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Effect of adding hydrogen-rich synthesis gas and ethanol on NOx emissions with gasoline at different air/fuel mixtures

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ABSTRACT

Environmental contamination poses a real threat to the environment and all organisms. Air pollution has increased markedly due to an increase in human activities and petroleum use for electricity generation, transportation, and industrial applications. Internal combustion engines play a significant role in society's health and power requirements. However, automobiles are the main source of pollution and NO_X emissions. This work presents a study of the performance and exhaust emissions of an internal combustion engine fuelled by gasoline available in the Saudi Arabian market, RON91/RON95, with an admixture of syngas and 5% by volume pure ethanol (E5) in the presence of different ultra-lean mixture regimes, including λ=1 for a stoichiometric mixture. The studied ranges were λ=1.13, λ=1.26, λ=1.43, and λ=1.67. An entirely automated engine and plasma converter system was developed for feeding the same type of fuel. The engine was modified for a more efficient operation by introducing a plasma-based fuel reformer. Syngas was produced through the partial oxidation of gasoline with air in a plasma-assisted fuel reformer in the presence of steam to reduce the amount of soot formed in the plasma reactor. The fuel consumption and related emissions were measured. The experimental results demonstrated a significant total reduction of NO_x emissions compared with those from the original engine. The most obvious reduction (approximately 50%) of harmful pollution was observed under lean conditions, and the total gasoline consumption (including the gasoline required for the plasma-assisted converter) slightly increased. Comparing the results for the two used gasoline types, gasoline RON 91 showed more NO_x reduction more than gasoline RON 95.

Keywords: Plasma, Fuel reforming, Syngas production, Ethanol, Emissions, Nitrogen oxides.

INTRODUCTION

Recently, reducing emission emitted from engines such as carbon dioxide (CO_2), hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO) has attracted researchers more to face the strict regulations on the environment protection. Emissions exhausted from engines are considered as a major cause of global warming and play a major role in human health and respiratory diseases. As precursors of acidity, NO_X and SO_2 emissions have direct effect on the atmospheric aerosols' acidity, and NO_X indirectly influences the acidity by affecting ozone (O_3) and hydroxyl radicals (OH), which have a big impact in the development of acids and its compounds in the atmosphere. High levels of particulate matter (e.g., 500 $\mu g/m^3$) in the atmosphere can result in premature death (Egebäck et al. 2005; Gallagher et al. 2010).

In Saudi Arabia, automobiles are considered the main source of pollution. A study by (Azhari, 1990) estimated the annual emissions of SO_2 and NOx and their comparative influence on the entire emissions in Saudi Arabia. The study showed that the most contributed SO_2 emissions are by combustion of crude oil, fuel oil, diesel oil, and gasoline by 64%, 23%, 12%, and 1%, respectively. Furthermore, the study found that diesel oil, natural gas, gasoline, and fuel were the major source of NOX emissions by 47%, 25%, 12%, and 3%, respectively, which are higher compared with the emission levels reported by different nations in the world. A research has shown that the incidence rate of the most common cancers in Saudi Arabia is linked with urban air pollution exposure, especially exposure to NO_2 (Al-Mutaz, 1987).

Nomenclature

ICE	internal combustion engine	SO_2	sulfur dioxide
CO	carbone monoxide	PPM	parts per million
CO_2	carbone dioxide	RON 95	rating octane number 95
E5	ethanol 5	NO_2	nitrogen dioxide
NO_x	nitrogen Oxide	C	carbon
OH	hydroxyl	CU	control unit
HC	hydro Carbone	RPM	revolution per minute
λ	lambda	O_2	oxygen
ECU	engine control unit	PM	particulate
RON 91	rating octane number 91	FI	fuel
H_2	hydrogen	Syngas	synthesis gas
°C	celsius	PC	personal computer

Several factors could affect and reduce the amount of exhaust emissions from gasoline engines, such as the addition of hydrogen to the combustion process, use of lean mixture conditions, alternative (clean) fuels, and fuel additives. Several researches have been expended to develop fuel reformers that convert different kinds of fuels into synthesis gas (“syngas). The addition of synthetic gas to the intake manifold resulted in a considerable reduction in NO_x emissions. Studies of lean mixture regimes have shown that NO_x could be reduced dramatically (Alharbi et al., 2016).

Plasmatron reformer was utilized to produce hydrogen, where methane, as a fuel, was investigated to determine the effect of the flow rate distribution and plasma power on the reformation process and hydrogen concentration (Bromberg et al., 2005). Many studies of vehicles fuelled with ethanol-blended gasoline have been carried out and showed that the emissions were reduced by different levels, depending on the percentage of ethanol added to the gasoline (Egebäck et al., 2005). Benefits of blending ethanol with automobile engine fuel were evaluated due to its high octane number and its capability to increase the gasoline octane value (Schäfer et al., 1995; Bechtold et al., 1997; Hsieh et al., 2002). Another valuable property of the chemical structure of ethanol is the high oxygen content, which assists with complete combustion to reduce emissions (Hansen et al., 2005). NOx emissions can be controlled during engine operation by using lean mixtures; this approach enables the use of less emission control hardware (Schweikert et al., 1976), and because the entire combustion process has an air-dominant status, which reduces NOx formation during this process (Keunsoo et al., 2017).

Ethanol reforming process for hydrogen production is attractive because ethanol is nontoxic and can be created from renewable resources such as biomass. The reformed CO_2 is consumed by biomass growing, offers a closed loop for carbon, and does not contribute to greenhouse emissions. The advantages of ethanol reforming bring into question the benefits of reforming gasoline blended with ethanol, and the increasing use of renewable fuels in vehicles motivates research on an on-board hydrogen supply. Hydrogen production by ethanol reforming for use in, for example, fuel cell applications, has attracted significant attention in both academic and industrial fields (Comas et al., 2004; Deutschmann, 2012; Ni et al., 2007). Xinli et al. (2011) used a nonthermal plasma reactor at a low temperature to produce hydrogen-rich gas products.

A recent numerical study by Mariani et al. (2019) on a Controlled Auto Ignition engine fed by pure methane and methane enriched with 10% and 20% hydrogen by volume found that using small concentrations of hydrogen in the engine helps speed up the combustion and reduces the duration of combustion. In addition, a certain equivalent ratio of the hydrogen-fuel mixing can improve engine efficiency and reduce NOx emissions due to lower boost pressure and EGR rate.

A Study by Ahmad et al. (2018) was performed on SI engine fuelled with gasoline and gasoline blended with 10% and 20% pure ethanol to show the effect of compression ratio on engine performance and exhaust emissions. Two blended fuels were compared to the pure gasoline. The results revealed that the brake mean effective pressure, brake thermal efficiency, and brake specific fuel consumption gained by the using of gasoline blends at all compression ratios were higher in general comparing to those of pure gasoline. Moreover, gasoline blends gave lower exhaust emissions than the gasoline's emissions at all compression ratios, whereas NOx was the most affected one of all exhaust emissions.

This study is an on-going work that investigates the exhaust emissions and performance of a gasoline engine. The early experimental outcomes obviously demonstrated a significant decrease in NOx engine emissions when syngas formed by a plasma-assisted fuel reformer was added to the intake manifold of the experimental engine. The most noticeable decrease in harmful pollutions was observed under lean conditions (Alharbi et al., 2016; Alenazey et al., 2016). The present study investigates the effect of adding syngas along with presence of ethanol-gasoline blend (E5) fuel that is supplied to the engine, simultaneously, at different air/fuel ratios, stoichiometric and lean mixtures. The study covered two types of fuel available in the Saudi Arabian market: RON91 and RON95.

MATERIALS AND METHODS

EXPERIMENTAL SET-UP

The test bench used in this study consisted of four supported systems: modified gasoline engine, feeding, plasma, and load. The experiment was conducted on a Subaru EH72 FI gasoline engine. Table 1 lists properties and constituents of Saudi Arabia's RON 91 and RON 95 sample (Binjuwair et al., 2016). Table 2 lists all engine specifications. Fig. 1 shows the schematic diagram of the test bench, and Fig. 2 shows a view of the test bench. The engine was modified to enable external electronic control with a specially developed engine control unit (ECU). For precise airflow measurement, a Bosch HFM5 flow meter was installed in the suction duct of the engine. To enable computer control over the throttle position, a Hitec HS635HB servo was installed and connected to a throttle arm. The engine was equipped with a crankshaft position probe to control the engine shaft speed and position for proper ignition timing.

To monitor the exhaust emissions (CO_2, CO, NOx, and HC) as well as the O_2 concentrations, an automotive INFRACAR 5M3T.01 exhaust gas analyser was used. A mid-power electric generator was used as the engine load and was coupled to the engine shaft. The output of the electric generator goes to the load system. This system transforms electrical power into thermal energy that is consumed by electric heaters that dissipates heat into the ambient surroundings.

The fuel converter used to generate syngas consisted of a plasma discharge unit and a reactor. Fig. 3 shows the scheme of the plasma discharge chamber. The completely evaporated and mixed incoming fuel mixture enters the inner annular space of the converter and then passes via a number of tangential slots to the discharge chamber, creating a swirling gas flow. The cathode of the plasmatron is a copper electrode cooled by water with a tungsten rod inserted into the copper tip. The cathode is electrically isolated from the water-cooled stainless steel anode by a polytetrafluoroethylene (PTFE) bush. High-voltage constant-current power supply is used for the plasmatron operation in a glow-to-arc transition mode of the discharge at nearly atmosphere pressure. The reactor consisted of a quartz tube wrapped with thermally isolating alumina wool, and it was placed in a stainless steel water-cooled enclosure. Gas reaction products were cooled to room temperature with a water cooler. Condensed water vapour and heavy hydrocarbons were collected in a condenser vessel. For continuous monitoring of the synthesis gas composition (CO, CO_2, and H_2), gas card NG infrared gas analysers and an INCOVT DV-32 hydrogen probe were used. The addition of steam to the fuel mixture helps avoid soot formation during gasoline reforming. A mixture of the super-heated steam with heated air atomizes the gasoline in a plain-jet air blast atomizer, as shown in Fig. 4.

Table 1. Properties and constituents of Saudi Arabia's RON 91 and RON 95 sample.

Description	RON 91	RON 95
Calculate octane number	90.44	94.66
Initial boiling point (C)	39	35.7
Final boiling point (C)	204	197.2
Relative density	0.679	0.688
Vapor pressure (kPa @ 37.8 C)	36.75	39.58
Lower heating value (kJ/kg)	43.932	43.304
Constituents (% mass) Paraffins	10.544	9.033
I- paraffins	36.853	37.500
olefin	13.911	13.373
Naphthenes	5.665	10.427
Aromatic	28.870	24.961
Total C14+	0	0.096
Total unknown	1.752	2.269
Total	100	100
% Carbon	86.045	86.413
% Hydrogen	13.156	13.163
H/C	0.153	0.152
Average molecular weight	85.571	88.288

Table 2. Technical specifications of the engine.

Description	Specification
Type	Air-Cooled, 4-Stroke, V-Twin Cylinder, Horizontal P.T.O. shaft, OHV Gasoline Engine
Bore × Stroke, mm	84 × 65
Displacement, cm^3	720
Compression ratio	8.1
Continuous output, kW (HP) / r.p.m.	14.9 (20.0) / 3600
Maximum torque, Nm / r.p.m.	52.2 / 2800
Charging capacity, V - A	12 - 15 or 12 - 30 (Option)

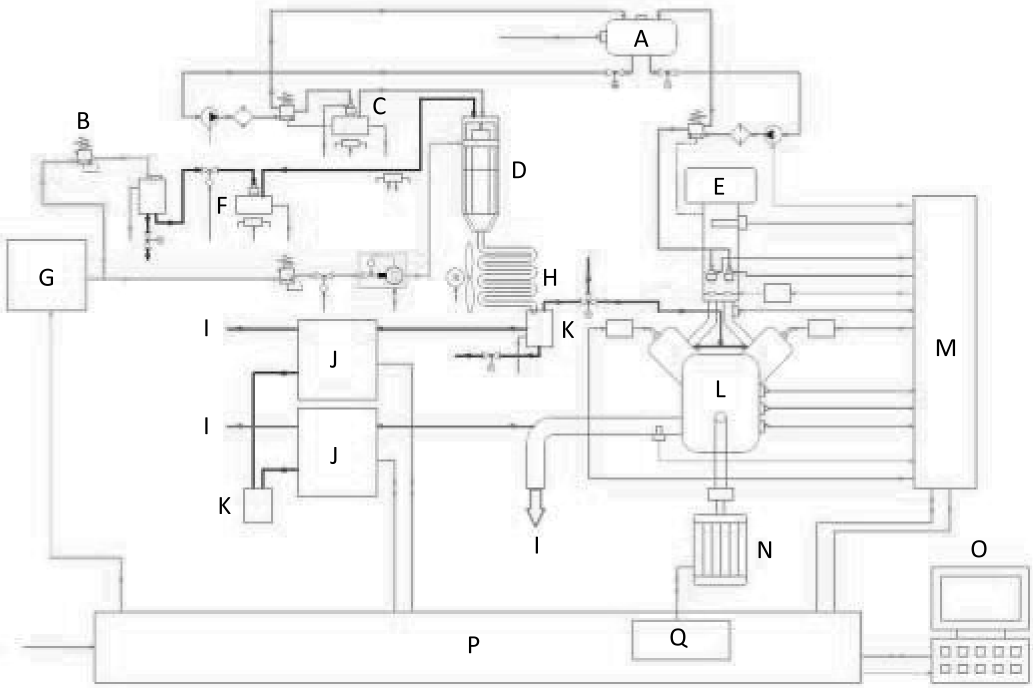
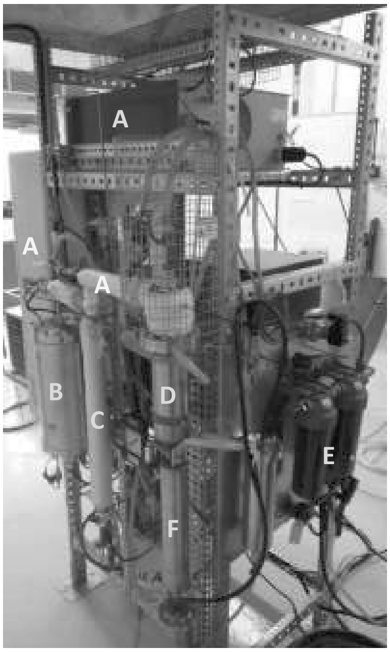


Fig. 1. Schematic of the experiment showing the following components: (A) Fuel Tank, (B) Pressure Regulator, (C) Fuel Evaporator, (D) Plasma Converter, (E) Air Filter, (F) Water Evaporator. (G) Air Compressor, (H) Chiller, (I) Exhaust, (J) Gas Analyser, (K) Condensate Tank, (L) Engine, (M) ECU, (N) Electric Generator, (O) PC, (P) Stand CU, and (Q) Inverter.



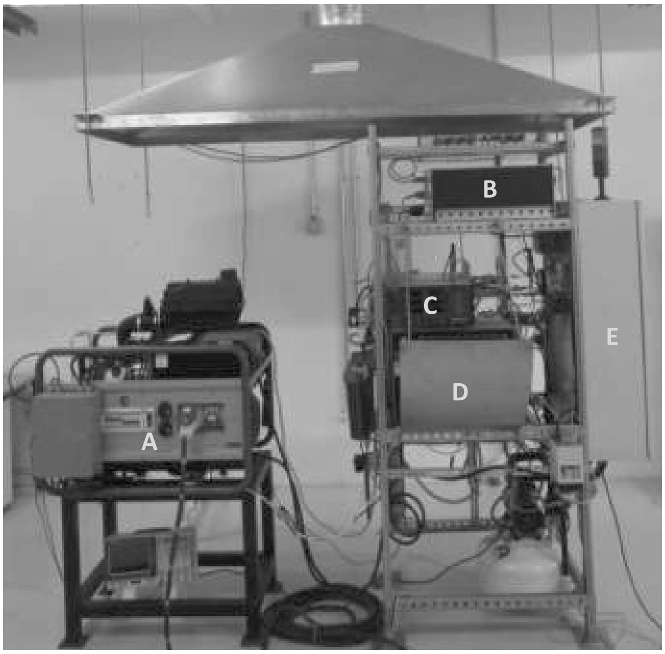


Fig. 2. Left: Rear view of the test bench showing the following components: (A) Power Supply, (B) Boiler, (C) Air heater, (D) Reactor, (E) Filters, and (F) Cooler. Right: Front view of the test bench showing the following components: (A) Engine, (B) Power Supply, (C) Engine Gas Analyser, (D) Chiller, and (E) Main Control Box.

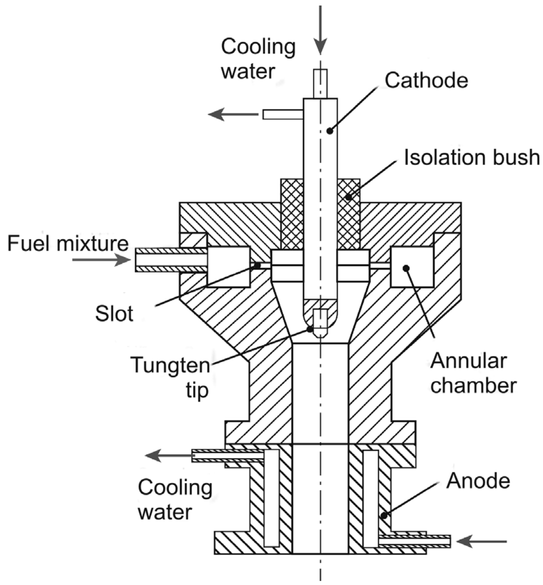


Fig. 3. Discharge unit of the plasma converter.

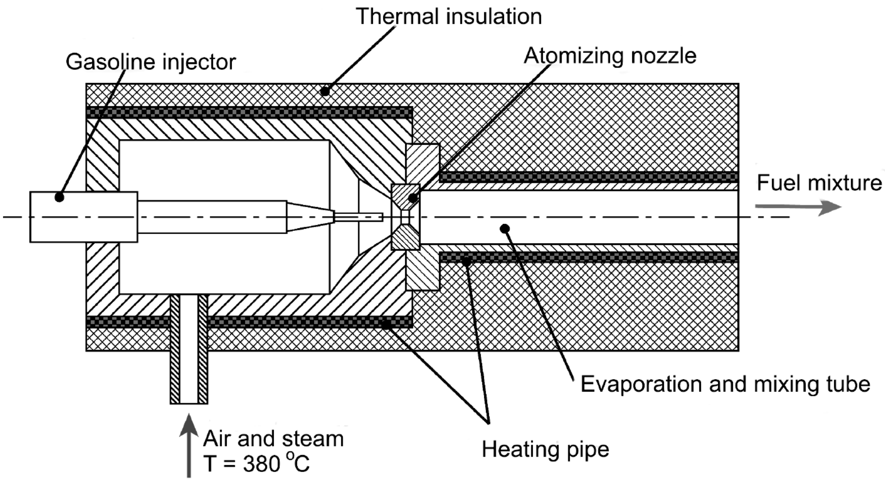
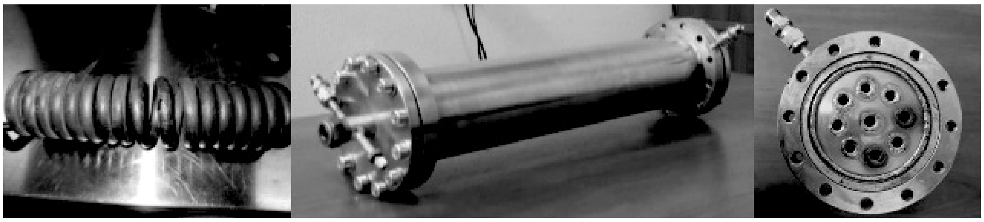


Fig. 4. Scheme of plasmatron fuel mixing and the evaporation unit.

The steam generator was composed of an electrically heated boiler and super heater operated at an elevated pressure ranging from 3.5 to 6 bar. The steam mass flow rate was measured with a circular orifice operating under choked conditions using the measured values of steam pressure and temperature upstream of the orifice. An Omega 5400 mass flow controller and an ISMATEC REGLO-CPF dispensing pump controlled the mass flow rates of air and gasoline, respectively, used to produce the synthesis in the plasma reformer.

EXPERIMENTAL PROCEDURE

The experimental studies were performed at four fixed engine speeds (2400, 2700, 3000, and 3300 rpm). For each engine speed, more than 500 runs with different electrical power loads were performed. Five test series were set up with various values of air/fuel ratio λ. In the first series, the engine was fuelled with a nearly stoichiometric mixture ($\lambda = 1.01$). In the other series, the engine fuel mixture was lean and extra lean ($\lambda = 1.13$, $\lambda = 1.26$, $\lambda=1.43$, and λ=1.67). The oxygen content in the exhaust gas measured with an oxygen sensor was used to control λ in the test runs with lean fuel mixtures. The oxygen concentrations in the engine test series were 0.2%, 2%, 4%, 6%, and 8%. During the experiment, the cooler for the plasma conversion products was given a new design due to the formation of a solid carbonic plug that rendered the cooler coils impermeable. To facilitate removal of tar sediment during the cooler operation, two principal improvements to the cooler design were made. First, the coil was replaced with a bundle of nine straight tubes, thus facilitating drainage of the tar film along the tube surface. Second, the design of the cooler was dismountable. Thus, the clogged gas channels could be easily cleaned from both sides of the cooler using a simple sharp steel rod when the flanges of the cooler were dismounted. An overview of the new cooler is given in Fig. 5.



A B C

Fig. 5. Fragments of the old cooler coil (A) and destruction of gas in the new cooler coil (B and C).

RESULT AND DISCUSSION

Different engine speeds, namely, 2400, 2700, and 3000 rpm, for the stoichiometric regime with and without plasma-produced syngas were studied for comparison. Fig. 6 and Fig. 8 indicate the NOx content for gasoline 95 and E5-gasoline 95 fuels, respectively. The results show a considerable reduction in NOx content when operating the engine with gasoline + syngas and even more NOx reduction when adding 5% ethanol (by volume) for different engine speeds. Fuel consumption values for the gasoline 95 and E5-gasoline 95 fuels at the same engine speed and regime are shown in Fig. 7 and Fig. 9, respectively. It is remarkable that the fuel consumption slightly increased, in general, when gasoline + syngas was used, and there was no significant effect of using ethanol (E5) on fuel consumption. The effect of using different types of fuels (gasoline only, gasoline + syngas, E5, and E5 + syngas for) on the emission content compared to that of the base fuel (gasoline 95) is illustrated in Table 3 for two points in the mid-range load of 4 and 6 Kw for three engine speeds. Feeding syngas with gasoline to the engine reduced NO_x content by 21.9% on average, and the reduction was even higher (40%) when gasoline was blended with 5% ethanol. The highest percentage of NO_x reduction (61.4%) was observed when syngas was supplied to the engine along with E5 fuel. As shown in Table 4, at the maximum load point for each engine speed, the reduction percentage depending on the fuel type is close to the reduction percentage for the two points in the mid-range loads. After comparing all speeds, 2700 rpm was chosen to study fuels with different octane numbers (91 and 95). The NO_x emissions for the two types of fuels supplied to the engine, gasoline + syngas (G+S) and gasoline only (G), for different lean mixtures (regimes) at different increasing loads are shown in Fig. 10 for gasoline 91, and in Fig. 11 for gasoline 95. Using gasoline 91, there is a decreasing trend for NO_x emissions as λ (oxygen access content) increases, and there is a considerable reduction in NO_x content for the gasoline + syngas operation for each regime.

There is a slight increase in fuel consumption as λ increases, and the fuel consumption slightly decreases for the gasoline + syngas operation for each regime compared with that for the gasoline only operation. The results for NO_x emissions and fuel consumption when using gasoline 95 are the same as those obtained when using gasoline 91, with a decreasing trend for NO_x emission as λ increases and a considerable reduction in NO_x content for the gasoline + syngas operation for each regime, as shown in Fig. 12. For the same operations, the regimes and fuel used in Fig. 13 show that there is a slight increase in fuel consumption as λ increases, and fuel consumption slightly increases for the gasoline + syngas operation for each regime compared with that for the gasoline only operation. The results of NO_x emissions for the two types of fuel used in KSA (gasoline 95 and gasoline 91) show that the NO_x content is lower using gasoline 95 than that using gasoline 91. In addition, using gasoline 95 + syngas led to a lower NO_x content than using gasoline 91 + syngas.

When using gasoline 91 blended with 5% ethanol (E5), the results of NO_x emissions shown in Fig. 14 reveal a decreasing trend for NO_x content as λ increases, and a considerable reduction in NO_x content for the gasoline + syngas operation for each regime. Fig. 15 shows a slight increase in fuel consumption as λ increases, and the fuel consumption decreases for the E5 + syngas operation for each regime compared with that for the E5 only operation.

The NO_x emissions when using gasoline 95 blended with 5% ethanol (E5) are shown in Fig. 16. The NO_x content decreased as λ increased. In addition, a significant effect of using "syngas" was observed in which there was a considerable reduction in NO_x content for the gasoline + syngas operation for each regime. Fig. 17 shows a slight increase in the fuel consumption as λ increases, and fuel consumption decreases for the gasoline + syngas operation for each regime compared with that for the gasoline only operation. The blending of 5% of ethanol with the two types of fuel used in KSA (gasoline 95 and gasoline 91) results in two types of fuel, E5-gasoline 95 and E5-gasoline 91. The emissions results for these new blends show that the NO_x content is lower for E5-gasoline 91 than for E5-gasoline 95. In addition, the NO_x content is generally lower when using E5-gasoline 91 + syngas than that using E5-gasoline 95 + syngas.

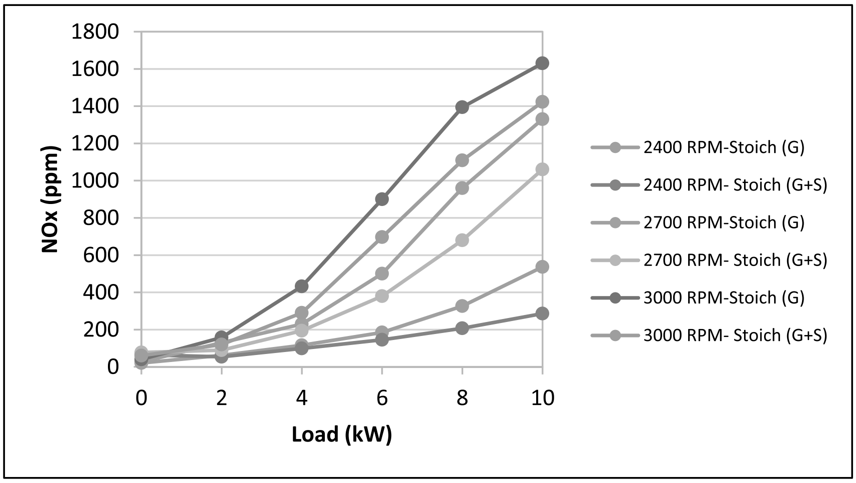


Fig. 6. NOx Emissions for Gasoline 95 Octane Number for different Engine Speeds with a Stoichiometric Mixture with and without Syngas.

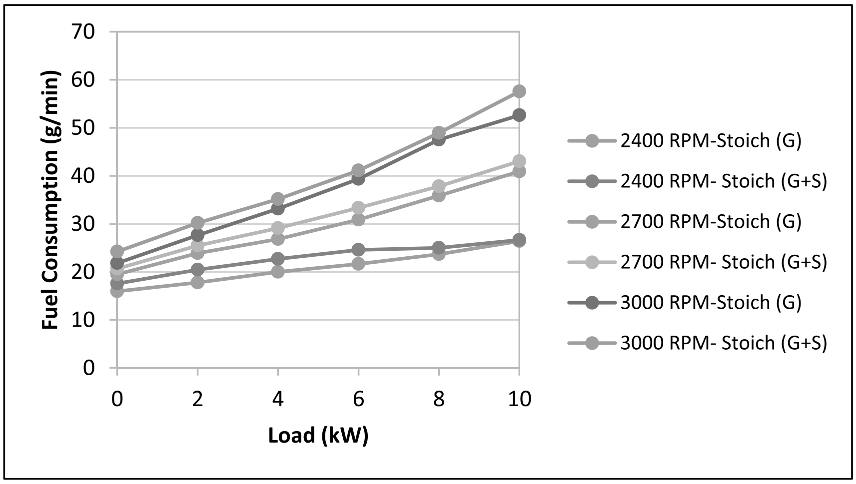


Fig. 7. Fuel Consumption for Gasoline 95 for different Engine Speeds with a Stoichiometric Mixture with and without Syngas.

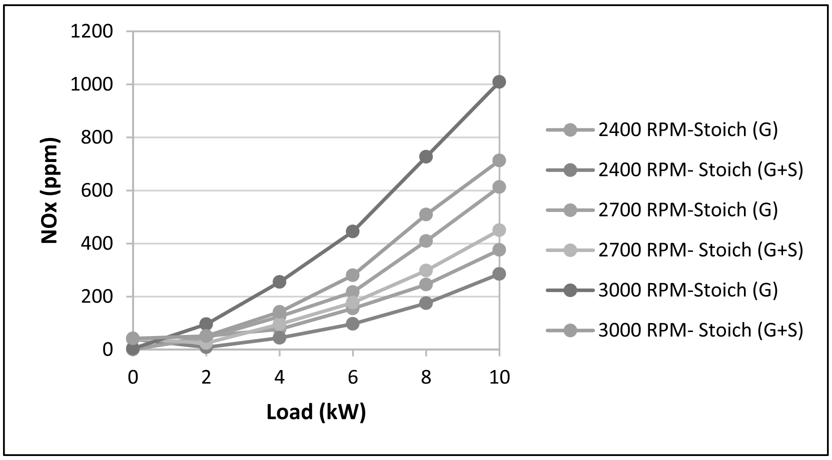


Fig. 8. NOx Emissions for E5-Gasoline 95 for different Engine Speeds with a Stoichiometric Mixture with and without Syngas.

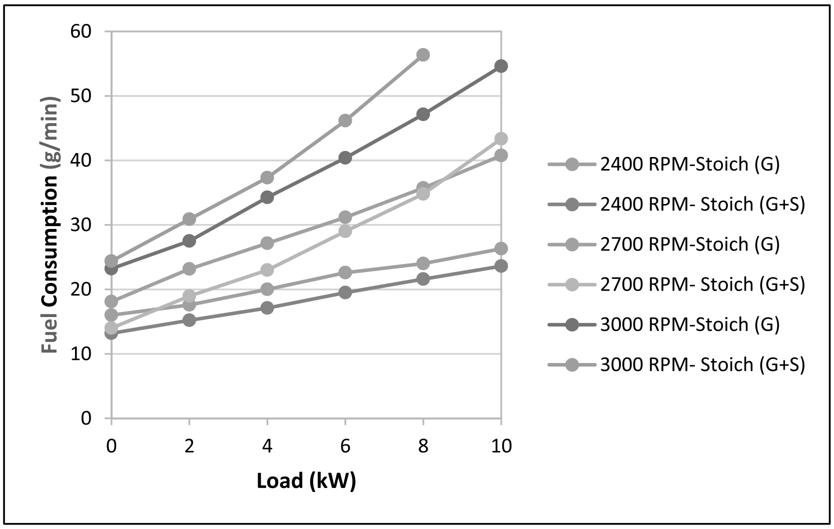


Fig. 9. Fuel Consumption for E5-Gasoline 95 for different Engine Speeds with a Stoichiometric Mixture with and without Syngas.

Table 3. NO_x Emissions (ppm) for three engine speeds at two points of mid-range loads for each fuel type of Gasoline 95.

	2400 RPM		2700 RPM		3000 RPM		
	4 kW	6 kW	4 kW	6 kW	4 kW	6 kW	
NO_x from Gasoline (ppm)	116	185	230	500	432	900	
NO_x from Gasoline + Syngas (ppm)	99	145	194	380	290	697	
% Reduction in NO_x	14.7	21.6	15.7	24	32.9	22.6	Avg. =21.9 %
NO_x from Gasoline with E5 (ppm)	77	155	125	217	255	445	
% Reduction in NO_x	33.6	16.2	45.7	56.6	41	50.6	Avg. =40.6 %
NO_x from (Gasoline + Syngas) with E5 (ppm)	44	97	96	177	142	280	
% Reduction in NO_x	62.1	47.6	58.3	64.6	67.1	68.9	Avg. =61.4 %

Table 4. NO_x Emissions (ppm) for three engine speeds at maximum loads for each fuel type of Gasoline 95.

	2400 RPM	**2700 RPM**	**3000 RPM**	
	10 kW	10 kW	10 kW	
NO_x from Gasoline (ppm)	537	1330	1630	
NO_x from Gasoline + Syngas (ppm)	286	1060	1423	
% Reduction in NO_x	46.7	20.3	12.7	Avg. =26.6 %
NO_x from Gasoline with E5 (ppm)	376	613	1009	
% Reduction in NO_x	30	53.9	38.1	Avg. =40.7 %
NO_x from (Gasoline + Syngas) with E5 (ppm)	285	450	713	
% Reduction in NO_x	46.9	66.2	56.3	Avg. =56.5 %

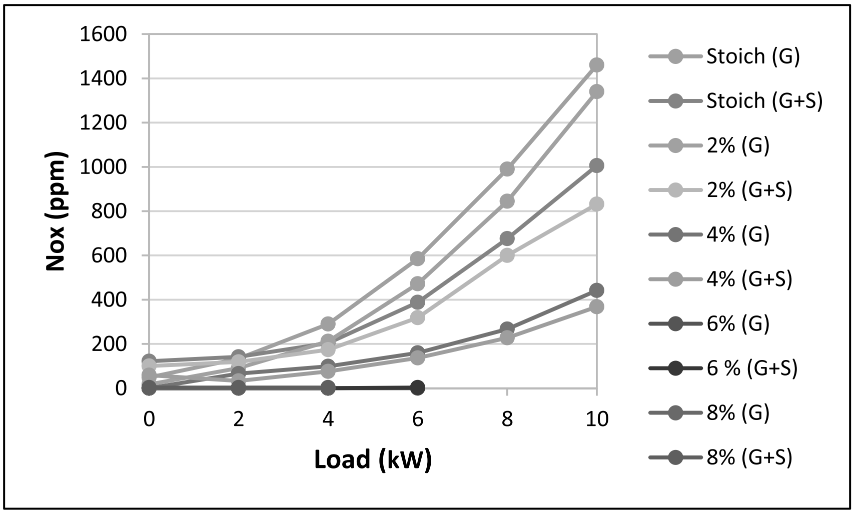


Fig. 10. NOx Emissions for Gasoline 91 using Different Lean Mixtures.

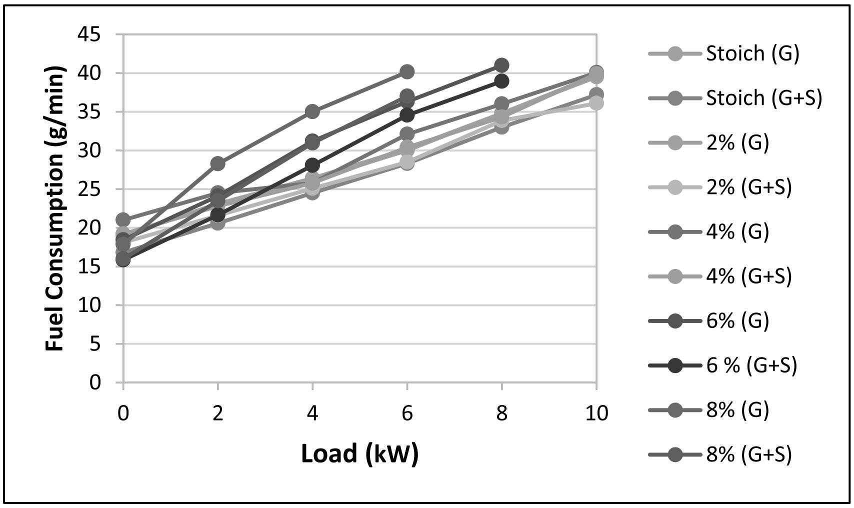


Fig. 11. Fuel Consumption for Gasoline 91 with Different Lean Mixtures.

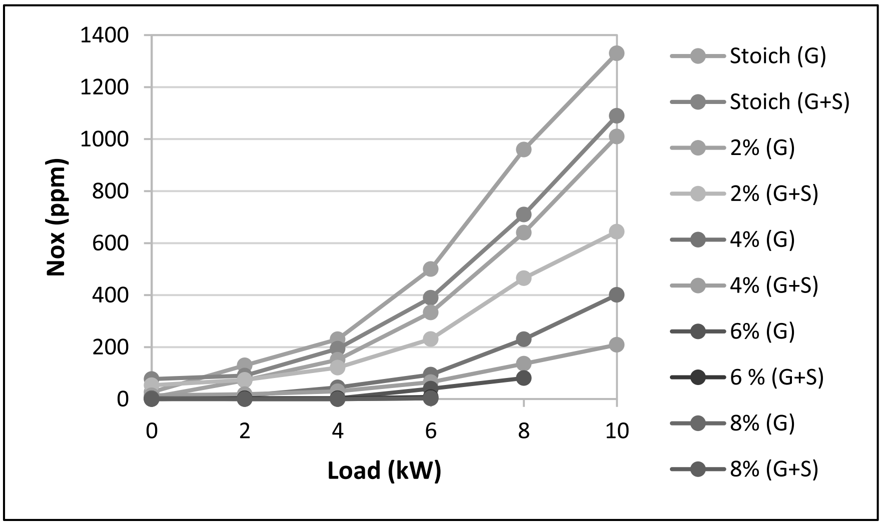


Fig. 12. NOx Emissions for Gasoline 95 with Different Lean Mixtures.

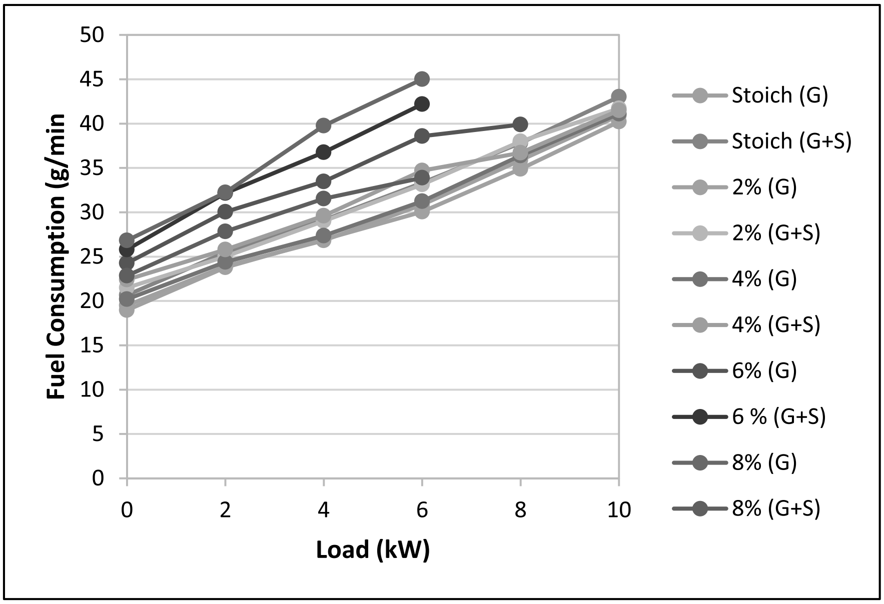


Fig. 13. Fuel Consumption for Gasoline 95 with Different Lean Mixtures.

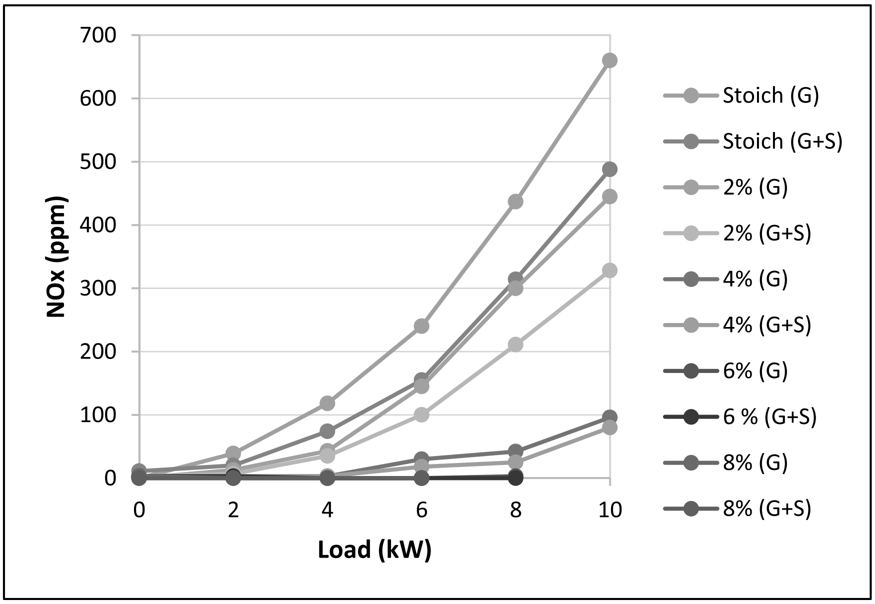


Fig. 14. NOx Emissions for E5-Gasoline 91 with Different Lean Mixtures and at 2700 rpm.

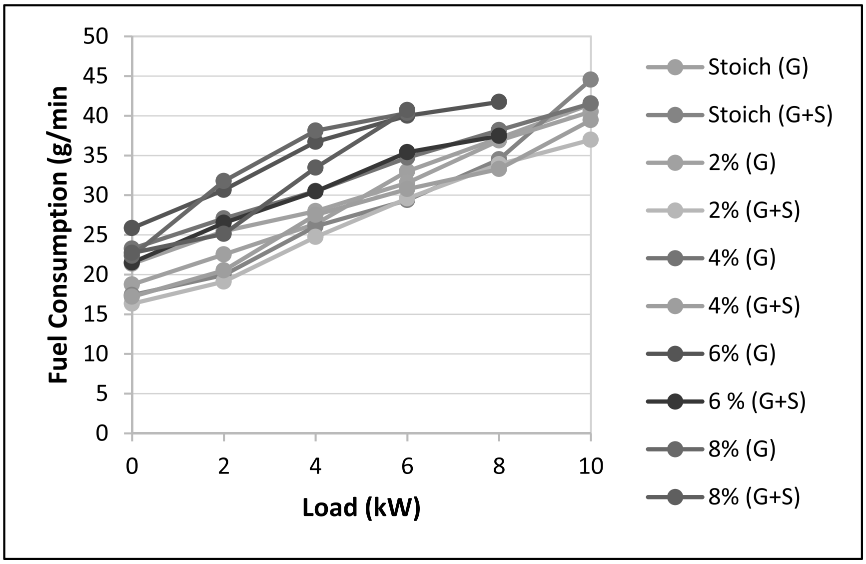


Fig. 15. Fuel Consumption for E5-Gasoline 91 at Different Lean Mixtures and at 2700 rpm.

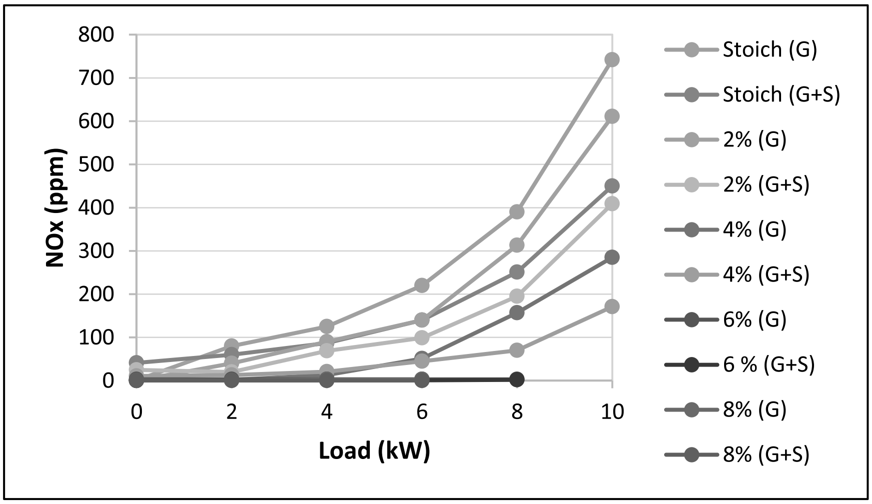


Fig. 16. NOx Emissions for E5-Gasoline 95 with Different Lean Mixtures.

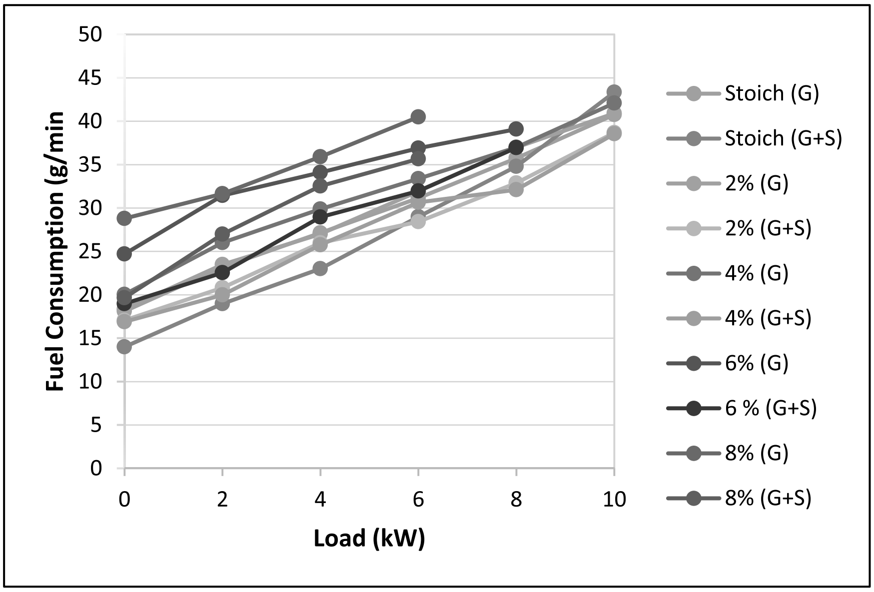


Fig. 17. Fuel Consumption for E5-Gasoline 95 with Different Lean Mixtures**.**

CONCLUSION

This study investigates the exhaust emissions, performance of a gasoline engine, and the effect of different fuel mixtures: stoichiometric and ultra-lean mixture regimes (λ=1.13, λ=1.26, λ=1.43, and λ=1.67 and λ=1.0) in the presence of 5 vol. % ethanol-gasoline blend fuel (E5) for two types of fuel available in the Saudi Arabian market: RON91 and RON95.The experimental results demonstrated a significant total reduction of NO_x emissions compared with those from the original engine. The main fading regarding the plasma system and the engine operations can be summarized as follows:

- Mixing syngas with gasoline while supplying the engine had a positive effect on the emissions content, whereby NO_x was dramatically reduced.

- Operating the engine using lean mixture regimes reduced the NO_x content, and NO_x decreased as λ increased.
- Using gasoline blended with 5% ethanol (E5) resulted in a considerable reduction of NO_x content with no significant effect on fuel consumption.
- The results of NO_x emissions for the two types of fuel used in KSA (RON95 and RON91) showed that the NO_x content was lower using RON95 than when using RON91. In addition, the NO_x content was generally lower when using gasoline 95 + syngas than when using gasoline 91 + syngas.
- The total gasoline consumption was slightly increased.

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تأثير إضافة الغاز الاصطناعي الغني بالهيدروجين والايثانول مع نسب مختلفة من خليط الوقود والهواء على انبعاثات أكاسيد النيتروجين

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الخلاصة

يشكل التلوث البيئي تهديداً حقيقياً لجميع الكائنات الحية، حيث يزداد تلوث الهواء بشكل ملحوظ بسبب الزيادة في الأنشطة البشرية واستخدام البترول لتوليد الكهرباء والنقل والتطبيقات الصناعية. تمثل محركات الاحتراق الداخلي دوراً هاماً في متطلبات الطاقة وتُعتبر المركبات هي المصدر الرئيسي للتلوث وانبعاثات أكاسيد النيتروجين. يقدم هذا البحث دراسة عن أداء وانبعاثات عوادم محرك الاحتراق الداخلي الذي يعمل بالبنزين المتوفر في سوق المملكة العربية السعودية – أوكتان 91 و95 – مع مزيج من الغاز الاصطناعي و5% من حجم الإيثانول النقي (E5) في وجود خليط اشتعال يحتوي على نسبة هواء أكثر مقارنة مع الوقود (ultra-lean mixture)، يتضمن أيضاً خليط بنسبة مثالية (stoichiometric mixture, $\lambda = 1$). تمت الدراسة على عدة نسب مختلفة من خليط الوقود (λ=1.13، λ=1.26، λ=1.43 وλ=1.67). وتم استخدام نظام محور للوقود يعمل بالبلازما في التجارب المعملية حيث تم استخدام النظام بالكامل لتزويد مفاعل البلازما والمحرك بنفس النوع من الوقود. كذلك تم تعديل نظام الاشتعال في المحرك للحصول على احتراق أكثر كفاءة. تم خلال الدراسة قياس استهلاك الوقود والانبعاثات الناتجة بحيث أظهرت النتائج التجريبية انخفاضاً كبيراً في انبعاثات أكاسيد النيتروجين مقارنةً بالنتائج الصادرة عن المحرك الأصلي. ولوحظ أن التلوث الناتج في الخليط (ultra-lean mixture) كان أكثر انخفاضاً (تقريباً 50%)، ولوحظ أيضاً ازدياد إجمالي استهلاك البنزين (بما في ذلك البنزين المطلوب لمحور الوقود بمساعدة البلازما) بزيادة طفيفة. أظهرت النتائج أيضاً أن محتوى أكاسيد النيتروجين كان أقل عند استخدام البنزين 91 و5% إيثانول (E5) من استخدام البنزين 95 و5% إيثانول (E5) وكان أقل بوجه عام في استخدام البنزين 91 و5% إيثانول (E5) مع الغاز الاصطناعي مقارنةً مع استخدام البنزين 95 و5% إيثانول (E5) مع الغاز الاصطناعي.