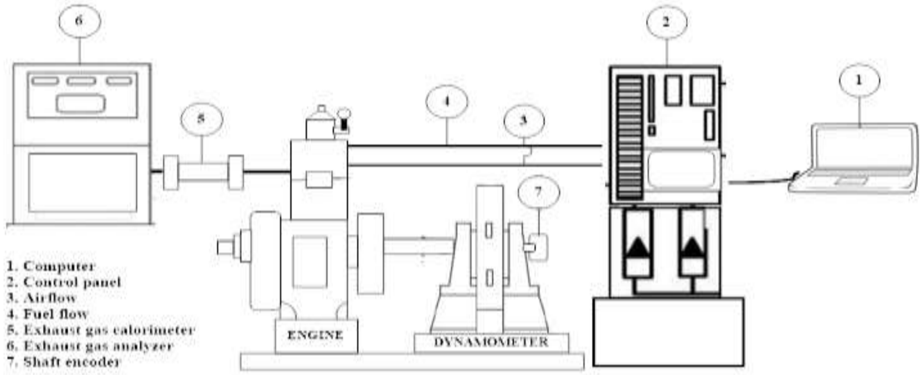

Figure 1. Schematic diagram of test engine arrangement

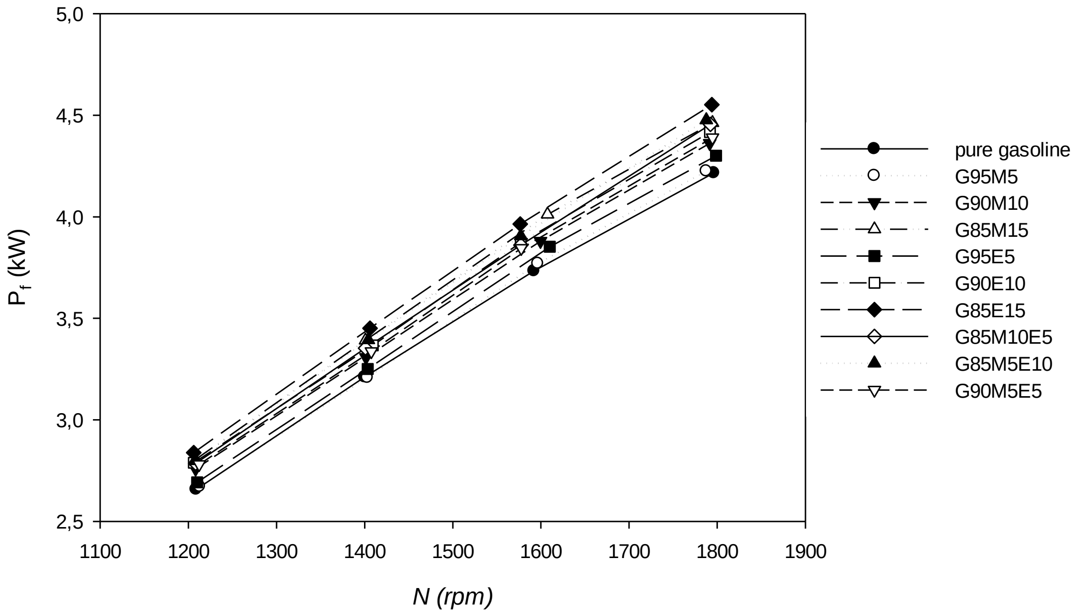

Figure 2. Variation of brake power with engine speed for the test fuels.

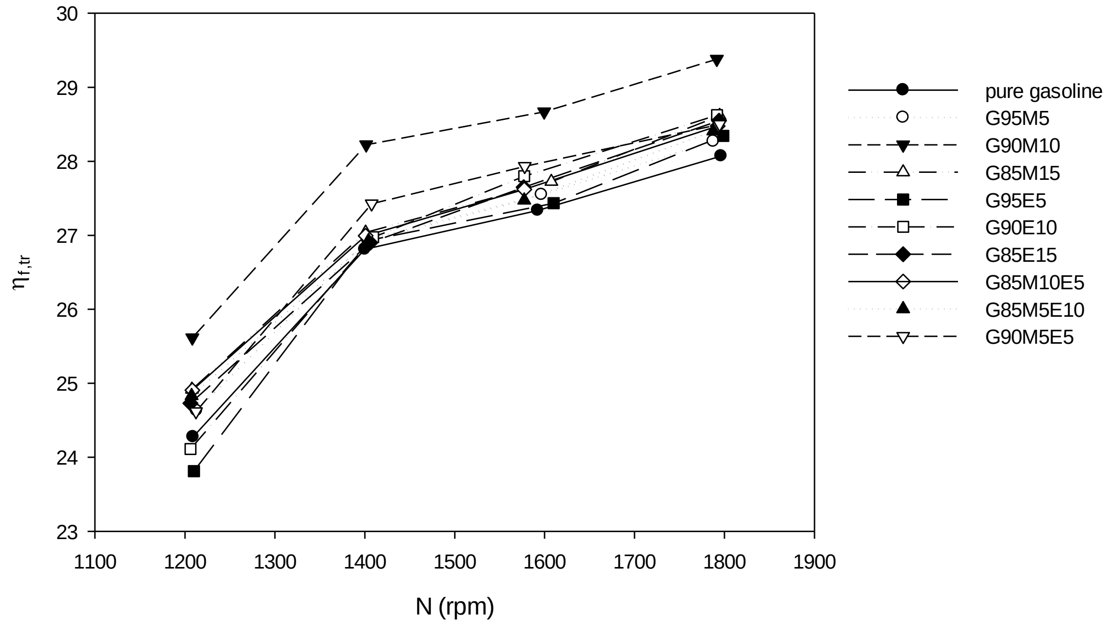

Figure 3. Variation of BTE with engine speed for the test fuels.

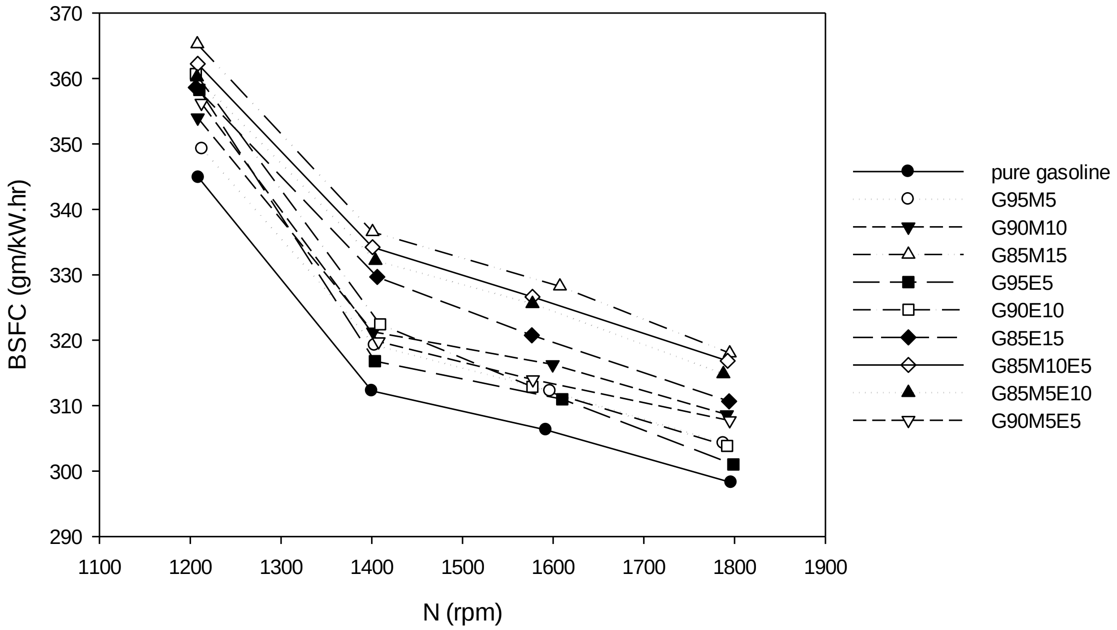

Figure 4. Variation of BSFC with engine speed for the test fuels.

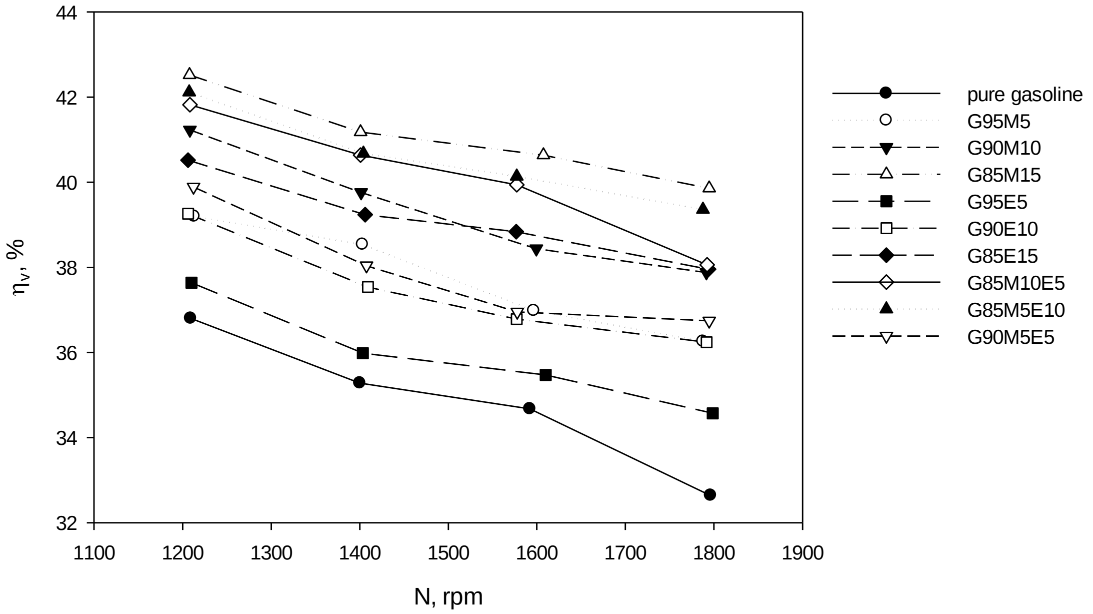

Figure 5. Variation of volumetric efficiency with engine speed for the test fuels.

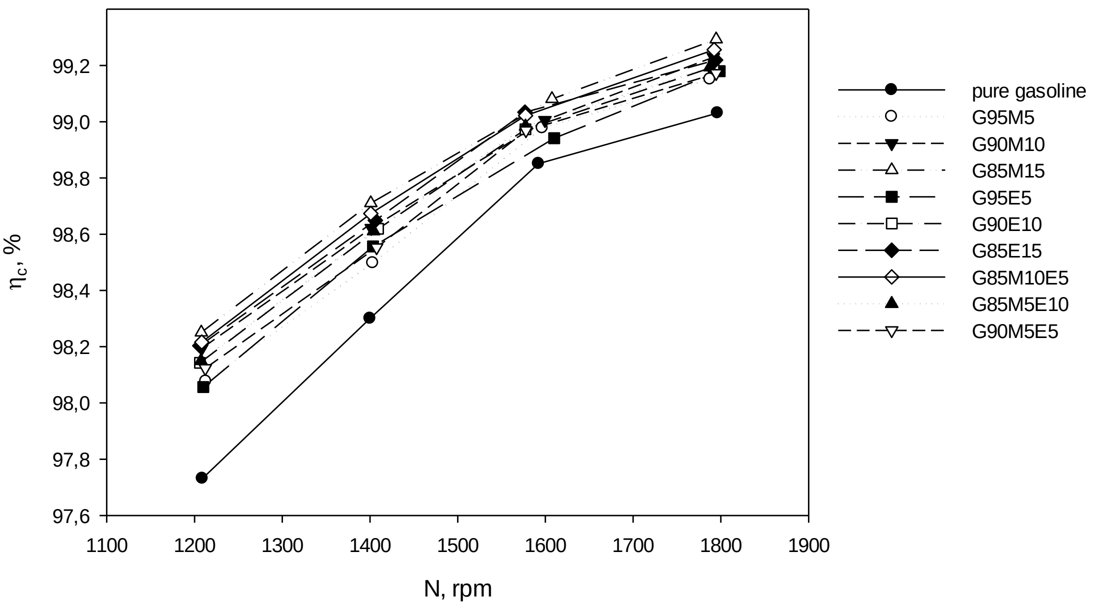

Figure 6. Variation of combustion efficiency with engine speed for the test fuels.

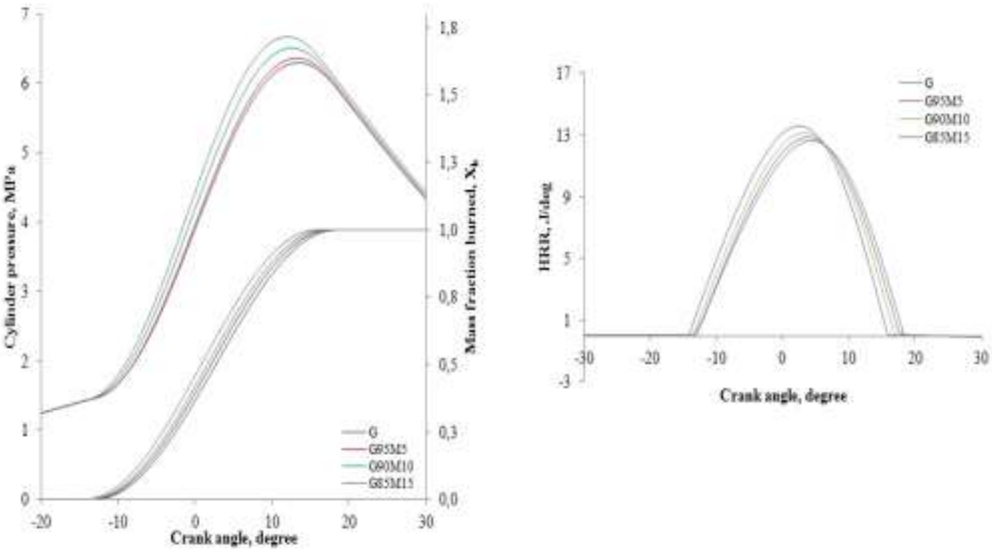

Figure 7.In-cylinder pressure, MFB and HRR for different methanol -gasoline blends

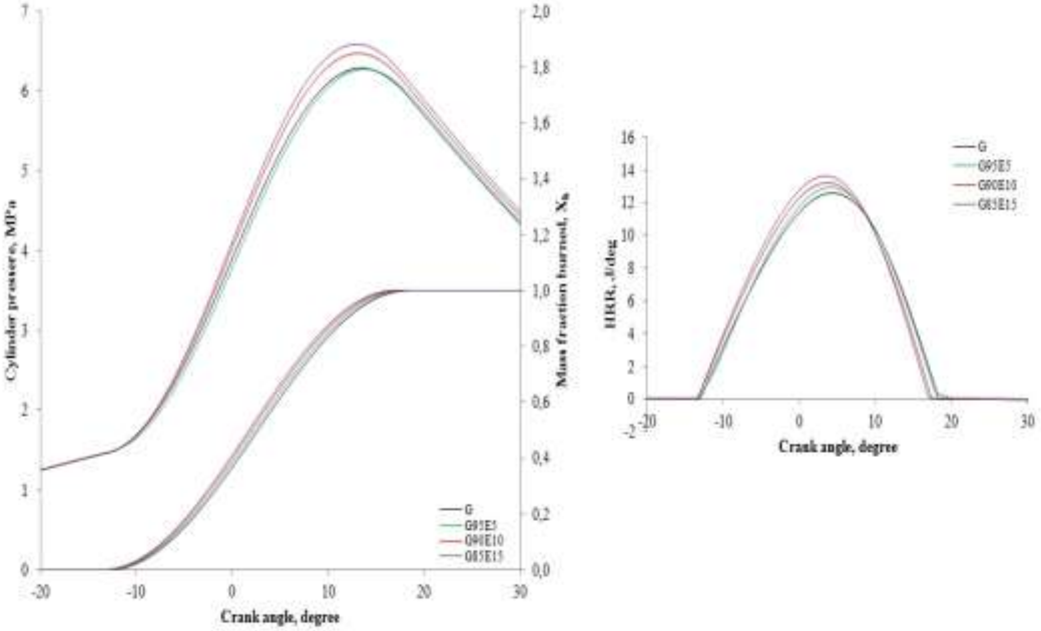

Figure 8.In-cylinder pressure, MFB and HRR for different ethanol -gasoline blends

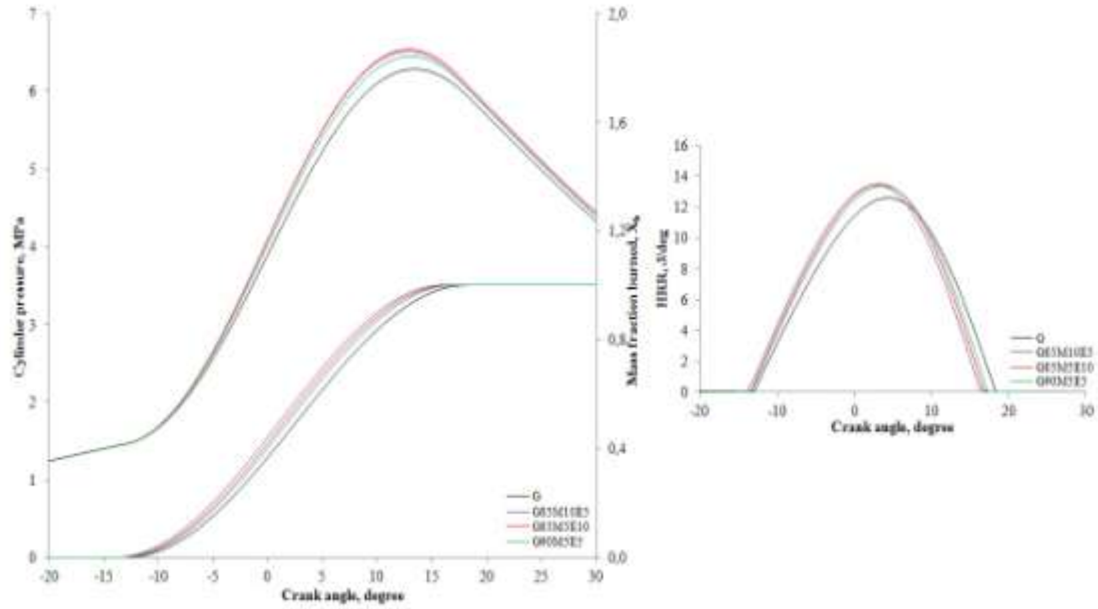

Figure 9.In-cylinder pressure, MFB and HRR for different methanol-ethanol and gasoline blends

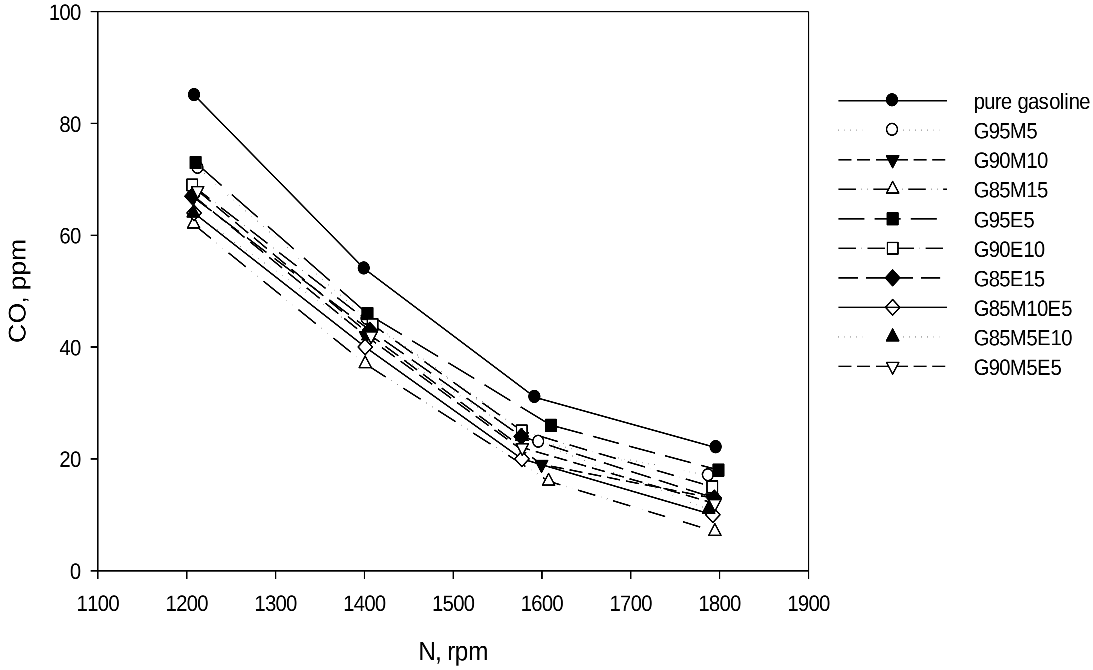

Figure 10. Variation of CO emissions with engine speed for the test fuels.

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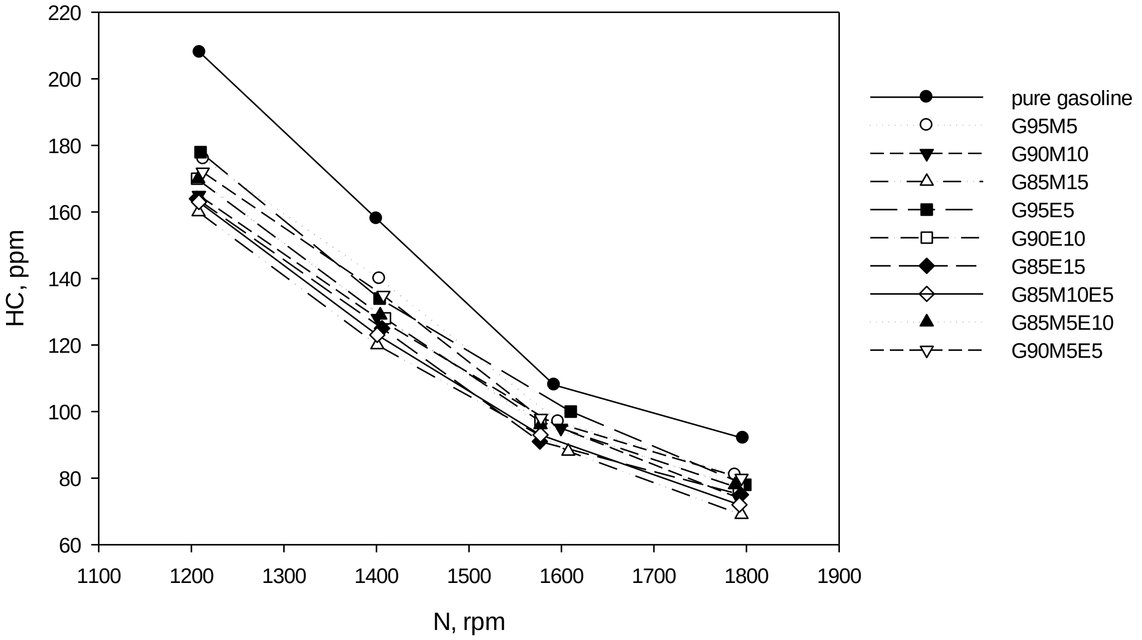

Figure 11. Variation of HC emissions with engine speed for the test fuels.

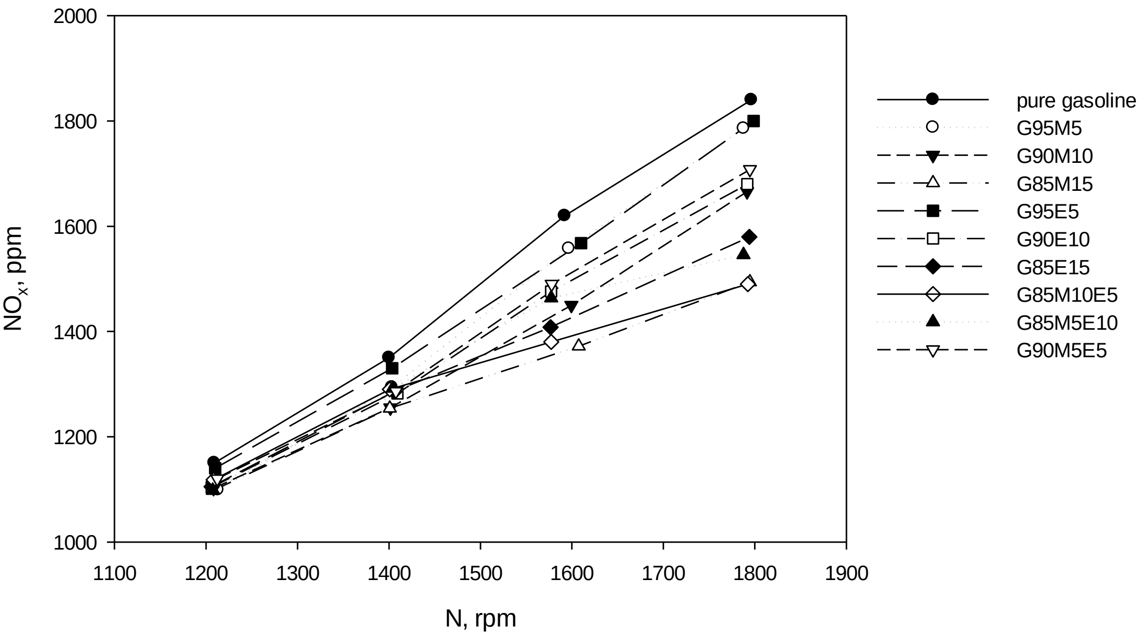

Figure 12. Variation of NOx emissions with engine speed for the test fuels

Hakan ÖZCAN.” The Effects of Ethanol-Gasoline, Methanol-Gasoline and Ethanol-Methanol-Gasoline Blends on Engine Performance, Combustion Characteristics, and Exhaust Emissions." The International Journal of Engineering and Science (IJES) 7.6 (2018): 70-82