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Experimental Assessment of Single (Petrol) or Dual Fuel Mode (LPG-Petrol) for Internal Combustion Engines in Iraq

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Abstract: This research is concerned with investigations switching the conventional fuel (gasoline) by an alternative fuel 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. An instrumented experimental setup is prepared to conduct practical tests of various operating parameters such as Brake specific fuel combustion, brake power, brake thermal efficiency, volumetric efficiency engine speeds, air fuel ratio in cylinder pressure, exhaust gas temperature, CO, CO_2, CxHy, O_2 and NOx. Concerns have been prepared for better understanding of operating conditions and constrains for LPG fueled internal combustion engine. The obtained experimental results revealed that LPG fuel improves the brake specific fuel consumption and brake thermal efficiency but reduces the brake power compared to gasoline fuel operation, the maximum of percentage deviation BSFC in gasoline fuel compare with LPG fuel reported is 3.11% for engine brake power equals to 10 kW when compression ratio equal 9.9:1. The maximum cylinder pressures predicted for LPG are lower than that produced by gasoline fuel which causes no damage to engine structural elements. LPG reduces the engine volumetric efficiency compared to that produced by gasoline fuel, so, engine effective power is decreased, the maximum volumetric efficiency in all cases is reached at 3500 rpm and for equals to 10 kW. The volumetric efficiency was 76.8% for LPG and 85.9% for gasoline when compression ratio equals to 9.9:1. Compression ratio and equivalence ratio have a significant effect on both performance and emission characteristics of the engine and have to be carefully designed to achieve the best engine performance characteristics. The equivalence ratio is higher for gasoline than LPG because the first has higher BSFC due to increase in actual air-fuel ratio required for combustion, that inversely proportional with the equivalence ratio. In a general behavior the exhaust gases temperature increases with increasing engine speed, compression ratio and brake power for both fuels. For the same brake power and engine speeds, it is found that exhaust gas temperatures for gasoline fuel be higher at all engine speeds compared that for LPG fuel, the maximum exhaust gas temperature reported is 706°C for LPG fuel while that for gasoline is 741.4°C at point 1 for brake power on engine equals to 10 kW and compression ratio equals to 9.9:1. Gas emission of CO, CO_2, NOx and CxHy with LPG fuel is found lower than that produced by gasoline fuel. O_2 emissions for LPG fuel be higher compared to that produced by gasoline fuel.

Key words: SI engine, gasoline, Liquefied Petroleum Gas (LPG), performance, exhaust emission, equivalence ratio

INTRODUCTION

The combustion engines derive their name from the fact that the transformation of the energy from chemical (that is to say contained into the fuel that is being burned) to mechanical and therefore available to the motor shaft to operate various devices (cars, trucks, alternators, trains, etc. Yadav *et al*. (2014). Internal combustion engines have been in use for more than a century and have undergone tremendous changes in design, materials used and operating characteristics. Never ones during their long history of development have they lost their importance as the planet most widely used prime movers. It is a well-known fact that petrol engine is one of the most fuel-efficient power producing units in use today. During the last decade, gaseous fuels such as Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG) have been widely used in commercial vehicles and promising results were obtained in terms of fuel economy and exhaust emissions (Bayraktar and Durgun, 2005). LPG

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as a low carbon and high octane number fuel produces lower Carbon dioxide (CO_2) emission as compared to gasoline (Yeom *et al.*, 2007). LPG is obtained from the processes of natural gas and crude oil extraction and as by product of oil refining. Its primary composition is a mixture of propane and butane. It has higher octane number (105) than petrol (91-97) and therefore, can be operated at higher compression ratio with increased efficiency. In a study conducted by Yoong and Watkins (2001), simulation results obtained confirmed that the use of LPG in internal combustion engines yielded higher thermal efficiency and better fuel economy compared to unleaded gasoline. This is due mainly to the higher octane rating which permits greater engine compression ratio without the occurrence of knock. Furthermore, LPG also has higher heating value compared to other fuels and can be liquefied in a low pressure range of 0.7-0.8 MPa at atmospheric pressure (Lee and Ryu, 2005). Many investigations have reported favorable results from emission perspectives when LPG is use as an alternative fuel in spark ignition engines. Emissions from LPG vehicles are significantly lower than conventionally fuelled vehicles (Price *et al.*, 2004). Snelgrove *et al.* (1996) stated that over the European test cycle at 25°C an LPG operated vehicle reported Hydrocarbon (HC) emissions as 40% lower, Carbon monoxide (CO) as 60% lower and Carbon dioxide (CO_2) as substantially reduced.

In addition, since, LPG has lower carbon content than gasoline, it virtually produces zero emissions of particulate matter (Schifter *et al.*, 2000) and lowered amount of NOx emission as well. The present research is therefore carried out with the particular attention of comparing the performance and emission characteristics of a four cylinder four-stroke SI engine running on both gasoline or LPG fuels. The experimental and computational information obtained in this study would be useful to establish and compare the performance of LPG fueled engine and its gasoline counterpart.

MATERIALS AND METHODS

Experimental setup and procedures

Experimental apparatus: The four-stroke spark ignition engine used in this study has a displacement of 1797 cc and a compression ratios of 9.9:1 and 10.25. It is a four cylinder, water cooled in piston combustion chamber and equipped with a Double Overhead Camshaft (DOHC). The detail specifications of the engine are listed in Table 1. The test rig used in this research mainly consists of the engine, a 30 kW Eddy current dynamometer and a e-Instruments International (Model E4500, UAS origin) exhaust gas analyzer is illesterated in Fig. 1. The test engine was mounted onto a steel structure which was fabricated in the researcher's machine workshop to

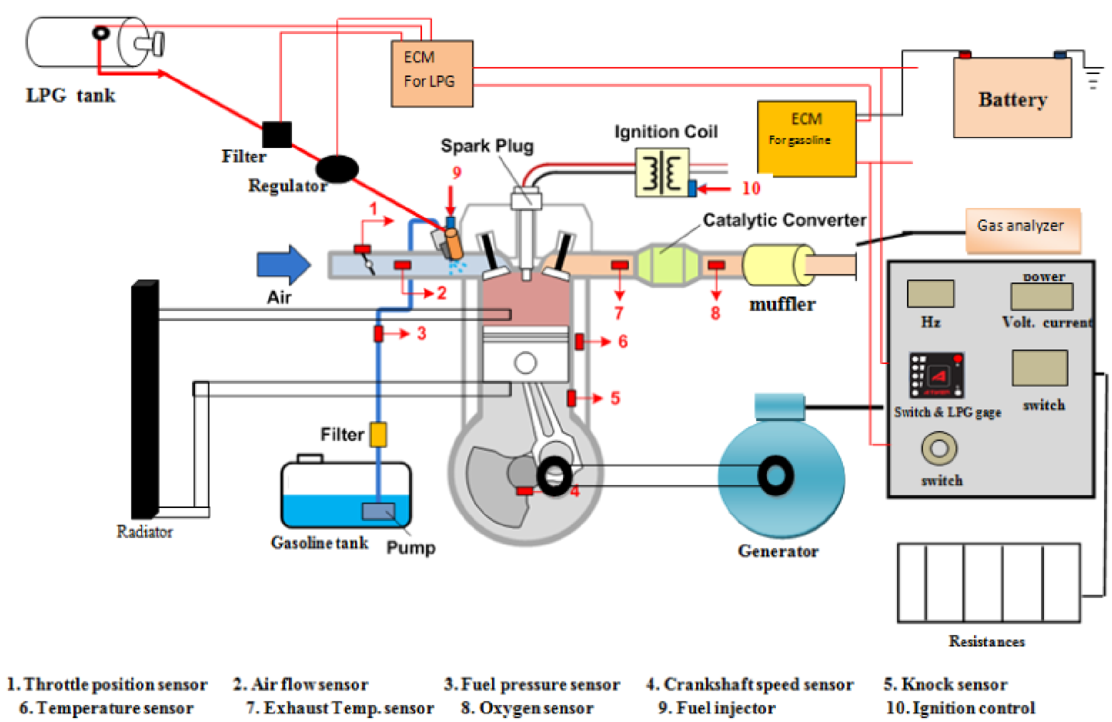
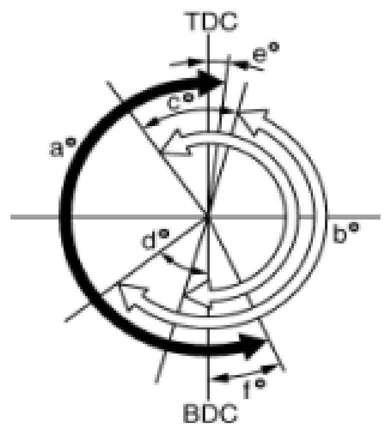


Fig. 1: Schematic diagram of experimental setup

Table 1: Specification of the test engine

Details		Specifications
Engine type		MR18DE
Cylinder arrangement		In-line 4
Displacement (cm^3)		1,797
Bore and stroke (mm)		84.0 * 81.1
Valve arrangement		DOHC
Firing order		1-3-4-2
Number of piston rings	Compression	2
	Oil	1
Compression ratio		9.9
Compression pressure (bar)	Standard	15.0
	Minimum	12.0
	Differential limit between cylinders	1
Valve Timing		



A	b	c	d	e	f
212	224	-8	52	7	25

facilitate the installation of the dynamometer. The height of the steel structure was meticulously calculated and designed to ensure perfect alignment with the dynamometer during installation. Throughout experimental testing, the whole engine and steel structure were placed on top of four-rubber damper-legs to alleviate the constant occurrence of vibration. The engine was coupled to 30 kW Eddy current dynamometer using a connector. The performance of the engine running on both gasoline and LPG were basically determined from data obtained from the dynamometer. The dynamometer permits different sets of speed and load measurement in this study. The e-Instruments International (Model E4500, UAS origin) exhaust gas analyzer was positioned at the exhaust tailpipe for emission measurement. The analyzer has the capability of sampling various exhaust products such as Hydrocarbon (CxHy), Carbon monoxide (CO) and Carbon dioxide (CO_2) and Oxides of Nitrogen (NOx). All exhaust gases were sampled at a point of around 40 cm beyond the exhaust valve.

Test procedures: Tests are carried out on SI four stroke-four cylinder engine fueled by either gasoline or LPG for two compression ratios (9.9:1 and 10.25) and different range of engine speeds (1000-3500 rpm) with steps of 500 rpm at various loads from (0-18 kW). In case of LPG fuel, the engine is started by gasoline alone, then the LPG fuel has been injected. Two sets of tests are performed as follows:

- Constant engine speed with variable loads from (0-18 kW)
- Constant engine load with variable speeds from 1000-3500 rpm with steps of 500 rpm

The following experimental methodologies are adopted:

- Step 1; The engine speed is set at a minimum speed 1000 rpm
- Step 2; The load is varied from 0-18 kW
- Step 3; The exhaust gas temperature is recorded by Atiker program or Autoboss device after the engine reach to study state
- Step 4; The time of fuel consumption during a certain volume is recorded
- Step 5; The exhaust gas analyzer is turned on almost for 20 min, then the concentration of CO, CO_2, HCO_2 and NOx are recorded
- Step 6; Calculate the engine characteristics (brake power, thermal efficiency, specific fuel consumption, brake mean effective pressure and total fuel consumption)
- Step 7; Repeating steps from 3-6 for each speed
- Step 8; Repeating steps from 3-7 for each type of fuel

Data analysis: SI engine performance parameters are calculated with the following Eq. 11 Heywood (1988) Pearson *et al*. (2002).

The Displacement Volume (VD) is equal to the volume of part of the cylinder envelope between Top Dead Center (TDC) and Bottom Dead Center (BDC). This volume can be calculated by:

$$V_d = \frac{\pi}{4} b^2 s \tag{1}$$

Where:
s = Stroke (mm)
b = Cylinder bore (mm)

The brake power, P_e (kW) and torque τ_e, (Nm) are calculated with the equations given:

$$P_e = I*V \tag{2}$$

Where :
I = Current (A)
V = Voltage

The brake specific fuel consumption, bsfc (g/kWh) is calculated with the following formula as:

$$bsfc = \frac{\dot{m}_f}{P_e} \tag{3}$$

where, the brake thermal efficiency of the system, η_{th} can be calculated with:

$$\eta_{th} = \frac{3600 P_e}{\dot{m}_f * Q_{LHV}} \tag{4}$$

where, Q_{LHV} represents Lower Heating calorific value of fuel (kJ/kg). Finally, volumetric efficiency is defined by:

$$\eta_v = \frac{2\dot{m}_{ia} 10^3}{60 \rho_{ia} V_d N} \tag{5}$$

where:
$\dot{m}_{ia}$ = Inlet air mass flow rate (g/h)
ρ_{ia} = Inlet air density (kg/m^3)

Inlet air density is calculated as:

$$\rho_{ia} = \frac{\rho_{ia} 10^3}{RT_{\rho_{12}}} \tag{6}$$

where, R is air constant (287 kJ/K.mol). A dimensionless measure of the fuel air ratio is the fuel air equivalence ratio, ϕ which is the actual fuel-air ratio, divided by the stoichiometric fuel/air ratio:

$$\phi = \frac{FA}{FA_S} \tag{7}$$

The equivalence ratio has the same value on a mole or mass basis. If ϕ<1 the mixture is lean, if ϕ>1 the mixture is rich and if = 1 the mixture is stoichiometric.

Error analysis: The measurements were repeated 5 times for each test and the average value has been taken into account. Data that lie outside the probability of normal variations will incorrectly offset the mean value inflate the random error estimates. Therefore, a Chauvenet criterion was used to detect such data points known as outliers. Performance parameters involve a number of independent variables. Thus, the uncertainty of each variable affects the result by propagating. Each independent variable x_i involves systematic uncertainty B_{xi} and measurement standard random uncertainty P_{xi}. The true mean involving total uncertainty is:

$$R = \bar{R} \pm u_R \tag{8}$$

where, $\bar{R}$ is the mean value of the result. The propagation of random and systematic uncertainties through the variables to the result are given, respectively by:

Table 2: Properties of fuels

Properties	LPG	Gasoline
Density at 15°C (kg/cm^3)	0.554	0.737
Lower heating value (MJ/kg)	45.25	43.96
Octane number	104	82
Boiling temperature (°C)	2.2	210
Vapor pressure at 37.8°C (kg/cm^2)	8-10	0.45-0.62

$$p_x = \left(\sum_{i=1}^{N} [\theta_i p_{xi}]^2 \right)^{1/2} \quad (9)$$

$$B_x = \left(\sum_{i=1}^{N} [\theta_i B_{xi}]^2 \right)^{1/2} \quad (10)$$

where, u_R is the sensitivity index. θ_i can be as combined uncertainty.

$$u_R = \pm \left[B_x^2 + \left(t_{V,\,99} p_x \right)^2 \right]^{1/2} \quad (11)$$

where, t is an estimator and can be obtained from tables called the student's t distribution tables depending on the confidence levels.

All the total uncertainties of performance characteristics are calculated as described previously. The accuracy and total uncertainty of characteristics calculated with respect to measured values are shown in Table 2.

RESULTS AND DISSECTION

Engine performance

Brake specific fuel consumption: Figure 2 shows a comparison of experimental and computational results of brake specific fuel consumption (gasoline or LPG) against engine speed (rpm) for two compression ratios (9.9:1 and 10.25:1) and for brake power of 10 kW. The results show that as the engine speed increases, the BSFC is decreased gradually to its minimum value at engine speed of 3000 rpm, then increases as the speed was increased to 3500 rpm. This behavior was observed for both fuels gasoline and LPG. The maximum of percentage deviation BSFC in gasoline fuel compare with LPG fuel reported is 3.11% when compression ratio equal 9.9:1. While that obtained for compression ratio of 10.25 was 3.51 % for LPG compared with gasoline fuels. Since, the BSFC is the measure of the "fuel economy", lower BSFC should be the ultimate target in all engine designs and adding LPG system to the SI engine was beneficial towards improving BSFC. It is also evident that the BSFC deteriorates as the engine speed approaches 3500 rpm and this was attributed to the increase power required to overcome the frictional power. Since, frictional power loss is proportional with engine speed, extra fuel is required to ensure sustainable engine operation which explains a sudden increase in BSFC during the window of operation from 3000-3500 rpm.

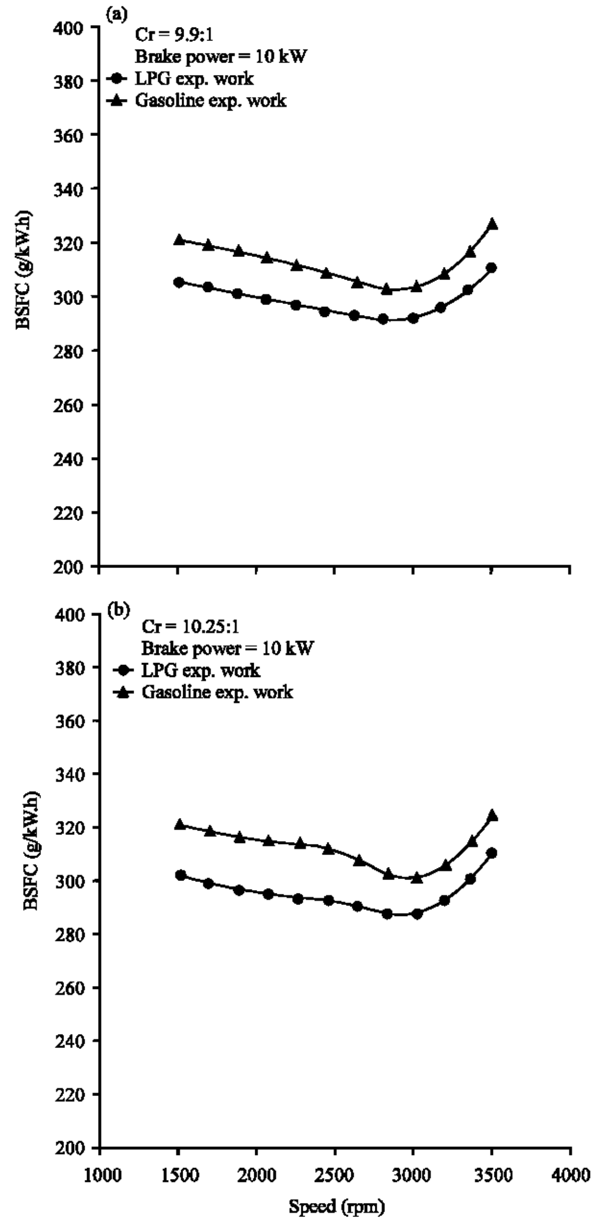


Fig. 2: Variation of brake specific fuel consumption versus engine speed

Brake power: Figure 3 presents the relation between brake power (kW) and engine speed (rpm) for LPG and gasoline fuels for the two compression ratio (9.9:1 and 10.25:1). Peaks of brake power was indicated at engine speed of 3500 rpm for all experimental results. Brake

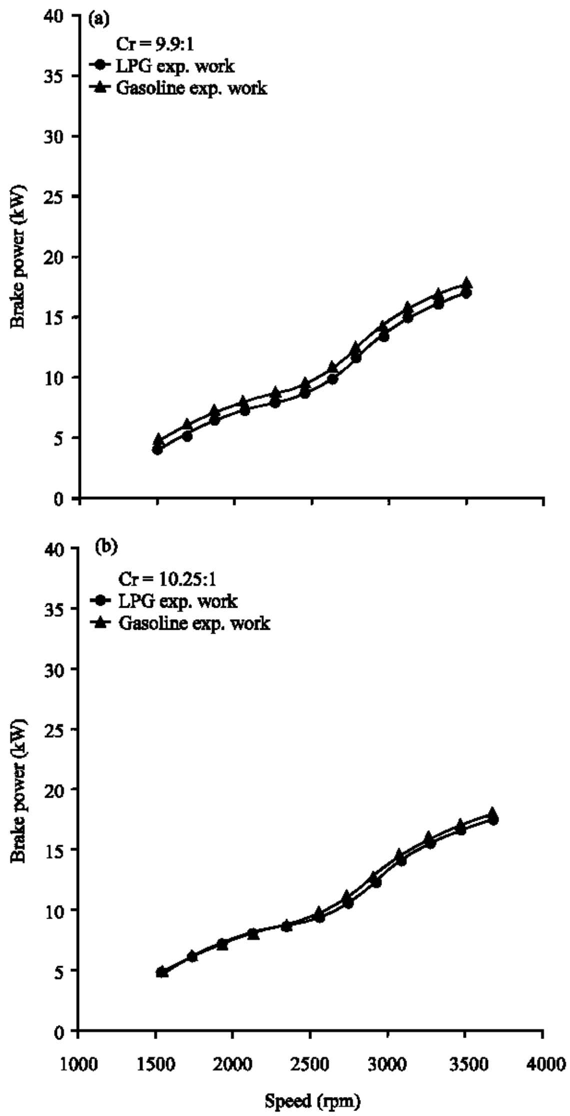


Fig. 3: Variation of brake power versus engine speed

power increases rapidly with increasing of engine speed for each compression ratios equal to 9.9:1 and 10.25:1, the maximum of percentage deviation brake power in gasoline fuel compare with LPG fuel reported is 16.7, 11.1, 9.1, 6.25 and 5.26% at engine speeds 1500, 2000, 2500, 3000 and 3500 rpm, respectively for compression ratio equal 9.9:1. While, the maximum of percentage deviation brake power in gasoline fuel compare with LPG fuel reported is 15.4, 8.5, 7.8, 5.9 and 5.3 at engine speeds 1500, 2000, 2500, 3000 and 3500 rpm, respectively compression ratio equals to 9.9:1. Further for a given engine speed, the engine brake power increases as compression ratio increases. This can be explained that the brake power is the function of torque and speed. The reduction in the brake power

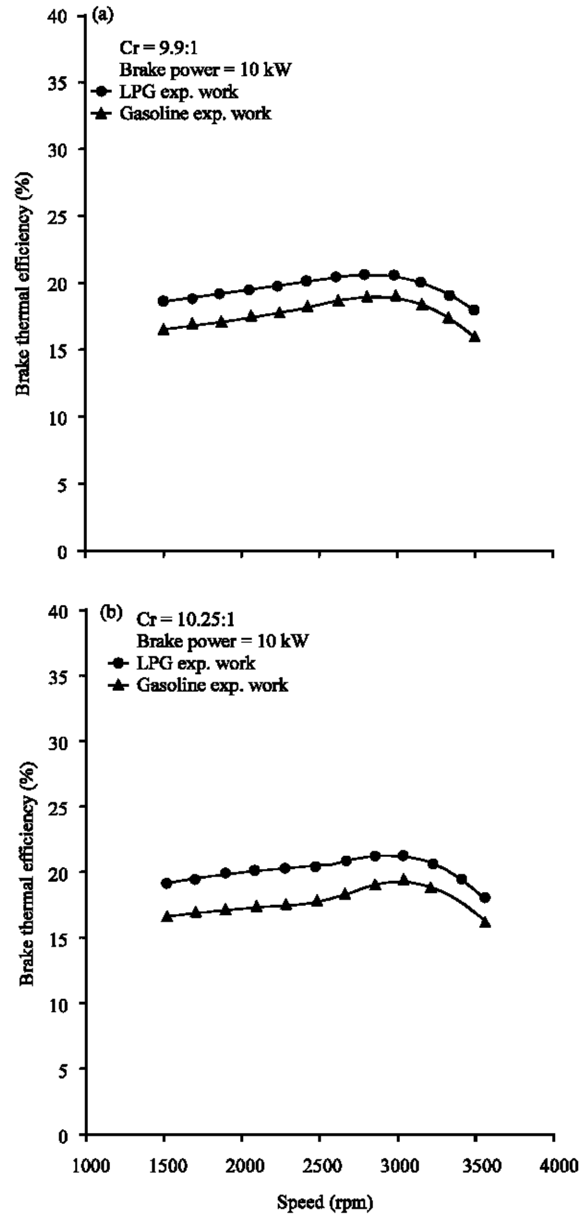


Fig. 4: Variation of brake thermal efficiency versus engine speed

varies between 5-16% for LPG compared to gasoline fuel for experimental results. It is obvious that the addition of LPG was not beneficial to improve the power output of the engine. Due to the displacement of the fresh charge at the chamber during the intake stroke which resulted in a decreased volumetric efficiency throughout the engine.

Brake thermal efficiency: Figure 4 shows the brake thermal efficiency for different values of engine speed (rpm) different operating fuel (LPG and gasoline) and two compression ratio of (9.9:1 and 10.25:1). The peak brake thermal efficiency in all cases is reached at 3000 rpm. The range of brake thermal efficiency varies from 25.1% (engine using gasoline fuel) to 30.3% (engine using LPG fuel) at compression ratio equal 9.9:1. while its varies from 25.9% (engine using gasoline fuel) to 31.4% (engine using LPG fuel) at compression ratio equal 10.25:1. The maximum of percentage deviation of peak brake thermal efficiency in gasoline fuel compare with LPG fuel at 3000 rpm for compression ratio equal to 9.9:1 and 10.25 equal to 4.2 and 4.7%, respectively. LPG addition has inconsiderable improvement in terms of brake thermal efficiency. The reason for this behavior is related to the properties of gasoline and LPG when they are used as fuel in internal combustion engines. The heat of engine will be increased for LPG compared with gasoline. This is due to the higher heating value of LPG (45.25 MJ/kg) compared to gasoline (43.96 MJ/kg). Thus, at a given engine operational speed, the amount of heat release will be greater for LPG fuel. This will subsequently leads to higher engine brake thermal efficiency. Higher H/C ratio for LPG compared to gasoline also ensures adequate oxygen molecule for complete carbon combustion for useful thermal conversion which improves the thermal efficiency of the engine. Where, the higher rate of fuel utilization and higher air to fuel ratio greatly increases the combustion rate of the engine, since, more air and fuel is introduced to the system. At engine speeds higher than 3000 rpm, the thermal engine efficiency starts to decrease slightly due to the effects of engine knocks which not only causes output power losses but also damages the engine.

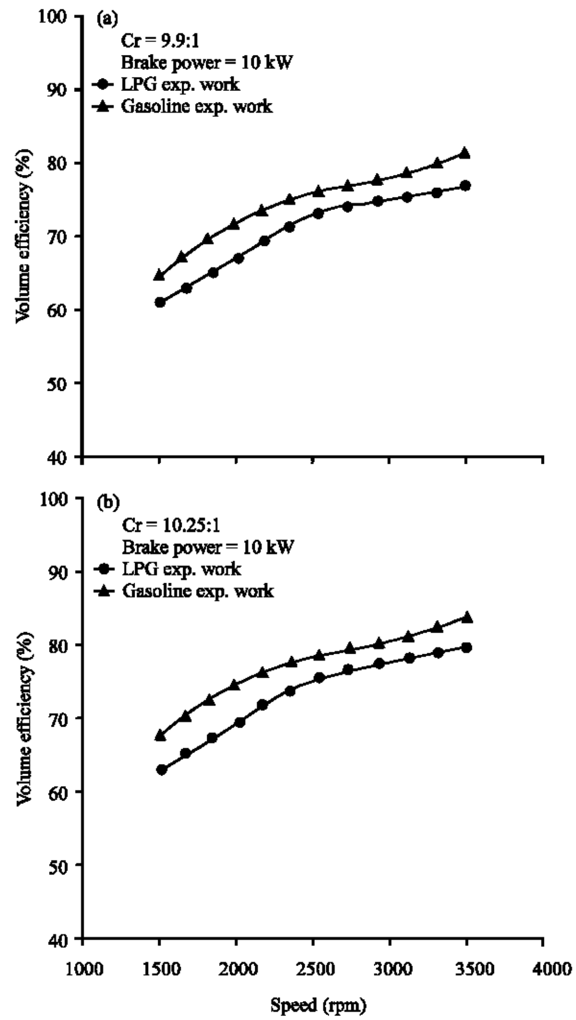


Fig. 5: Variation of volumetric efficiency versus engine speed

Volumetric efficiency: Figure 5 shows the volumetric efficiency verses engine speed (rpm) and different operating fuels (LPG and gasoline), brake power equals to 10 kW and two compression ratios (9.9:1 and 10.25:1). It was found that the volumetric efficiency increases with an increase of compression ratio and engine speed. The maximum volumetric efficiency in all cases is reached at 3500 rpm. The volumetric efficiency was 76.8% for LPG and 83.9% for gasoline when compression ratio equals to 9.9:1. While that compression ratio equals to 10.25:1 was79.6% for LPG and 85.9% for gasoline. The maximum difference of volumetric efficiency at 3500 rpm between gasoline and LPG was 4.65 and 4.2 % for compression ratio 9.9:1 and 10.25, respectively. Increasing compression ratio improved engine volumetric efficiency used LPG fuel and bring it close to gasoline. Major reason to justify lower power output is volumetric efficiency. Volumetric efficiency of gasoline is higher than LPG because gasoline is injected in a liquid form and as it vaporizes, it cools air, thus, produces improved volumetric efficiency. The vaporized LPG fuel leads to discharging intake air because gaseous nature will occupied the space and reduce the amount of air entering in the engine cylinder. Most of the LPG conversion inject the fuel at intake system or intake manifold and the vaporization of fuel depends on few factor such as pipes thermal insulation ambient air and liquid fuel temperatures, shape and dimensions of the intake system, heat of vaporization of the fuel, load and rotational speed of the engine. Pumping loss associated with conversion system hardware also is the reason in loss volumetric efficiency. It was found that the volumetric efficiency of LPG was less than gasoline.

In-cylinder pressure: Figure 6 presents the relation between cylinder pressure of SI engine and crank angle for LPG and gasoline fuel, brake power equals to 10 kW,

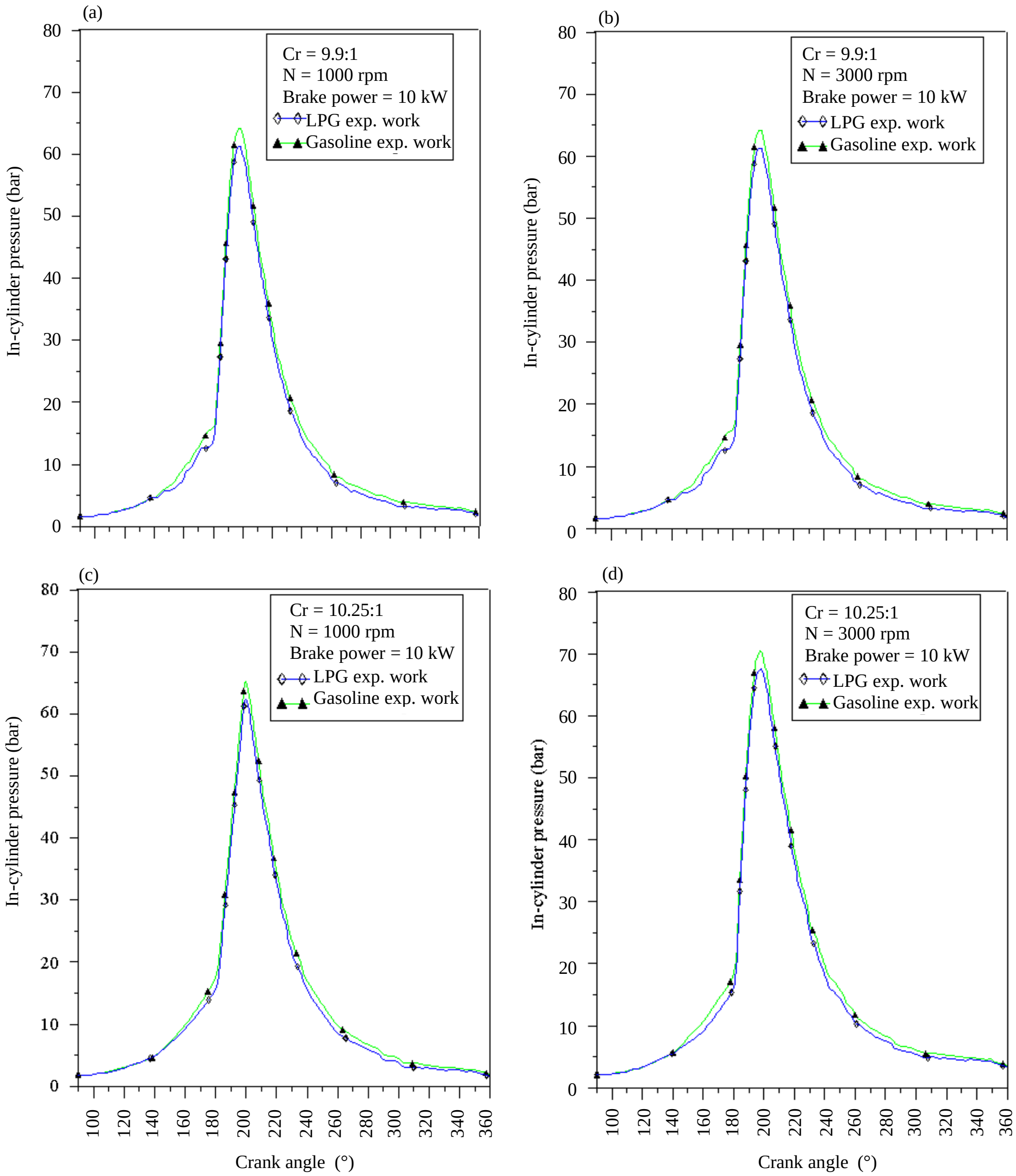


Fig. 6: Variation of in-cylinder pressure versus crank angle

engine speed (1000 and 3000 rpm) and two compression ratios (9.9:1 and 10.25:1) for experimental results. In general, the same global behavior for cylinder pressure via crank angle is found except the differences in the value and timing of peak pressure which depended on the difference in the fuel type, brake power, engine speed and compression ratio. It can be seen that as engine speed increases maximum pressure increases reaching its maximum value at 3000 rpm. The increase of speed from 1000-3000 rpm, causes an increase in the maximum pressure from (62-71.5) bar for gasoline and from (60-67.12) bar for LPG when 9.9:1 compression ratio. While that for compression ratio equals to 10.25:1, the maximum pressure increases from (64.4 -71.8) bar for gasoline and from (61.5-70) bar for LPG at brake power equals to 10 kW. Figure 6 indicated that there is an increase in the maximum pressure from (61-74.8) bar. This is because the high flame speed for gasoline fuel and the chemical properties of gasoline which contains the amount of carbon atoms higher from LPG, therefore, the energy is higher. Which in turn causes clear reduction in the combustion duration.

Emission characteristics

Exhaust gas temperature: The exhaust temperature is one of engine performance indicators. The exhaust

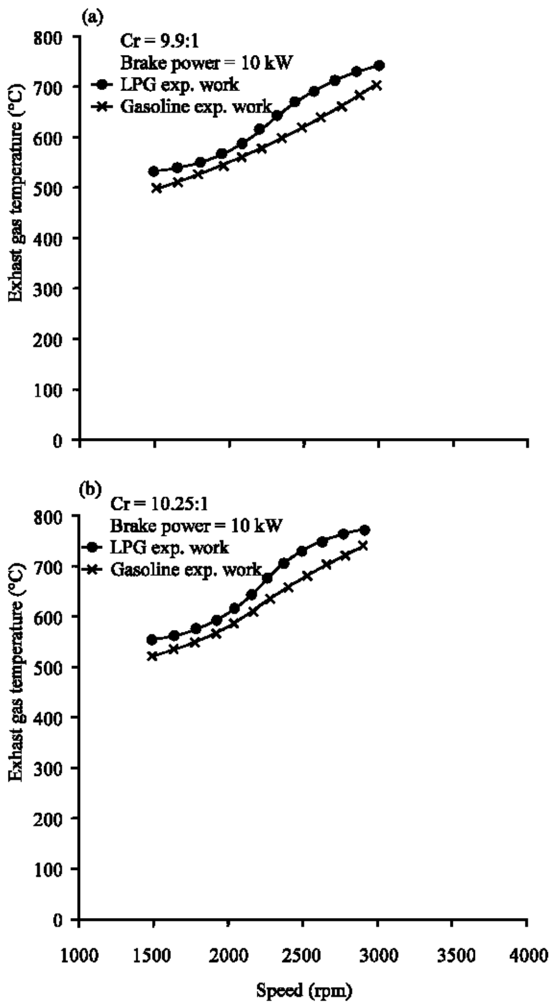


Fig. 7: Variation of exhaust gas temperature versus engine speeds

temperature was measured for various of engine speeds, different fuels (gasoline and LPG) and compression ratio. The variation of exhaust gas temperature at the selected four locations versus engine speed (rpm) under different operating fuels (LPG and gasoline) and brake power equals to10 kW is shown in Fig. 7 for compression ratio equals to 9.9:1 and 10.25:1. In general the exhaust gas temperature increases with increased engine speed and compression ratio. Similar trends are also observed when LPG fuel is used. For the same brake power and engine speeds, it is found that exhaust gas temperatures for gasoline fuel be higher at all the engine speeds compared that for LPG fuel. The increase in exhaust gas temperature is a direct indicator to the increase in the energy released in the combustion chamber. The increase in released energy is either due to an increase in the energy consumption rate or/and the complete combustion of available fuel. The maximum exhaust gas temperature reported is 706°C for LPG fuel while that for gasoline is 741.4 for compression ratio equals to 9.9:1. When engine compression ratio equals to 10.25:1, the maximum exhaust gas temperature is 742°C for LPG fuel compared with that for gasoline is 773°C. The increase in exhaust gas temperature is due to the increase in peak cylinder temperature and peak pressure, due to faster running of fuel combustion. Gasoline produced the higher exhaust gas temperatures taking advantages of its higher volumetric efficiency and its higher heating value. The depreciation of LPG volumetric efficiency caused this reduction in exhaust temperature. Many parameters operated against LPG, like low volumetric efficiency and lower pressure and temperature inside combustion chamber. These are behind the reason of temperature rise with increasing of the speed to inject largest quantity of fuel. It can be noted that the temperature of the exhaust gas at point 1 was higher than other points where the temperature of exhaust gas outside the combustion chamber is measured before entering the exhaust system (converter catalytic and muffler). The temperature of other points are gradually decreases as they pass through the converter catalytic and muffler which in turn flue gases reduces the temperature through heat exchange with the atmosphere by (convection, conduction and radiation).

Carbon monoxide (CO): The variation of CO emission versus engine speed (rpm), different operating fuels (LPG and gasoline) and brake power equals to10 kW are present in Fig. 8 for two compression ratio equals to 9.9:1 for two compression ratio equals to 10.25:1. CO is produced when the fuel does not burn completely, the carbon in the fuel will be converted to CO. Note that emissions of CO increases with increasing of engine speed, compression ratio and brake power. For the same brake power and speed, it is seen that CO emissions with LPG fuel be lower at all engine speeds compared to that produced by gasoline fuel. The maximum of percentage deviation CO contain in gasoline fuel compare with LPG fuel reported is 89% for compression ratio equal 9.9:1. When compression ratio equals to 10.25:1. The maximum of percentage deviation CO contain in gasoline fuel compare with LPG fuel reported is 88.1%. Note that the CO emissions at point one (exit combustion chamber) entering the exhaust system (converter catalytic and muffler) is higher from other points. A large decrease in CO emissions is indicated as flue gases pass through the converter catalytic, since, the converter catalytic was built from a porous honeycomb or pellet geometry to expose the exhaust gases to a larger surface made of small

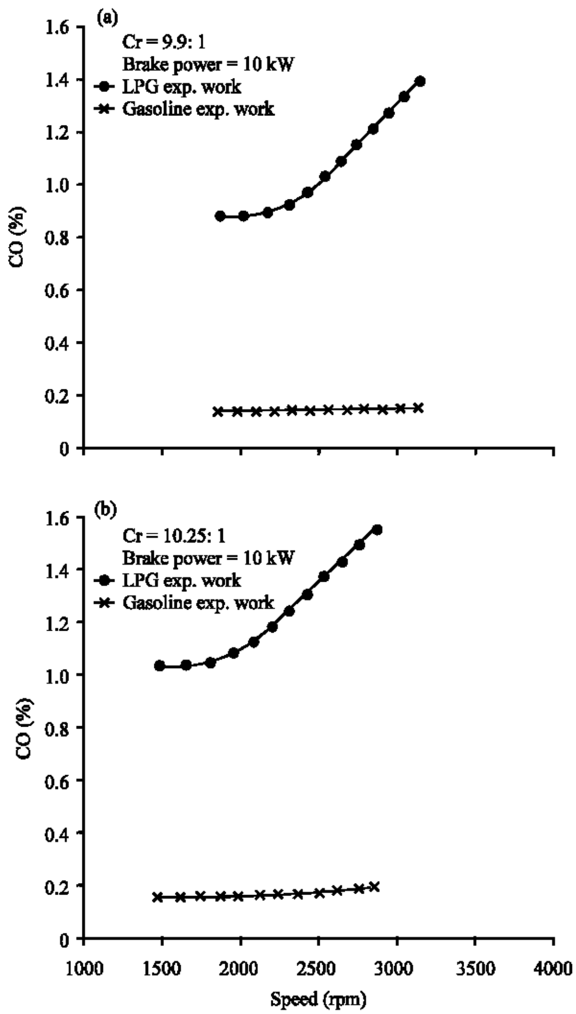


Fig. 8: Variation of CO emission versus engine speed

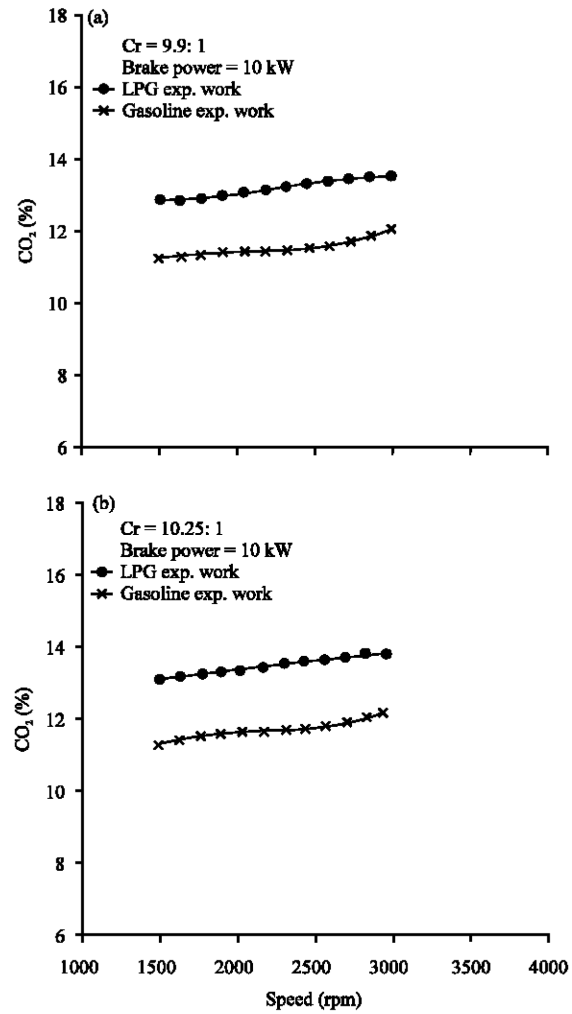


Fig. 9: Variation of CO_2 emission versus engine

particles (<50 nm) of one or more of the noble metals, Platinum (Pt), Palladium (Pd) and Rhodium (Rh). Platinum is the principal metal used to remove CO (Ferguson, 2016).

Carbon dioxide (CO_2): The variation of CO_2 emission versus engine speed (rpm) for different operating fuels (LPG and gasoline) and brake power equals to 10 kW with two compression ratio equal to 9.9:1 and 10.25:1 is illustrated in Fig. 9. CO_2 is produced when the fuel does burn completely, the carbon in the fuel will converted into CO_2. When engine speed increases and compression ratio so, the CO_2 emissions follow a minor increase. For the same brake power and engine speed, CO_2 emissions with LPG fuel were found to be lower than that for gasoline fuel, since, LPG fuel has lower carbon content than gasoline and it produces less CO_2 which plays a major role in global warming during combustion. Measured of CO_2 emission was lower for LPG fuel compared with gasoline fuel. The maximum of percentage deviation CO_2 content in gasoline fuel compare with LPG fuel reported is 13.6% for compression ratio equal 9.9:1. When engine compression ratio equals to 10.25:1. The maximum of percentage deviation CO_2 contain in gasoline fuel compare with LPG fuel reported is 14.

Nitrogen oxides (NOx): The variation of NO_x emission versus engine speed (rpm), different operating fuels (LPG and gasoline) and brake power equals to10 kW with two compression ratio equal to 9.9:1 and 10.25:1 are illustrated in Fig. 10. Generally as the engine speed increases the NOx emissions also show an increasing trend. NOx emissions increases with increased engine speed and compression ratio. For the same brake power and speed, it is seen NOx emissions with gasoline fuel was found higher at all engine speeds compared with LPG fuel. This

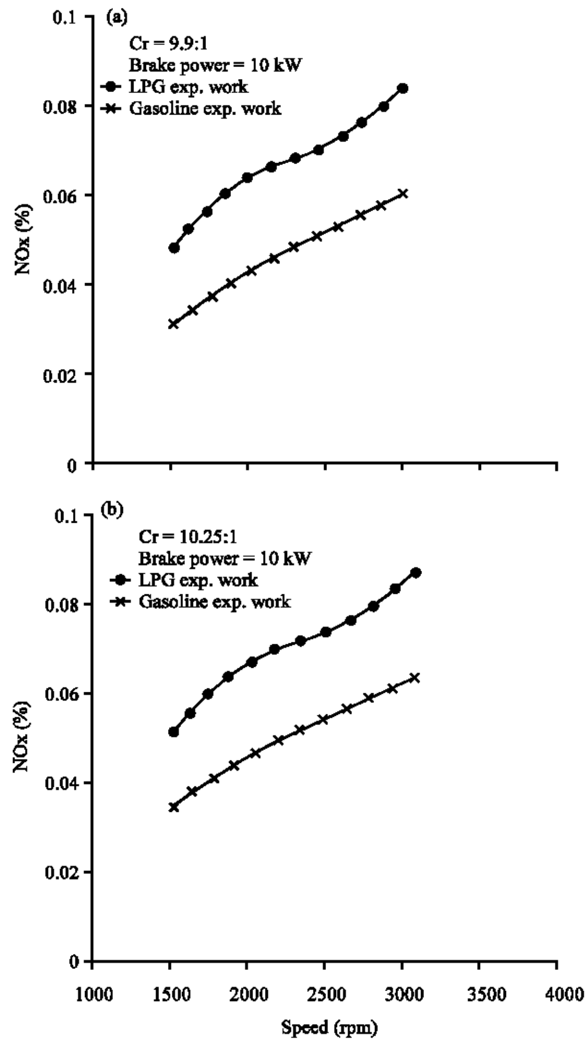


Fig. 10: Variation of NOx emission versus engine

can be attributed to increase in fuel consumption as load increases which lead to increase in temperature during combustion process thus increase NOx. Due to increase in compression ratio the temperature at the end of compression increases, hence, increase in temperature which gives higher NOx. The maximum of percentage deviation NOx content in gasoline fuel compare with LPG fuel reported is 35.5% for compression ratio equal 9.9:1. When compression ratio equals to 10.25:1. The maximum of percentage deviation NOx contain in gasoline fuel compare with LPG fuel reported is 32%. Note that the NOx emissions is higher at higher engine speed due to combustion temperatures increased depending on the increments of the fuel mass and this results in higher NOx emissions.

Hydrocarbons emissions (CxHy): The variation of CxHy emission versus engine speeds (rpm), different operating

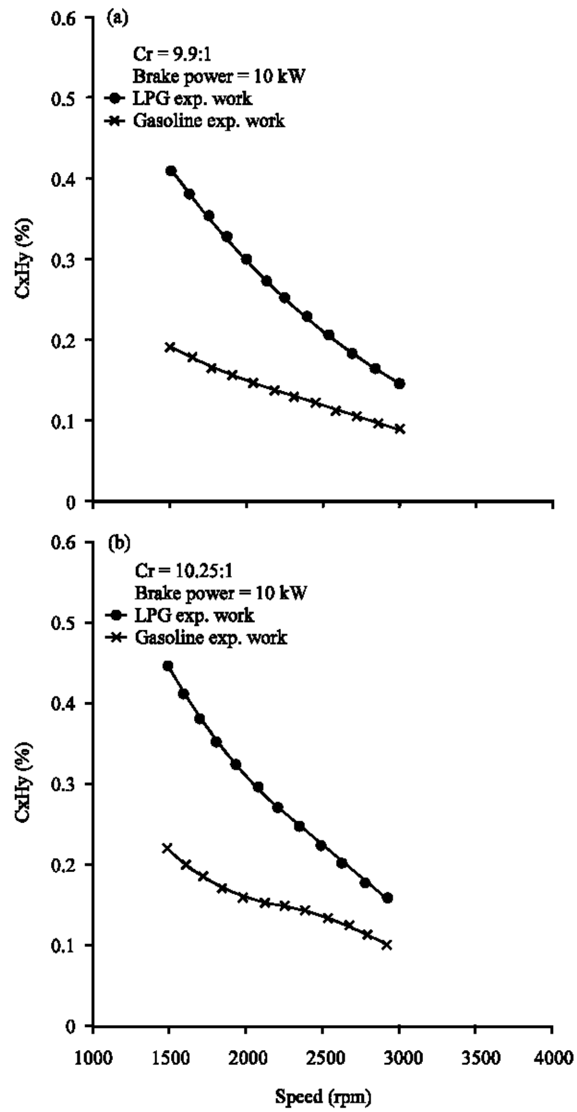


Fig. 11: Variation of C_xH_y emission versus engine speed

fuels (LPG and gasoline) and brake power equal to 10 kW are presented in Fig. 11 for compression ratios equal to 9.9:1 and 10.25:1. Existence of CxHy in exhaust gasses points out that fuel didn't burn completely. It was found that the CxHy decreases with increase of engine speed. Main reasons for failure to complete combustion and formation of CxHy are lower temperature, lack of oxygen and no homogeneity of mixture. The maximum of percentage deviation CxHy content in gasoline fuel compare with LPG fuel reported is is 50% for compression ratio equal 9.9:1. When compression ratio equals to 10.25:1, The maximum of percentage deviation CxHy contain in gasoline fuel compare with LPG fuel reported is 52%. CxHy emissions decrease with the increase in LPG usage level. Because the mixture becomes more homogeneous with the increase in LPG usage level, combustion is improved and HC emissions decrease. With the increase in engine speed, HC emissions increase due to the enrichment of mixture. CxHy and CO emissions are strongly related to cylinder gas temperature at post flame. LPG has higher cylinder gas temperature than that of gasoline and this will enhance CxHy and CO oxidation in the post flame. This factor also leads to the low value of CxHy and CO emissions.

CONCLUSION

Comparisons between theoretical results obtained from the presented model and experimental results given in several literatures have confirmed the reliability and accuracy of the present model for predicting the cycles and performance of SI engines running on gasoline and LPG fuels. An extensive investigation of the combustion, cycle, performance parameters and exhaust emissions of an SI engine running on gasoline and LPG has been performed by means of the present model. From the obtained results and various comparisons, the following conclusions can be drawn: From the analysis of the results, it is revealed that LPG fuel improves the brake specific fuel consumption and brake thermal efficiency but reduces the brake power compared to gasoline fuel operation. The maximum cylinder pressures predicted for LPG are lower compared to that produced by gasoline fuel. This is does not cause damages on engine structural elements. LPG reduces the engine volumetric efficiency compared to that produced by gasoline fuel, thus, engine effective power is decreased. Compression ratio and equivalence ratio have a significant effect on both performance and emission characteristics of the engine and have to be carefully designed to achieve the best engine performance characteristics. The exhaust gas temperature increases with increased engine speed, compression ratio and brake power in all points. Similar trends are also observed when LPG fuel is used. For the same brake power and engine speeds, it is found that exhaust gas temperatures for gasoline fuel be higher at all the engine speeds compared that for LPG fuel. CO, CO_2, NOx and CxHy emissions with LPG fuel be lower compared to that produced by gasoline fuel. O_2 emissions with LPG fuel be higher compared to that produced by gasoline fuel.

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