THE PERFORMANCE AND EMISSIONS CHARACTERISTICS OF A COMPRESSED NATURAL GAS SPARK IGNITION ENGINE

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Abstract

This paper presents the experimental results of a spark ignition engine to evaluate its performance and emissions characteristics while using conventional fuel and alternative fuel; compressed natural gas (CNG). To evaluate the performance, the engine is operated between 1500-4000 rpm, under steady state condition with wide open throttle (WOT). The emissions test was performed with various constant loads at each speed. The first experiment is did by using conventional fuel and followed by CNG. The engine performance and emissions results such as brake power, brake specific fuel consumption (BSFC), CO, HC and NOx from CNG were measured and compared to conventional fuel. The experiment has performed at Automotive Laboratory Faculty of Mechanical Engineering, University Malaysia Pahang by using in-housed developed engine test rig. From the experiment being done it is demonstrated that the potential of reducing emissions while applying CNG as fuel is obvious. However, the further study of required improving the performance of the engine. The results and analysis will be useful for the development of dedicated CNG engine in the future. The application of CNG as fuel for spark ignition engine gives the average reduction power of 25% at WOT, 45% at POT and gives the average brake power reduction of 37% at WOT and 56% at POT base from spark ignition engine. Average BSFC of CNG are near about 33% higher than gasoline for WOT and 39% higher than gasoline for POT. The average CO emission reduction is reduction is 66% at WOT and 64% at POT. The average reduction of CO_2 emission at WOT while using CNG is 6% and at POT only 1%. The average reduction of HC emission at WOT is 76% and at POT is 74%. The average reduction of NOx emission at WOT is 15% and at POT is 18%. The disadvantages of CNG as fuel in spark ignition engine has reduced power 37-56%, but the advantages for environment protection CNG as fuel has reduced the exhaust gas emissions.

Keywords: *compressed natural gas engine, emissions, performance, spark ignition*

1. Introduction

As long as there are combustion engines, pollutants will be produced. Therefore, it is important to reduce their volume by as much as possible. All hydrocarbon based fuels are mostly composed of hydrocarbons [1]. If a complete and uniform combustion can be achieved, there would be only be water (H_2O) vapour and carbon dioxide (CO_2) produced which are both harmless. The physical characteristics of engines and the constituents of fuels do not allow these ideal conditions to be realised [1-3]. Vehicle exhaust emissions are identified as the major source of air pollution in urban areas. The causes of air pollution are many and complex. Urban expansion and rapid population growth have resulted in more vehicles and contributing to worsening environment [3]. Realising this, most government and local authorities are planning to tighten or introduce stricter emission regulations for vehicles. The level of emissions from vehicles can be reduced by establishing strict emissions standards and making sure that the vehicles continue to meet these standards throughout their useful life. In order to comply with these emissions regulations, either more advance after treatment emissions control devices have to be incorporated into the vehicle or to use some alternative fuels which are capable of providing cleaner combustion. Alternative fuels are found to have good potential in solving the diesel particulate problem, reducing the overall toxic emissions problem from vehicles, and helping to reduce urban CO and ozone levels [4, 5]. During the past few decades the technical and economic aspects of using CNG as gasoline/diesel fuels substitute have been studied extensively.

The demand for such substitute and the potential for their production are much greater in developing country. A review on some of the recent research and development activities on the production, promotion and use of CNG as fuel substitute is present and result obtain from using CNG as fuel in internal combustion engines [5-7].

Tab. 1. Gasoline and CNG Stoichiometric [1]

Properties	Gasoline	CNG
Motor octane number	80-90	120
Research octane number	92-98	120
Molar mass (kg/mol)	110	16.04
Stoichiometric air-fuel ratio	14.6	16.79
Stoichiometric mixture density (kg/m3)	1.38	1.24
Lower heating value (MJ/kg)	43.6	47.377
Lower heating value of stoichimetric mixture(MJ/kg)	2.83	2.72
Flammability limits	1.3-7.1	5-15
Spontaneous ignition temp. (^{0}C)	480-550	645

2. Engine and Experimental Methods

This research is using the four stroke gasoline engine. The selected spark ignition engine is shown in Tab. 2.

Tab. 2. Engine Specification

Engine	Specification
Manufacturer	Proton
Model	4G15P
Type	Spark ignition
Capacity (cc)	1.488
Bore x stroke (mm)	75.5 x 82
Cylinder number	4
Maximum power (kW)	86
Maximum torque	12.7 kgfcm
Compression ratio	9.2:1

The experimental apparatus employed for the whole series of experimental investigation covered in this project. The experimental apparatus are dynamometer, surge tank, air flow meter, gas flow meter, liquid fuel flow meter, fuel supply system, cooling water system, manometer, exhaust gas analysis and strobotester. A fuel tank was used to store the gasoline fuel on the top of the dynamometer cooling system structure to provide sufficient space during operation and pressure head for the fuel supply. The fuel flows under the generated pressure head through a unit of two-way valve, fuel filter in a fuel hose to injection pump. Then it was sprayed into the combustion chamber through the carburetor. The fuel return hose was placed at the top of main distribution piping to recycle the overflow fuel back to fuel filter. Another fuel tank was used to store the CNG. It was placed lower position under the control panel and inside the box. The CNG with 200 bar pressure will flow to pressure regulator. There to stage of lowering pressure of CNG. At the first stage, it will drop to be between 3.5-4 bars and at the second stage, the pressure of CNG will be between 1.5 bars. The pressure at the outlet of pressure regulator is less than 1 bar. It will flow from this outlet to the CNG mixer. The flow rate of the CNG is measured through a gas flow meter in unit of m^3/hr.

3. Results and Discussion

In order to compare a conventional fuel, gasoline and alternative fuel CNG over a range of operating conditions it is necessary to adopt a common abscissa unit for graphing. Graphing result including load, power (indicated power & brake power), mean effective pressure (IMEP, BMEP, PMEP & FMEP), fuel consumption (BSFC & fuel flow rate), efficiency (brake thermal efficiency, mechanical efficiency, volumetric efficiency & fuel conversion efficiency), exhaust emission and air-fuel ratio against engine speed (rpm) are suitable for those two types of fuel. Exhaust emission gases such as hydrocarbon, carbon monoxide, carbon dioxide and oxide of nitrogen are evaluated. Each test has been repeated three times.

The engine performance results are shown in Fig. 1-3. Fig. 1 shows variation of indicated power in kW with engine speed. It can be seen that the indicated power increased as the engine speed increased. However the indicated power of CNG at POT is reduce after reaching 3000 rpm engine speed. The maximum indicated power at WOT of gasoline is 51 kW at 4000 rpm and the maximum indicated power of CNG at WOT is 32 kW at 3500 rpm engine speed. At POT the maximum indicated power of gasoline is 50 kW also at 4000 rpm of engine speed and the maximum indicated power of CNG is 22 kW at 3000 rpm of engine speed.

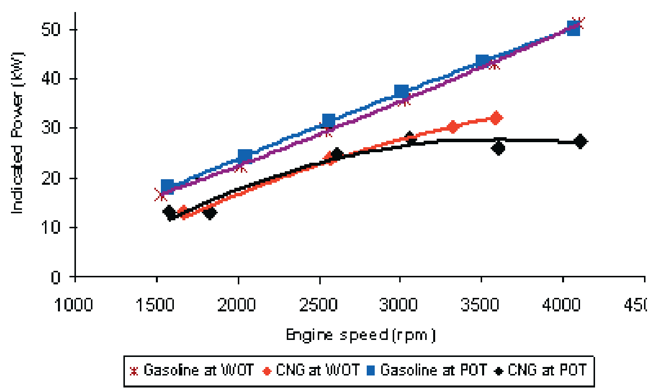

Fig. 1. Indicated power

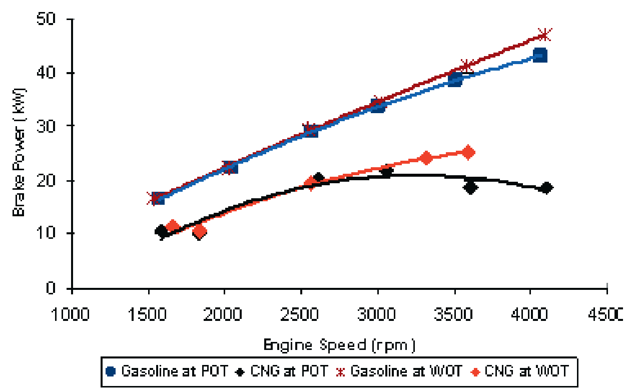

Fig. 2. Brake power

The variation of brake power (kW) with engine speed shown in Fig. 2. It can be seen that the brake power increased as the engine speed increased. However the brake power of CNG at POT is reduce after reaching 3000 rpm engine speed. It is found that the maximum brake power of gasoline at WOT is 47 kW at 4000 rpm and the maximum brake power of CNG at WOT is 25 kW at 3500 rpm engine speed. At POT the maximum indicated power of gasoline is 42 kW also at 4000 rpm of engine speed and the maximum indicated power of CNG is 21 kW at 3000 rpm of engine speed. The BSFC curve of Fig. 3 is shows for WOT and POT, variable speed operation. At any speed, it represents the BSFC which will result when the engine is carrying its maximum load at that speed. It is observed that BSFC drops as the speed is increase in the low speed range. This is because, at low speeds, the heat loss to the combustion chamber walls is proportionally greater, resulting in higher fuel consumption for the power produced. At high speeds, the friction power is increasing at a rapid rate, resulting in a slower increase in BSFC. It is observed that BSFC for CNG was always more than gasoline throughout the speed range. At WOT, the lowest BSFC occurred at 3000 rpm for both the fuels and its 0.268 kg/KWh and 0.3 kg/kWh for CNG. At POT, the lowest BSFC for gasoline occurred at 3000 rpm with 0.286 kg/kWh and for CNG at 2500 rpm 0.395 kg/kWh.

The exhaust gas emissions results are shown in Fig. 4-7. Fig. 4 shows the variation of CO as function of engine speed for both fuels at WOT and POT. CO values are below 11%. It is observed that the CO concentration at the low speed and high speed are higher than middle speed. The lowest concentration of CO for gasoline is 1.83% at 3000 rpm and for CNG is 0.06%, at 2500 rpm. At WOT, the highest concentration of CO for gasoline is 10% at 2000 rpm and for CNG is 5.18% at 1500 rpm. The lowest concentration of CO for gasoline is 4.47% at 3000 rpm and for CNG is 0.62% at 3000 rpm. At POT, the highest concentration of CO for gasoline is 10% at 2000 rpm for gasoline and for CNG is 4.98% at 1500 rpm. Fig. 5 shows the variation of CO_2 concentration with speed. It is observed that the values of CO_2 concentration between 7-14%. At Low speed and high speed the concentration is low and the higher concentration occurs at middle speed, at around 3000 rpm. The lowest concentration at WOT of CO_2 for gasoline is 7.9% at 2000 rpm, and for CNG is 8.3% at 1500 rpm. The highest concentration of CO_2 for gasoline is 13.8, and for CNG is 11.3% at 25000 rpm. At POT, the lowest concentration of CO_2 for gasoline is 7.9% at 4000 rpm, and for CNG is 8.3%. The highest concentration of CO_2 for gasoline is 12.1% and for CNG is 10.7% at 2500 and 3000 rpm.

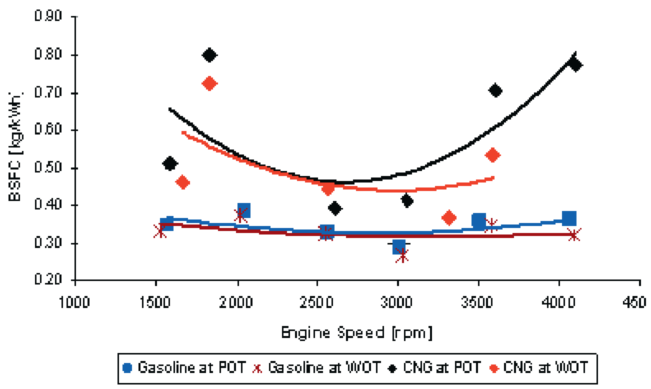

Fig. 3. Brake specific fuel consumption

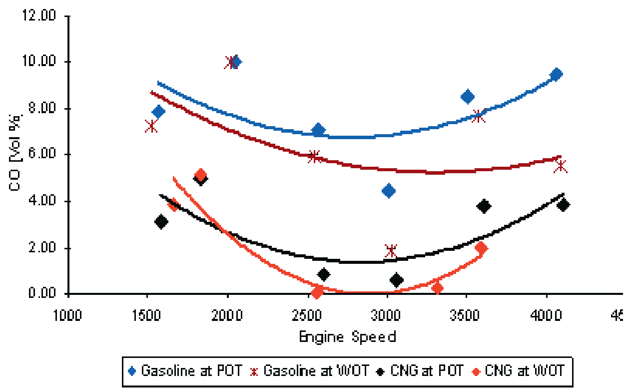

Fig. 4. CO concentration

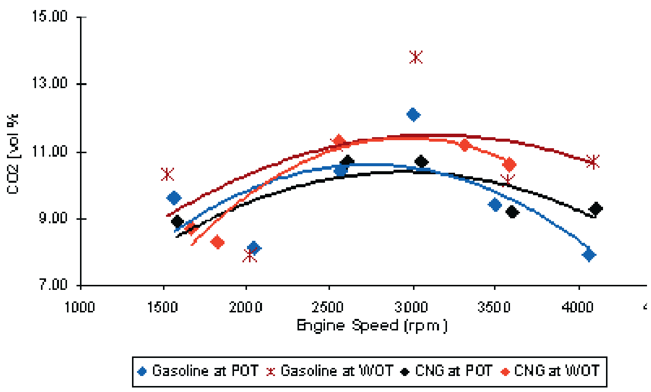

Fig. 5. CO_2 Concentration

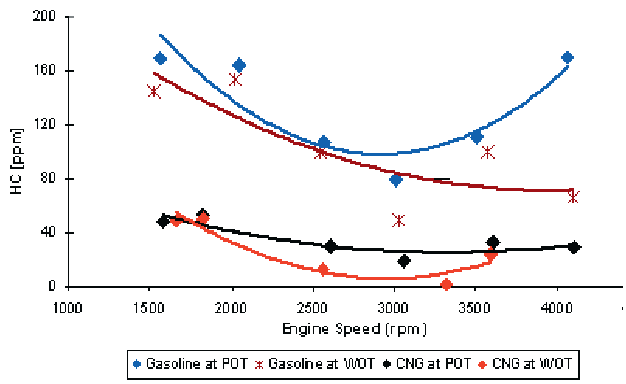

Fig. 6. HC concentration

Fig. 6 shows the variation of the HC concentration with speed for both fuels, gasoline and CNG at WOT and POT. HC values are between 2-170 ppm. At WOT, the lowest concentration of HC for gasoline is 49% at 3000 rpm, and for CNG is 2 ppm, also at 3000 rpm. The highest concentration of HC at WOT of gasoline is 154 ppm at 2000 rpm, and for CNG is 50 ppm at 1500 rpm. At POT, the lowest concentration of HC for gasoline is 79 ppm at 3000 rpm, and for CNG is 19 ppm at 3000 rpm. The highest concentration at POT of HC for gasoline is 170 ppm at 4000 rpm, and for CNG is 53 ppm at 1500 rpm. Fig. 7 shows the variation of NOx concentration with speed. Basically the percentage of NOx emission depend upon the air-fuel lambda, but this also develops inversely in proportion to the curve corresponding with the HC, as shown in figure above. This phenomenon can be explained by the reason that the HCs are widely burnt but the free oxygen existing now reacts with nitrogen as soon as the temperature increases and the pressure grows.

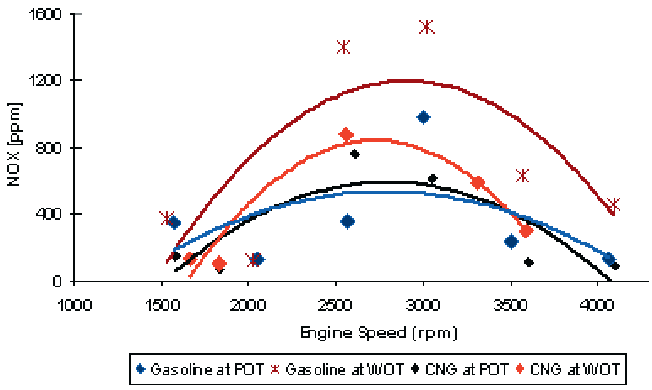

Fig. 7. NO_x Concentration

4. Conclusion

The application of CNG as fuel for spark ignition engine gives the average reduction power of 25% at WOT, 45% at POT and gives the average brake power reduction of 37% at WOT and 56% at POT base from spark ignition engine. Average BSFC of CNG are near about 33% higher than gasoline for WOT and 39% higher than gasoline for POT. The average CO emission reduction is reduction is 66% at WOT and 64% at POT. The average reduction of CO_2 emission at WOT while using CNG is 6% and at POT only 1%. The average reduction of HC emission at WOT is 76% and at POT is 74%. The average reduction of NOx emission at WOT is 15% and at POT is 18%. The disadvantages of CNG as fuel in spark ignition engine has reduced power 37-56%, but the advantages for environment protection CNG as fuel has reduced the exhaust gas emissions.

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