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Comparison of Performance Characteristics of LPG and Gasoline - Fuelled Single Cylinder SI Engine

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Abstract

The investigations have been concentrated on decreasing fuel consumption by using alternative fuels and on lowering the concentration of toxic components in combustion products. LPG as an alternative to gasoline has emerged as a solution to the deteriorating urban air quality problem, especially in an oil country like Iraq. LPG has already been used as cooking fuel in Iraq. In the present paper practical tests of various operating parameters and concerns have been prepared for better understanding of operating conditions and constrains for a LPG fueled internal combustion engine.

The results show that HUCR for gasoline was 8:1, and for LPG was 10:1. bsfc reduced by using LPG at its HUCR, while at CR=8:1 it became higher than that for gasoline. Volumetric efficiency reduced by using LPG due to its gaseous nature, but it was improved when the engine was run at HUCR. Brake thermal efficiency depends on bsfc and bp, so LPG preceded gasoline at medium speeds and torques. Exhaust gas temperatures reduced by using LPG, the minimum values were when the engine operated at CR= 8:1. The maximum values were for gasoline share.

Keywords: LPG, Spark ignition engines, Performance, Brake power, Volumatric efficiency, Brake thermal efficiency.

مقارنة أداء محرك إشتعال بالشرارة أحادي الأسطوانة عند عمله بالغاز النفطي المسال الكازولين

الخلاصة

ركزت البحوث على تقليل استهلاك الوقود وتقليل المركبات السامة في منتجات الاحتراق باستخدام بدائل وقود. اعتبر الغاز النفطي المسال كبديل للكازولين وحل لمشكلة تدهور نوعية الهواء في المدن، خصوصا لبلد نفطي كالعراق، إذ يستخدم الغاز النفطي المسال حاليا كوقود للطبخ. وفي هذا البحث تم فحص والأهتمام بعدة عوامل باختبارات عملية لغرض فهم أفضل لظروف والمعوقات التشغيلية لتزويد محركات الأحتراق الداخلي بالغاز النفطي المسال.

أظهرت النتائج أن نسبة الأنضغاط النافعة العليا للكازولين كانت 8:1 ، وللغاز النفطي المسال 10:1. يقل الأستهلاك النوعي المكبحي للوقود باستخدام الغاز النفطي المسال عند نسبة الأنضغاط النافعة العليا له، بينما عند نسبة انضغاط 8:1 يكون الأستهلاك أعلى من الكازولين. تقل الكفاءة الحجمية باستخدام الغاز النفطي المسال بسبب طبيعته الغازية، ولكنها تحسنت عند عمل المحرك بنسبة الانضغاط النافعة العليا له. تعتمد الكفاءة الحرارية المكبحية على الأستهلاك النوعي المكبحي للوقود وعلى القدرة المكبحية ، لذا يتقدم الغاز النفطي المسال على الكازولين عند سرع وعزوم محرك متوسطة، وتقل درجات حرارة الغاز العادم باستخدام LPG، وتكون أقل القيم عند عمل المحرك بنسبة انضغاط 8:1، وكانت اعلى القيم من نصيب الكازولين.

الكلمات الدالة: الغاز النفطي المسال، محركات اشتعال بالشرارة، اداء، قدرة مكبحية، كفاءة مكبحية، كفاءة حرارية مكبحية.

Introduction

Air pollution with the exhaust emission is still a serious problem, and an international concern has been raised for its control and restriction. Therefore, energy conservation with high efficiency and low emission are important research topics for development of engine system [1]. Recently, the engine which uses alternative fuels such as natural gas (NG), LPG (Liquefied Petroleum Gas), DME (Dimethyl Ether), GTL (Gas to Liquids), and hydrogen is actively developed to solve these problems [2,3].

LPG is paid to attention as a useful alternative fuel which can be substituted from production from not only the oil refinement but also the gas refinement to oil. LPG is a by-product of both petroleum refining and natural gas processing plants. Liquefied petroleum gas (LPG) is any mixture of several hydrocarbon compounds that are gases at normal room temperatures and pressures but can be liquefied under moderate pressure at atmospheric temperatures [4,5]. LPG has many properties that make it useful as a vehicle fuel. While fuel storage volumes and weights are higher than those required for gasoline, they are lower than for CNG and comparable to M85 and E85. The octane and vapor pressure of LPG is high enough to allow an increase in compression ratio in the engines of dedicated propane vehicles, which should improve overall efficiency relative to gasoline [6,7].

Propane is an odorless, nonpoisonous gas that has the lowest flammability range of all alternative fuels. High concen-trations of propane can displace oxygen in the air, though, causing the potential for asphyxiation. This problem is mitigated by the presence of ethyl mercaptan, which is an odorant that is added to warn of the presence of gas. While LPG itself does not irritate the skin, the liquefied gas becomes very cold upon escaping from a high pressure tank, and may therefore cause frostbite, should it contact unprotected skin. As with gasoline, LPG can form explosive mixtures with air. Since the gas is slightly heavier than air, it may form a continuous stream that stretches a considerable distance from a leak or open container, which may lead to a flashback explosion upon contacting a source of ignition [8]. Many proce-dures are used to treat LPG leakage. The simplest one is the addition of repulsive gas like H_2S in low percentages to denote the leakage if any.

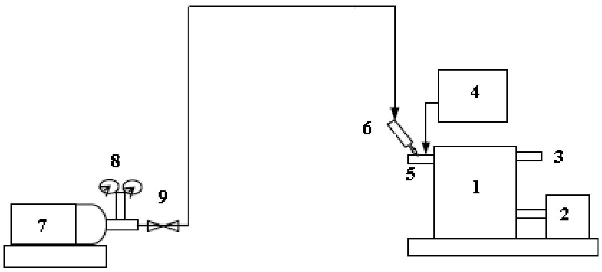
Many literatures showed that LPG as alternative fuel to gasoline improved combustion characteristics, performance and emissions characteristics at various conditions such as changing the piston cavities, air fuel ratio, speed etc. [9]; found that Lean burn operation of an LPG SI engine resulted in improved fuel consumption for both the full and half load cases. As the in-cylinder flow was made more turbulent by suitable piston cavity modification, the cyclic variation and combustion duration both declined. Lee et al. [10] investigate the combustion characteristics and flame propagation of the LPG (liquefied petroleum gas) and gasoline fuel. The flame propagation speed of the fuel is increased with the decrease of initial pressure and the increase of initial temperature in the constant volume chamber. The results also show that the equivalence ratio has a great effect on the flame speed, combustion pressure and the combustion duration of the fuel-air mixture. Choi et al. [11] carried out to quantify the combustion and emissions characteristics of LPG fuelled SI engine with minor modification in original SI engine to run on LPG fuel with varying volume percentage of LPG at 5%, 10%, 20%. For each proportion of LPG in gasoline investigated, it was also observed that the CO_2 emissions peaked at around stoichiometric equivalence ratio ($Ø=1$) and exhibits lower percentages at rich and lean mixtures. An increasing proportion of LPG in gasoline promotes faster burning velocity of mixture and hence reduce the combustion duration and subsequently the in-cylinder peak temper-ature increases. Myung et al.[12] focus on the experimental comparison of combus-tion phenomena and nanoparticle emission characteristics from a wall-guided DI spark ignition engine for gasoline and LPG. The combustion stability in a part-load condition of LPG was better than that of gasoline because it evaporated very rapidly and mixed well with the air. Further research has to be carried out by changing compression ratio, ignition timing to compare the performance and emissions characteristics.

The aim of this article is to evaluate the performance of single cylinder SI engine fueled with LPG and the effect of some engine parameters on it. The results will be compared to operating the engine with Iraqi conventional gasoline.

Experimental Work

Internal combustion engine and its accessories:

The engine used in these investigations was 4 stroke single cylinder, with variable compression ratio, spark timing, a/f ratio and speed Ricardo E6, the engine connected to electrical dynamometer, and lubricated by gear pump operated separately from it, the cooling water circulated by centrifugal pump. Figure (1) represents a schematic diagram of the used system, while Table (1) demonstrates the engine specifications.



1. Single cylinder engine
2. Dynamometer
3. Engines exhaust manifold
4. Air drum
5. Engine intake manifold
6. Gas carburetor
7. LPG cylinder
8. LPG flow meter
9. Pressure gauge and regulator

Fig. 1. Schematic diagram of the used system in the present study

Table 1. Engine characteristics

Model	Ricardo E6	Cycle	4-stroke
Type	IDI with the pre-combustion chamber	Compression ratio	From 5 to 22
Number of cylinders	1	Maximum power (kW)	9 naturally aspirated
Bore × Stroke (mm)	76.2×111.1	Maximum speed (rpm)	3000
Injection timing	Variable		

Gasoline supply system: This system consists of major tank (6 liter capacity), minor tank (1liter capacity), and gasoline carburetor.

LPG supply systems: This system consist of LPG tank, fuel drier, solenoid valve, LPG carburetor (simple gas adaptor), gaseous fuel flow measuring device (orifice plate), damping box.

Air flow measurement: Air interring the engine was measured by Alock viscous flow meter connected to flame trap.

Speed measurement: Engine speed was measured by tachometer.

Power measurement: In addition of it is used to measure power; it is used as electric motor also, to rotate the engine in the starting. The dynamometer is used to measures indicated power, brake mean effective pressure and friction lost power.

Exhaust gas temperatures measurement: Exhaust gas temperatures were measured by nickel chrome/ nickel aliumel thermocouple, which was calibrated before it was used.

A simple, low cost air-LPG mixing device, designed as shown in Figure (2), was used to mix LPG with inlet air during suction stroke.

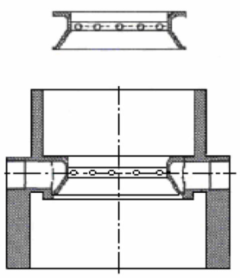


Fig. 2. The cross sectional drawing of the LPG-air mixer

The fundamental equations descri-bing the performance of spark ignition engine are [13]:

- The brake power:

$bp=w_b*N/348.067$ ………….……….. (1)

Where:
W_b= the load in (N)
N= speed engine (r.p.m.)

- The brake specific fuel consumption:

$bsfc= m^o{}_f*3600/Bp$ …………………..(2)

Where:
$m^o{}_f$ = fuel consumption mean (kg/kw.hr)

- The volumetric efficiency:

$\eta_{vol}= (m_a)_{act}/(m_a)_{theo}$ ………………... (3)

- The brake thermal efficiency:

$\eta_{bth}= pb/ m^o{}_f*(L.C.V)$……………….…(4)

Where:
L.C.V.= 43700 (kJ/kg) for gasoline

- The equivalent ratio:

$Ø= (A/F)_{stoichiometric}/ (A/F)_{actual}$ ……….(5)

Materials

In this work the gasoline used was Iraqi conventional Dora refinery production with octane No. 82. Iraqi gasoline is characterized by its low octane number and high lead content. In practice, much of the gaseous fuels available are usually mixtures of various fuels and some diluents, constituents that can vary widely in nature and concentration, depending on the type of fuel and its origin (Chaichan, 2007). The LPG fuel produced from Al Taji Gas Company; consist of ethane 0.8%, 15.47 isobutane, 52.8% propane and 30.45% butane and 0.48% other gases like methane, hydrogen and H_2S. Table (2) represents the used gasoline and LPG characteristics.

Table 2. Properties of gasoline and LPG

Property	Gasoline	LPG
Heating value , kJ/kg	43440	50000
Self ignition temperature, ºC	431	525
Boiling point range , ºC	30 - 225	-34
Flame propagation rate, cm/s	48	52-58
Flame temperature, ºC	1715	1985
Molecular weight (kg/kmol)	114.2	44.1
Upper flammability limits in air (% vol.)	7.6	74.5
Lower flammability limits in air (% vol.)	1.3	4.1
Density at 15ºC kg/l	0.705	0.507
Research octane number	82	100

The very wide diversity in the composition of the gaseous fuels commonly available and their equally wide variety of their associated physical, chemical and combustion characteristics make the prediction and optimization of their combustion behavior in engines a more formidable task compared to conventional liquid fuels.

Test procedure

The first tests were conducted to determine the higher useful compression ratio for each fuel. Engine performance was tested for wide range of speeds, full load conditions, optimum spark timing and 1500 rpm engine speed. The experiments were conducted on the engine with gasoline and engine performance was evaluated:

1-When the torque is constant at (10 N.m) and engine speed was varied (1000, 1500, 1750, 2000, 2250 and 2500 rpm).

2-When engine speed was fixed at (1500rpm) and engine torque was changed (10, 15, 20 and 25 Nm).

The second set of tests: the experiments were conducted on the engine with LPG fuel, and engine performance was evaluated and compared with the first case.

Results and Discussion

Figures (3) and (4) represent engine brake power resulted by fueling it with gasoline and LPG at stoichiometric equivalence ratio, variable compression ratios, full load conditions, optimum spark timing and 1500 rpm engine speed.

Brake power increased with engine speed increase. The HUCR for gasoline was 8:1 and 10.5:1 for LPG. LPG has higher octane number compared to gasoline which means higher knock resistance. In the following figures LPG at CR=8:1 which is HUCR for Iraqi conventional gasoline and LPG at HUCR=10:1 will be compared with gasoline at its HUCR= 8:1.

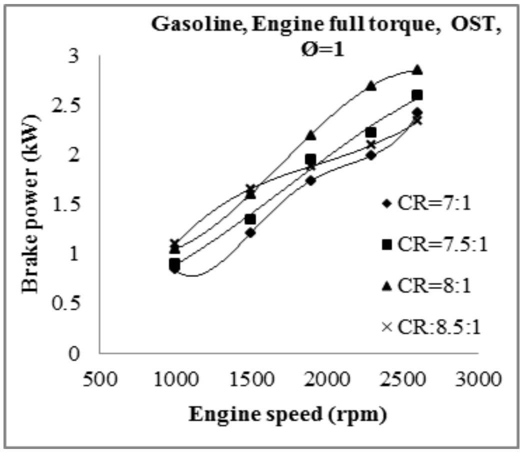


Fig. 3. CR effect on bp at variable engine speed for gasoline

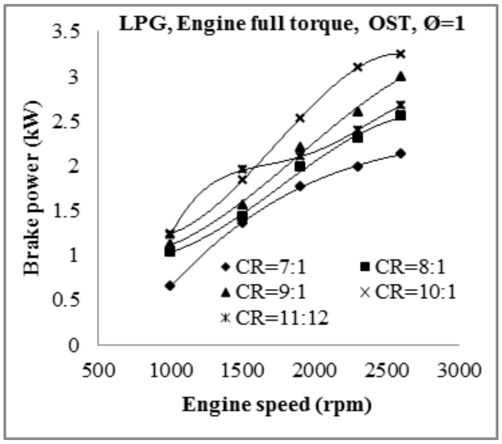


Fig. 4. CR effect on bp at variable engine speed for LPG

Figure (5) represents the variations in bp at variable engine speeds. LPG at CR=8:1 produced the lowest bp compared to the other conditions. LPG at its HUCR produced bp relatively equal to gasoline one except for high engine speeds. LPG entered the combustion chamber in gaseous phase reducing volumetric efficiency which resulted in reducing bp at high speeds.

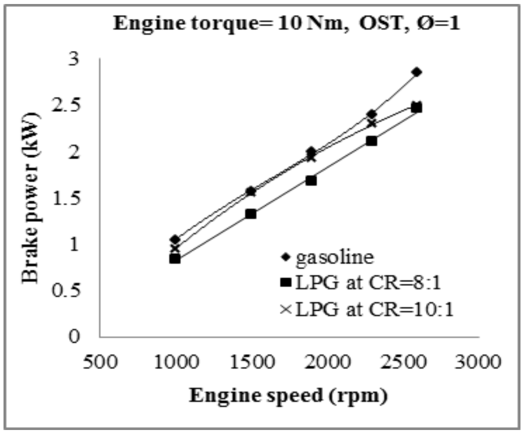


Fig. 5. Comparison of bp for gasoline and LPG at variable speed

BSFC for LPG at its HUCR is little less than that for gasoline, but at CR=8:1 it increased gasoline consumption, as Figure (6) manifests. AT CR=10:1 combustion chamber pressure and temperatures were high. In addition to high heating values of LPG, the cooperation of these two parameters reduced bsfc for LPG at its HUCR. At CR= 8:1 another parameter interfared in increasing bsfc of LPG, it was the declination of volumetric efficiency.

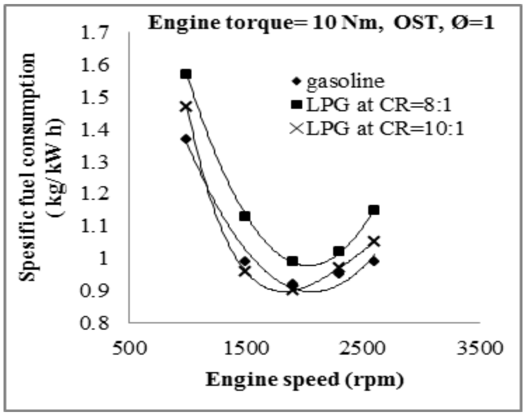


Fig. 6. Comparison of bsfc for gasoline and LPG at variable speed

Due to the gaseous phase of LPG entering combustion chamber, its volumetric efficiency reduced compared to gasoline as Figure (7) shows. Gasoline evaporates at carburetor absorbing heat of evaporation from surrounding air, reducing air temperature and increasing its density causing higher volumetric efficiency. Increasing CR improved LPG volumetric efficiency and bring it close to gasoline one.

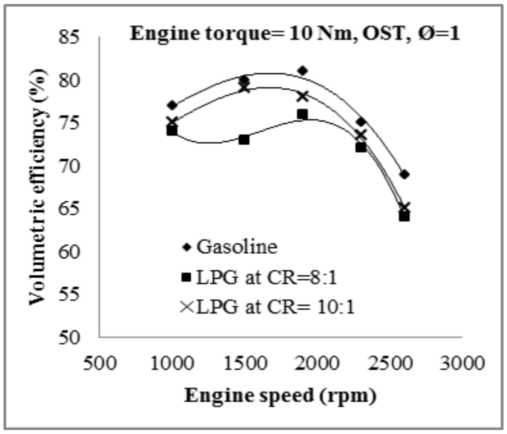


Fig. 7. Comparison of volumetric efficiency for gasoline and LPG at variable speed

Figure (8) represents the effect of engine speed on brake thermal efficiencies for the studied cases. Brake thermal efficiency depends on bsfc, when it reduced brake thermal efficiency increases. This is why brake thermal efficiency with using LPG at its HUCR was less than that for gasoline. While at HUCR for gasoline LPG bsfc was higher than that for gasoline.

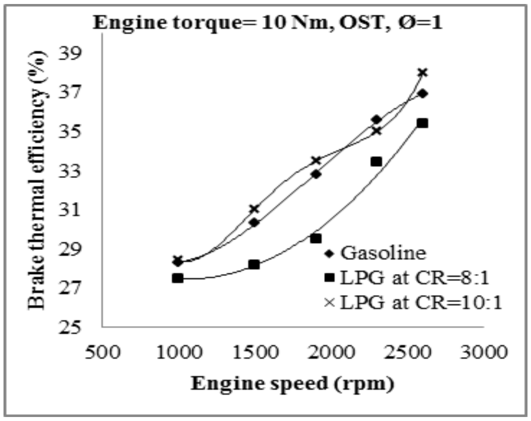


Fig. 8. Comparison of brake thermal efficiency for gasoline and LPG at variable speed

Figure (9) illustrates the effect of engine speed variation on exhaust gas temperatures for the studied cases. Gasoline produced the higher exhaust gas temperatures taking advantages of its higher volumetric efficiency, working at its HUCR and its high heating value. LPG at its HUCR produced exhaust gas temperatures close to those produced by gasoline but still less than it. The depreciation of its volumetric efficiency caused this reduction. At CR=8:1 many parameters operated against LPG, like low volumetric efficiency and lower pressure and temperature inside combustion chamber.

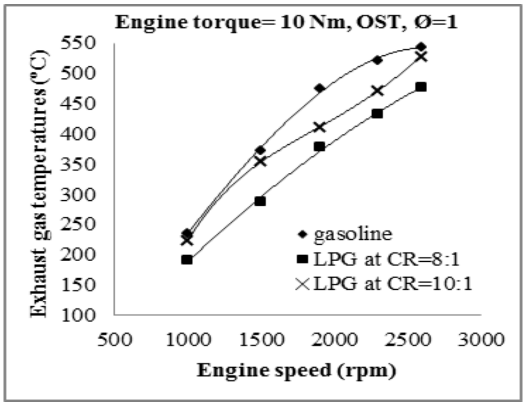


Fig. 9. Comparison of brake thermal efficiency for gasoline and LPG at variable speed

Figure (10) shows the effect of engine torque variation on bp for the studied cases. Increasing load increased bp more than gasoline for LPG at CR=10:1. Increasing torque increased combustion chamber temperatures which improved LPG results. While working at CR=8:1 reduced bp for LPG compared with gasoline. The optimum presentation of LPG engines is by increasing its compression ratio to HUCR for it.

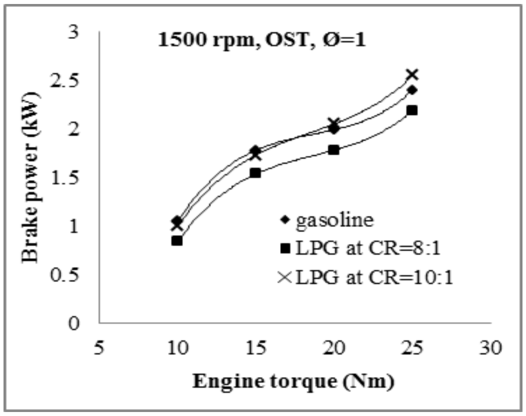


Fig. 10. Comparison of bp for gasoline and LPG at variable torques

Figure (11) represents engine torque variation effect on bsfc for the studied cases. BSFC for gasoline was less than that of LPG at low and medium torques, but at high torques LPG bsfc was less at its HUCR. Operating the engine at HUCR for LPG produced best bp and the least bsfc, which means the optimum operation.

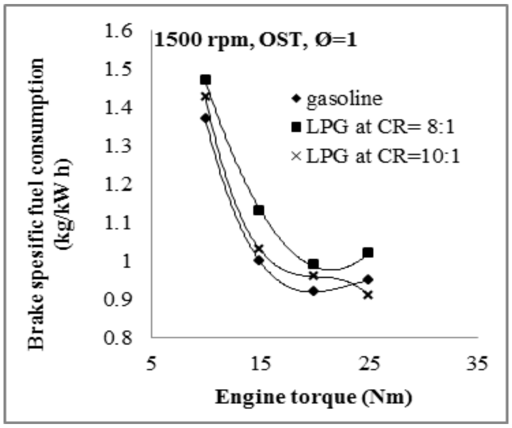


Fig. 11. CR effect on bp at variable engine speed for LPG

Figure (12) demonstrates that volumetric efficiencies for LPG at its HUCR improved at medium torques and desends slightly at high torques compared with gasoline. Operating LPG engine at any compression ratio less than HUCR will cause losses in bp, bsfc and lower volumetric efficiency as the figure clarifies.

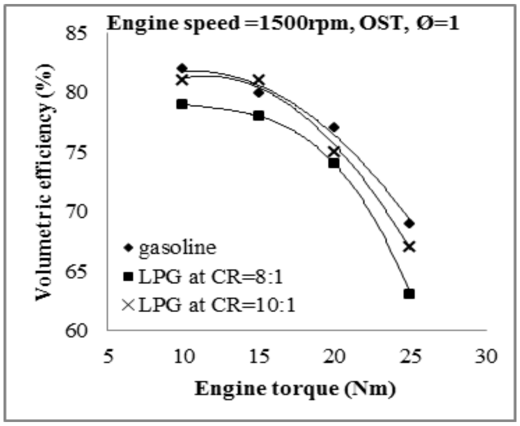


Fig. 12. Comparison of volumetric efficiency for gasoline and LPG at variable torques

Figure (13) demonstrates that LPG at its HUCR resulted in higher brake thermal efficiencies at medium torques compared to gasoline, while at low and high torques gasoline surpassed LPG. At low torques the combustion chamber temperature is low and at high torques more LPG (with its gaseous phase) must be entered to combustion chamber to preserve the required speed.

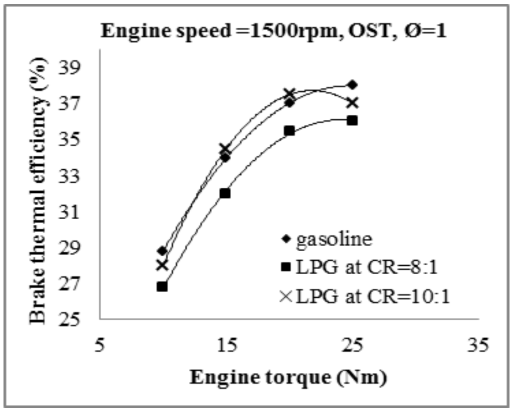


Fig. 13. Comparison of brake thermal efficiency for gasoline and LPG at variable torques

Figure (14) represents the effect of engine torque on exhaust gas temperatures for the studied cases. Gasoline still emitting the higher temperatures compared with LPG. LPG at its HUCR emitted exhaust gas temperatures close to that emitted by gasoline. While LPG at CR=8:1 still emitting lower exhaust gas temperatures.

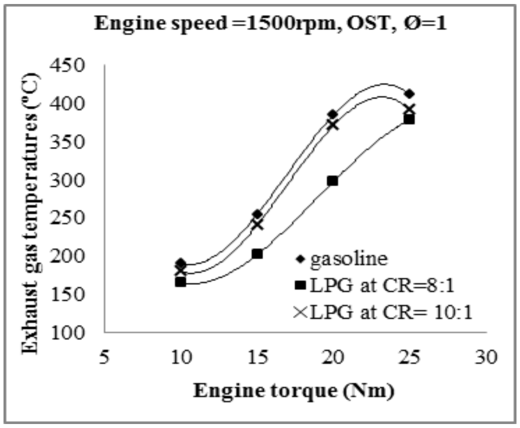


Fig. 14. Comparison of exhaust gases temperatures for gasoline and LPG at variable loads

Conclusions

The aim of this work was to compare engine performance when it was fueled with gasoline and LPG. The engine performance of gasoline as the reference fuel was compared with its performance when it was fueled with LPG as international expected alternatives. LPG engine performance was studied at two cases: when engine run at CR=8:1 (which is HUCR of gasoline) and when it was run at CR= 10:1 (Which is the HUCR of LPG). The results show that:

1. HUCR for gasoline was 8:1, and it was 10.0:1 for LPG.
2. Gasoline bp precedes the other fuels brake powers, when the engine operated at gasoline HUCR=8:1. But LPG at its HUCR brake powers converged to gasoline bp.
3. Bsfc reduced by using LPG at its HUCR, while at CR=8:1 it became high.
4. Volumetric efficiency reduced by using LPG due to its gaseous nature, but it was improved when the engine was run at HUCR.
5. Brake thermal efficiency depends on bsfc and bp, so LPG preceded gasoline at medium speeds and torques.
6. Exhaust gas temperatures reduced by using LPG, the minimum values were when the engine operated at CR= 8:1. The maximum values were for gasoline share.
7. Using LPG as a fuel for spark ignition engine demands increasing engine compression ratio

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