Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 14 (4): 386-390, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.386.390

Comparison of Performance and Emission of a Gasoline Engine Fuelled by Gasoline and CNG Under Various Throttle Positions

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Abstract: This study presents comparison of performance and emission of a gasoline engine fuelled by gasoline and CNG under various throttle positions by test results from running 1596 cm^3, 4-cylinder spark-ignited gasoline port injection. CNG is considered as a popular alternative fuel and many studies focus on this field. Performance and emission measurements were recorded under steady-state operating conditions using an engine control system and the portable exhaust gas analyzer. The engine was run at (50, 100%) throttle position, 100% engine load and speed ranging from 1000 revolutions per min (rpm) to 6000 rpm with 500 rpm increments. Results show gasoline is more power, torque and Brake Mean Effective Pressure (BMEP) than CNG but Brake Specific Fuel Consumption (BSFC) of gasoline is not as much as CNG. Furthermore it shows to a smaller extent carbon dioxide (CO_2) and carbon monoxide (CO) in CNG compared to gasoline. Nitric Oxide (NO) and Mono-Nitrogen Oxides (NO_x) emission for CNG is less than gasoline.

Key words: Compressed natural gas, gasoline, throttle position, performance, emission

INTRODUCTION

In recent years, natural gas has been seen as an alternative clean fuel for Spark Ignition (SI) engines because of its relatively higher octane number. Lean burning of natural gas which contains mostly methane, in SI engines has been potential to improve thermal efficiency and reduce emissions compared to gasoline. Due to its high Research Octane Number (RON) which is higher than 120, natural gas allows combustion at a higher compression ratio without knocking. It also offers much lower CO_2 gas emissions compared with other hydrocarbon fuels as a result of its higher hydrogen to the carbon ratio. For all these reasons, this study was provided the comparative the performance and exhaust emissions for gasoline built fuelled by gasoline and CNG with different throttle positions.

The most important effects on emission are injection time, natural-gas composition and initial temperature. Retarding fuel injection timing might reduce NO and increasing of ethane could advance ignition and increase NO (Zheng *et al*., 2005).

Another experiment by Wang *et al*. (2007) was to study the combustion behaviour of the Direct Injection (DI) engine with various natural gas-hydrogen. The results were shown to increase in bake effective thermal efficiency with the increase of hydrogen fraction. Unburnt Hydrocarbons (HC) and CO_2 decreased with the increase as the hydrogen and also NO_x concentration increased with the increase of hydrogen fraction (Wang *et al*., 2007). Zarante and Sodre (2009) were evaluated carbon emissions by using natural gas as fuel. According to result's CO and CO_2 were decreased when using natural gas compared to gasoline.

On the other hand, in a review study which focused on performance and emissions for natural gas fuelled spark-ignition and compression-ignition. The results were showing that natural gas can be used for both engines but improvement and optimization of engine are needed (Korakianitis *et al*., 2011).

Jahirul *et al*. (2010) compared the performance and exhaust emission on a gasoline and Compressed Natural Gas (CNG) fuelled spark-ignited engine at 50 and 80% throttle positions. Comparative analysis showed 19.25 and 10.86% reduction in brake power and 15.96 and 14.68% reduction in Brake Specific Fuel Consumption (BSFC) at 50 and 80% throttle positions, respectively while the engine was fuelled with CNG compared to that with the gasoline (Jahirul *et al*., 2010).

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Other studies were focused on the performance of natural gas using direct injection and compared with gasoline or diesel such as Kalam and Masjuk (2011) on the study "an experimental investigation of high performance natural gas engine with direct injection".

Many researches were studied the performance and exhaust emission of port injection using CNG such as How Heoy, Taib Iskandar, Shahrir Abdulla and Yusoff Ali. Using an engine with 1.5l (Mitsubishi 4G15) (Geok *et al*., 2009; Mohamad *et al*., 2010).

Another experimental using a 1.5 L, 4- cylinder Proton Magma retrofitted; results show that CNG has the low brake mean effective pressure, BSFC, higher FCE and lower emissions of CO, CO_2, HC but more NO_x compared to gasoline (Kalam *et al*., 2005). In another study that the direct and indirect (prechamber) spark ignition of the natural-gas engine by concerned engine parameters (spark timing and load) and turbocharger characteristics were compared. The main results showed that the indirect ignition 40 and 55% less CO and THC emissions, respectively. The delay of spark timing about 8° CA_{BTDC} was required for the prechamber ignition to reduce the cylinder pressure and decrease NO_X, CO and THC. Using a turbocharger was increased the fuel conversion efficiency but also was caused an increase of approximately 40% in THC emissions (Roethlisberger and Favrat, 2002).

From the review, CNG can be considered as a popular alternative fuel and a lot of studies have been focusing on this subject. Hence, this study aims to present and analyse the performance and emissions of CNG and gasoline in gasoline engine port injection with different throttle positions.

MATERIALS AND METHODS

A 1.6 L, 7.6 cm bore, 8.8 cm stroke, 4-cylinder spark ignition engine port injection filled with gasoline and compressed natural gas were installed to control the gasoline and CNG operation. The engine specifications are given in Table 1. Gasoline and CNG were used as fuel. The substantial advantage that CNG has in antiknock quality is related to the higher auto ignition temperature and higher octane number compared to that of gasoline as shown in Table 2. Also CNG has a high Air Fuel ratio $(A/F)_s$ and heating value with 17.23 and 47.377 (MJ kg^{-1}), respectively . The composition of CNG used in Malaysia is as shown in Table 3. The percentage of a Methane (CH_4) is 94.42% (Heywood, 1988; Turns, 2000). An engine control system and portable exhaust gas analyser were used for controlling engine operations and recording engine performance and emission's data. The KRONOS4 software is the software of the test bench The engine was converted to computer integrated CNG-gasoline bi-fuel operations by installing a sequential port injection CNG conversion system as shown in Fig. 1. Results were recorded in steady-state condition so ambient pressure, ambient temperature and humidity were noted to estimate air inlet density. Max monitor period was 60 sec. Portable exhaust gas analyser Kane-May which is an International Organization of Legal Metrology (OIML) class one certificate was calibrated for each test to get correct results. The engine was running at full load 100 and (50, 100%) throttles position. CNG was stored at 20 Mpa pressure in a tank and its pressure was reduced by a pressure regulator and a reducer as it is injected into the intake manifold. A check valve was installed on the fuel system to prevent the backflow of gas. The injection of CNG was controlled by the Sequential Gas Multipoint Injection System (SIGAS) CNG control software for the engine tuning calibration at different speeds. All tests have been done as shown in Table 4 and each test was conducted five times as repeatedly.

Table 1: Engine specifications

Parameter	Value	Unit
No. of cylinders	4	-
Type	Inline	-
Capacity	1596	cm^3
Bore	76	mm
Stroke	88	mm
Connecting rod length	131	mm
Crank radius	44	mm
Compression ratio	10	-

Table 2: Combustion related properties of gasoline and CNG

Properties	Gasoline	CNG
Motor octane number	80-90	120
Molar mass (g Mol^{-1})	110	16.04
Carbon weight fraction (mass %)	87	75
(A/F)s	14.7	17.23
Stoichiometric mixture density (kg m^{-3})	1.38	1.24
Lower heating value (MJ kg^{-1})	43.6	47.377
Lower heating value of stoic. mixture (MJ kg^{-1})	2.83	2.72
Flammability limits (Vol% in air)	1.3-7.1	5-15
Spontaneous ignition temperature (°C)	480-550	645

Table 3: Typical composition (Vol%) of CNG (Source: PRSS)

Component	Symbol	Volumetric (%)
Methane	CH_4	94.42
Ethane	C_2H_6	2.29
Propane	C_3H_8	0.03
Butane	C_4H_{10}	0.25
Carbon dioxide	CO_2	0.57
Nitrogen	N_2	0.44
Others	(H_2O+)	2.00

Table 4: Types of tests

Test	Fuel	Throttle position (%)
Test 1	Gasoline	100
Test 2	Gasoline	50
Test 3	CNG	100
Test 4	CNG	50

Fig. 1: Experiment setup

RESULTS AND DISCUSSION

The air temperature entered into the engine is taken as 32.8 and 33.73°C for CNG and gasoline, respectively. The pressure atmosphere was 1.003 bars and the humidity was 52.43% Hr for CNG but for gasoline, the pressure was 1.002 bars and the humidity was 45.71% Hr. At the first density of the air inlet should estimate because it is included in the formula above. The CNG can't start without some gasoline fuel to have an initial starting. The main objectives of this investigation are, to investigate the performance and emissions characteristics of CNG bi-fuel engine under various throttle positions and to study on mensuration between gasoline port injection (gasoline-PI) and CNG bi-fuel.

Brake power: Figure 2 shows brake power versus engine speed from 1000 to 6000 rpm for all tests at 50 and 100% throttle. The results were shown brake power of gasoline is more than CNG. At speed 6000 rpm brake power for gasoline was more 25% than CNG with 68.25 and 51.2 kW, respectively. With 50% throttle CNG is little more than 100% throttle. Furthermore, the results were shown approximately equal in gasoline at 50 and 100% throttle. The reason of minor brake power from CNG is mainly due to inferior brake torque which is related to the displacement of air by CNG that reduces the volumetric efficiency and effective cylinder pressure. One researcher was studying an engine capacity 1.468 L and

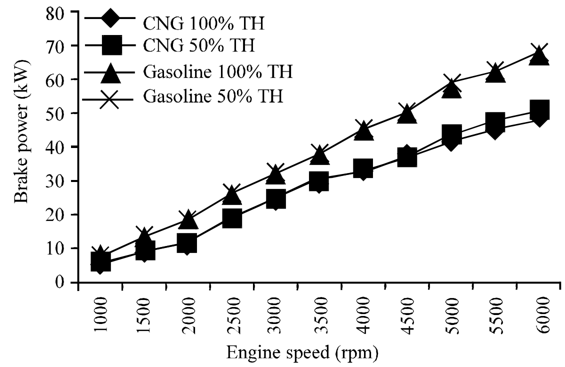

Fig. 2: Brake power versus engine speed

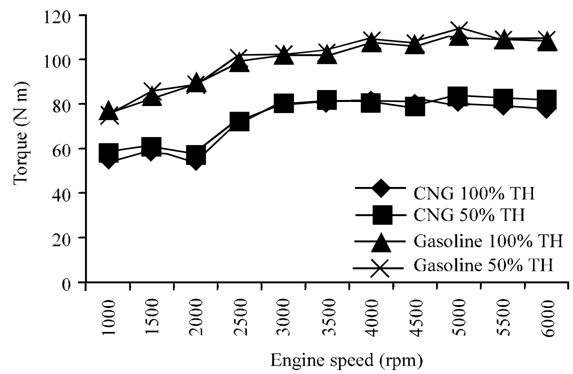

Fig. 3: Brake torque versus engine speed

a compression ratio 9.2. The natural gas engine produces 15-20% less brake power as compared to gasoline (Kalam *et al.*, 2005). Another researcher was reviewing the natural gas in spark-ignition engines. From the results, the natural gas engine produces lower power levels compared to gasoline at the same compression ratio (Korakianitis *et al.*, 2011).

Brake torque: Figure 3 shows the brake torque versus engine speed from 1000 to 6000 rpm. The results were shown brake torque for gasoline is more than CNG. The torque of gasoline and CNG was the highest at speed 5000 rpm with 113 and 82.95 N m, respectively. The torque of a gasoline was more 26.6% than CNG. The reason of production lower brake torque by CNG is due to lack of chemical energy conversion to mechanical energy which is related to volumetric efficiency, fuel mixing and cylinder pressure. On the other hand researcher was finding that gasoline-PI and CNG-BI produced their maximum torque are 128.42 and 100 N m (at 4500 rpm) (Kalam and Masjuki, 2011). However other paper results were shown that CNG produces less 8-16% of brake torque, brake power and BMEP compared to gasoline fuel (Geok *et al*., 2009).

Brake specific fuel consumption (BSFC) and Brake mean effective pressure (BMEP): Figure 4 illustrates the BSFC with engine speed at 50 and 100% throttle position.The reduction in BSFC with gasoline operation is observed throughout the speed range. BSFC of CNG at 50% is the highest BSFC. It is seen that BSFC drops as the speed increases in the high speed range and increases in the low-speed range. This is because the heat loss during combustion chamber walls but in high speed, the friction power is increasing. The BMEP curve of Fig. 5 is at 100-50% throttle valve opening with variable-speed operation. The reduction in BMEP with CNG operation is due to lower flame speed of CNG compare to gasoline. The BMEP of CNG is 28-59% less than gasoline. The maximum BMEP was observed 8.89 bars at 5000 rpm at 50% throttle position for gasoline but CNG was 6.53 bars at 5000 rpm at 50% throttle position. Generally, BMEP for both gasoline and CNG at 50% throttle position is more than 100% throttle position.

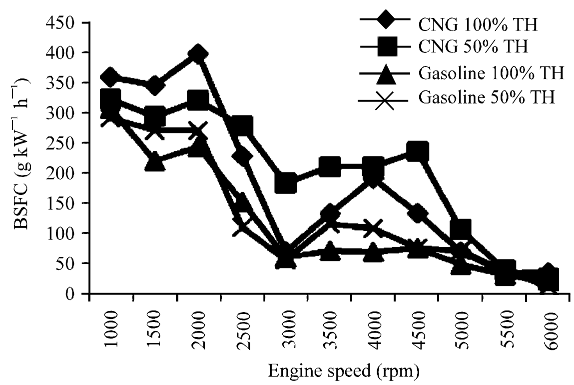

Fig. 4: Brake specific fuel consumption versus engine speed

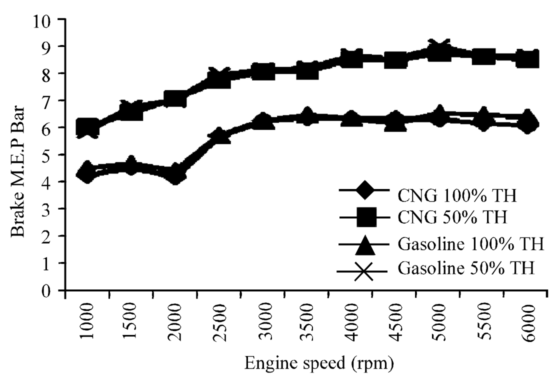

Fig. 5: Brake mean effective pressure versus engine speed

Exhaust emissions: The emission results of CO_2, CO, NO and NO_x is presented in Fig. 6 and 7, respectively. CO_2 and CO for gasoline is more than CNG. The results were shown CO_2 and CO is more at 100% TH than at 50% TH with both fuel's gasoline and CNG. NO_x is always more than NO. From observation data, NO and NO_x for CNG at 100% TH is more than at 50% TH. For gasoline NO and NO_x is more than CNG except at speed range 3000-3500 rpm. At speed 2000 rpm, CO_2 descended down, CO got higher but NO, NO_x are in the lowest values for CNG. At the same time BSFC had the highest amount at the same speed so the Carbon monoxide (CO) is formed by rich fuel-air mixtures and when there is insufficient oxygen to fully burn all the carbon in the fuel to CO_2. As CO is strongly correlated to rich fuel-air mixtures.

On the contrary BSFC had the lowest amount of speed (3000 rpm), these leads NO and NO_x increased for CNG. The main cause for the increase of NO_x is high combustion temperature.

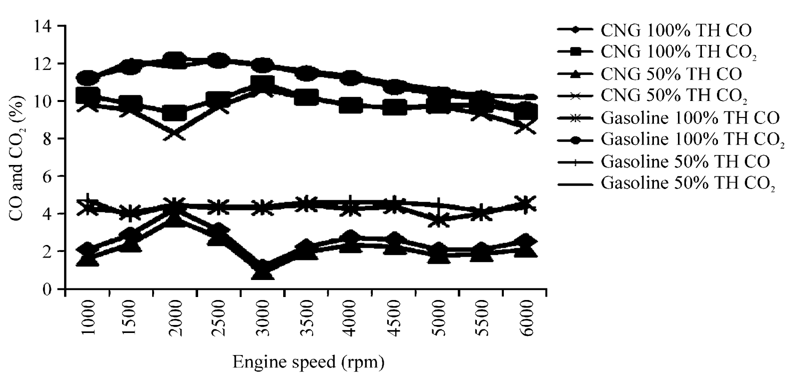

Fig. 6: CO and CO_2 versus engine speed

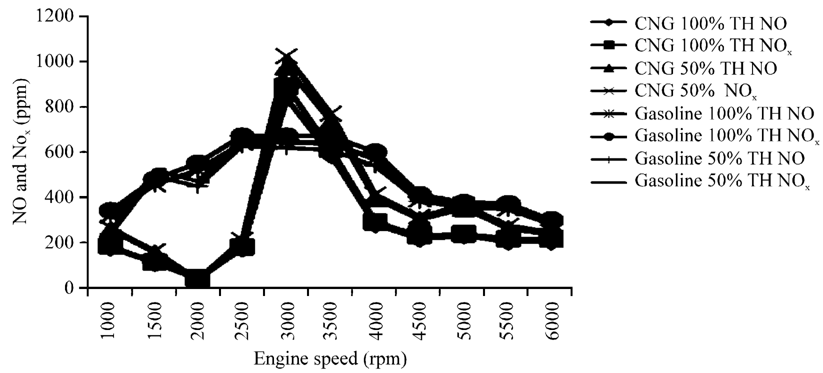

Fig. 7: NO and NO_x versus engine speed

CONCLUSION

This study has shown that CNG produce less exhaust emission for port injection gasoline engine. The following remarks can be drawn from the present study:

- On average, gasoline and CNG produce more brake power, brake torque and brake mean effective pressure at wide throttle position
- CNG operation produces less brake power, less brake torque and less brake mean effective pressure compare to gasoline
- Results also show that BSFC of gasoline is less than CNG
- The emission of NO and NO_x of CNG is lower at low speeds and high speed but the emission increases at 3000-3500 rpm
- The emissions of CO_2 and CO were found less of CNG compared to gasoline

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