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Performance Analysis of a Single Cylinder SI Engine using Compressed Natural Gas (CNG)

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ABSTRACT

Due to the unsteady oil prices, shortage continuity of fossil fuel and an emission crisis, automobile manufactured was motivated to find the solution for improve the efficiency of fuel. One of the factors that influence the performance of vehicle engine is the type of fuel used to complete the combustion. Compressed Natural Gas (CNG) is regarded as one of the most promising alternative fuels, and may be the cleanest fuel for the spark ignited (SI) engine. The natural gas is an alternative fuel and has economically and environmental benefits. Bi-fuel engines are powered by compressed natural gas (CNG) and gasoline that are an intermediate and alternative step to dedicated CNG engines. The conversion of bi-fuel CNG engine could be a short-term solution to air pollution problem in many developing countries. The aim of this study is to show the performance of the CNG fuel in spark ignition (SI) engine compared with the gasoline. In this paper, it is presented about the comparative experimental results of the fuel using of petrol and CNG in SI engine and the main components of converted CNG Engine.

KEYWORDS: *Petrol Engine, Brake Specific Fuel Consumption, Brake Mean Effective Pressure, Brake thermal Efficiency, Conversional Compressed Natural Gas (CNG) Engine*

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INTRODUCTION

Among the vehicular engines' increasing, the petrol driven engines are the major contributor of environmental pollution. The environmental pollution is increased by hydrocarbons HC, CO_2, CO, and NO_x day by day. Gasoline is the main factor causing the pollution. Gasoline is very volatile fuel, a combination of hydrogen and carbon and evaporated due to thermal effects at a high speed, and then produce carbon dioxide (CO_2) to pollute the atmosphere. Pollution has a significant impact on the environment and human health. Lead from gasoline not burned, carbon monoxide, compound containing gas and other gases polluting air deadly and harmful to humans, animals, and food crops [1].

Fuel is the important thing as the one of energy sources which is driving the economic growth of a country which laid the electric power generation, industry and transportation sectors. Based on this reason, the alternative fuels for internal combustion engine both in diesel or gasoline engine become a popular. The other reason is due to the strictly implementation of the regulations which is related to the limitation of exhaust gas emissions. In many places, the converted engine runs properly either petrol or CNG. The high cost of petroleum products; some developing countries are trying to use alternate fuels for their vehicles. The reason of motivating the development of the alternating fuels for IC engine is concerned over emission problem of gasoline engine. Combined with air-polluting systems, a large number of automobiles is a major contributor to the quality of air problem of the world [2].

To reduce this emissions characteristics, CNG is the most suitable for an internal combustion engine for its clean emission effects. Therefore, it is necessary to optimize CNG engine with high compression rate for getting the result of more power, less fuel consumption and emissions. CNG (compressed natural gas) is a mixture of hydrocarbons consisting of approximately 80-90%of methane.

Nowadays, a lot of studies have been carried out by many researchers to investigate the utilization of natural gas for vehicular engine. Munde Gopal G. [3] reviewed the research paper of compressed natural gas as an alternative fuel for spark ignition engine. According to this reviewed paper, it is studied that the compressed natural gas is a good alternative fuel for SI engine but some disadvantages observed from the studies of the different experimental results are: the engine thermal efficiency and exhaust gas temperature produced by the CNG engine is always higher than that of the petrol. CNG produces less 8 -16% of brake torque, brake power and BMEP compared to gasoline fuel cause of volumetric efficiency reduction and lower flame speed of CNG. By running the CNG engine, CO, CO_2 and HC emission are reduced to 20-98%, 8-20% and 40-87% respectively on average. Higher NOx emission is the main emission concern for CNG as automotive fuel that can be reduced by increasing fuel density and blending small quantities of H_2.

E. Ramjee and K. Vijaya Kumar Reddy [4] did an experimental investigations on a single cylinder 4-stroke air cooled type Bajaj-Kawasaki petrol engine to compute performance and exhaust emissions of the test engine. All tests have been carried out under steady state conditions for both petrol and CNG fuels and done the comparison of the performances of the engine with the fuel using of petrol and CNG. They found that speeds, the volumetric efficiency is reduced in the range of 10-14%; except thermal efficiency. The other performance parameters, BMEP, Torque, Power and BSFC are decreased for CNG fuelled engine compared to petrol fuelled engine. The emission characteristics of the CNG fuelled engine such as CO, CO_2, and HC are decreased except NO_x .The experiment tested at full load conditions and calibrated the various parameters of performance and emissions

Musthafah Mohd. Tahir [5] wrote the paper of Performance analysis of a spark ignition engine using compressed natural gas (CNG) as fuel. This study studied on the performance of CNG when used in a single cylinder SI engine. Based from the experiment in this study, compressed natural gas (CNG) produced low performance compared to liquid fuel (petrol). The power of CNG when compared to liquid fuel is reduced to about 18.5 %. The main reason for the lack of power when using CNG is because of the volumetric efficiency. According to this paper, the volumetric efficiency for this test engine is high when liquid fuel was used as the power source. However, when CNG was applied to this engine, it results low volumetric efficiency compare to liquid fuel. The lower volumetric efficiency is due to the gas property of CNG. The main particle consisting, CH_4 of CNG does not produce a cooling effect during this condition. This result is due to the CNG is in the gas phase and it is vapour at ambient temperature. In this study, it is intended to show the comparison results of petrol engine and conversional petrol engine using compressed natural gas (CNG). Petrol engine performance results are carried out and the detail installation of conversional petrol engine to compressed natural gas (CNG) engine.

Compressed Natural Gas

Compressed Natural Gas is a gaseous form of natural gas and is mixture of hydrocarbons. It acts as an alternative fuel due to its substantial benefits compared to gasoline and diesel. It exists in the gaseous state at normal temperature and pressure. CNG is mainly consists of methane. It emits about 70% less carbon monoxide and has much less ozone-forming potential than standard petroleum gasoline. CNG is cheaper than gasoline. It needs to require the heavy tanks to store it and requires the pressure of (200-300 bar).CNG is colorless, odorless, non-toxic, lighter than air and inflammable. The advantages of CNG are a unique combustion and suitable mixture formation. The engine operates smoothly with high compression ratios without knocking due to high octane number. It will lead to low exhaust emission and fuelling operating cost, during lean burning conditions. It has a lower flame speed and causes high engine durability.

Compressed Natural Gas (CNG) engine can be divided into three main types according to their fuel usages; Dual Fuel, Bi fuel (Diesel-CNG, Gasoline-CNG) and dedicated/mono fuel engine. The main problem of CNG engine is the lack of engine performance [3]. Its performance is lower than that of gasoline because of its losses in volumetric efficiency and low flame speed. This will cause the low engine power and torque. It needs to make design modification to achieve a faster burn to optimizing the engine performance [4].

In the country, Myanmar, compressed natural gas is very useful in public transportation field because of its cheaper costs than that of gasoline and diesel fuel. CNG was used almost in bus, city taxi and power generation turbine .There are four methods to inject the NG into the engine cylinder. First type of this is gas mixer/carburetor injection, second type is the single point injection, third type is multi point injection and fourth type is direct injection. This study will be emphasized on the performance of CNG when used in a single cylinder SI engine. The tested engine was equipped with CNG kit, which represent as the CNG system in the vehicle. The engine will be operated in two different fuel sources, CNG and liquid petrol fuel. The properties of petrol and CNG are listed in table 1.

Table 1. Propertiesof CNG and Gasoline [4]

Properties	Gasoline	CNG
Stoichiometric (A/F)s mass	14.2	15.7
Octane number (RON)	96	120
Higher heating value (MJ/kg)	45	50.3
Lower heating value (MJ/kg)	42.2	45.9
Molecular Weight (kg/kmol)	106.2	17.74

EXPERIMENTAL SETUP AND PROCEDURE

A. Experimental Setup

Engine Specification

The experiments are tested on a CL-3900H, single cylinder, four-stroke and spark ignition (SI) gasoline engine. The engine specification is given in Table 2.

Table2.Engine Specification

Bore x Stroke	(70mmx54mm)
Number of Cylinder	1
Cooling Type	Air – Cooled
Compression ratio	8:1
Maximum Output	7.5 Hp
Voltage	220VAC(AVR)
Ignition System	Transistorized ignition
Rated Speed	3000rpm
Engine Model	Corolla CL-3900H

The following figure illustrates the setup of the experiment for collecting the data.

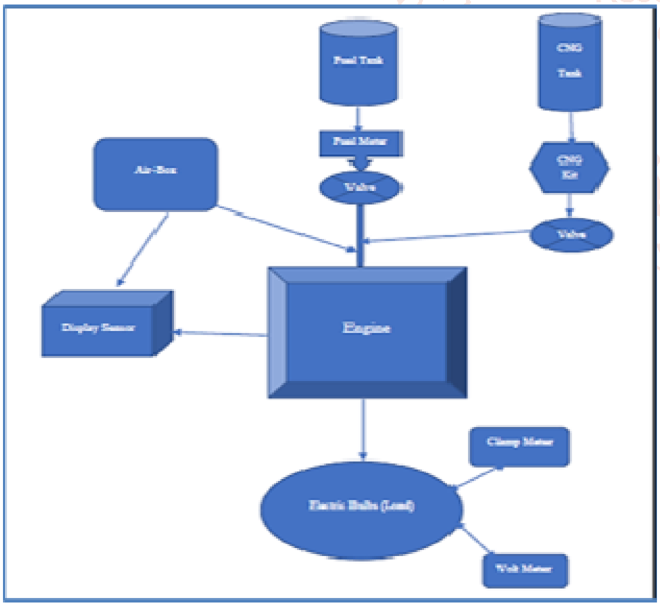

Fig. 1 Experimental setup block diagram for engine performance test

B. Experimental Procedure

A single cylinder, 0.208 litres, 4-stroke SI engine was set up as a test engine. The engine was joined with air flow meter to measure the air flow which enters the carburettor. And the fuel flow meter and engine intake air and exhaust display unit were installed to measure the fuel consumption and to measure the intake and exhaust temperature. Multi meter and clamp meter were set up with the test engine to measure the ampere, voltage and speed was measured by tachometer and electric bulbs were used to measure the loads.

This study spotlighted on the performance of CNG and petrol and used in test engine. A new 0.208 litres 4- cylinder SI engine was converted to the bi fuel system which operated with either petrol or CNG. This engine was investigating the performance of an engine using the fuel of gasoline and CNG. Before the test starting, the engine was warmed up 10 minutes, to measure the constant exhaust temperature and get the engine's running well. The following figure shows the photo of the conversion of petrol engine to converted CNG engine set up. The existing metering and mixing of the fuel may be accomplished using either a mechanical gaseous fuel mixer or carburettor. This approach tries to achieve a homogeneous mixture of air and fuel before the air flow splits in the intake manifold. The experimental set up in which the CNG kit installed has been shown in the following figure2.

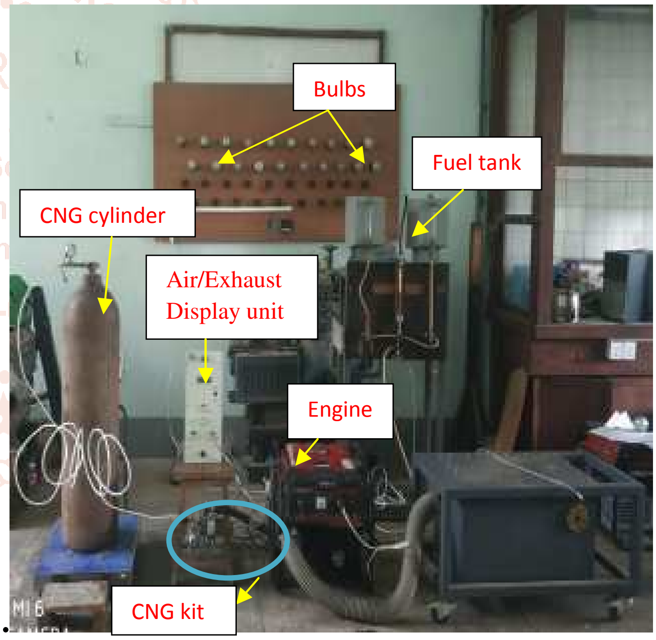

Fig. 2 Experimental set up photo of petrol engine to converted CNG engine

The following figure shows the fuel metering set up photo. The diameter of fuel flow meter tube is 0.013208m and the fuel length is 0.0762m). The fuel flow meter is used for the fuel, petrol.

Fig. 3 The fuel metering set up photo

The digital balance is used to measure the amount of CNG weight used as shown in this figure.

Fig. 4 The Digital balance photo

C. Theoretical Equation of Performance Parameters

The mass of fuel used for petrol or CNG can be calculated by the following equation and the fuel consumption time is marked by stopwatchfor the various loads.

$$m_f = \frac{\rho_f \times V_f}{fuel\ consumption\ t}$$ Equation (1)

Where, = mass flow rate of fuel (kg/sec or kg/hr)

= density of fuel (kg/m^3)

$(\rho_f)_{pet}$=719.7(kg/m^3)

$(\rho_f)_{CNG}$=0.7(kg/m^3)

= Volume of fuel ( )

In engine experimental work, after readings the data of the voltage, the current, load, speed and time for fuel flow throughout the engine operation, the following equations are used to find the engine performance, the brake power.

$$bp = \frac{Voltage(V) \times Ampere(I)}{\eta_{gen}}$$ Equation (2)

Where, bp brake power in Watt

V = voltage in Volt

I = current in Ampere

η= generator efficiency = 0.9(assume)

The brake mean effective pressure (bmep) is the average mean pressure in the cylinder that would produce the measured brake output. This pressure is calculated as the uniform pressure in the cylinder as the piston moves from top to bottom of each power stroke. The BMEP is a useful calculation to compare engines of any size .The brake mean effective pressure of the cycle is given by

$$bmep = \frac{n \times 60 \times I}{10^5 \times A \times L}$$ Equation (3)

Where, bmep= brake mean effective pressure (bar)

n = number of revolution per cycle

A×L = engine volume in m^3 (where bore and length of the test engine are 70mm and 54mm)

N = engine speed in rpm (constant speed, 2600 rpm)

Brake specific fuel consumption (bsfc) is a parameter by dividing the fuel mass flow rate to the engine output power. The brake specific fuel consumption is the fuel consumption rate for one unit engine brake power and can be calculated as:

$$bsfc = \frac{3600 \times m_f}{bp} \times 1$$ Equation (4)

Where, bp =brake power in Watt

bsfc = brake specific fuel consumption in kg/kWhr

The thermal efficiency of the engine is the brake power of a heat engine as a function of thermal input from the fuel. It is used to evaluate how well an engine converts the heat from a fuel to mechanical energy [6]. The thermal efficiency can be calculated by:

$$\eta_t = \frac{bp}{m_f \times C_L} \times 100$$ Equation(5)

Where, η_t = brake thermal efficiency (%)

= calorific value in J/kg

EXPERIMENTAL RESULTS AND DISCUSSION

Performance test is done on the 4 stroke, single cylinder SI engine to study and compared its performance under various loads using the fuel of petrol and CNG. The result data of the performance of the SI engine with the petrol fuel and the CNG fuel are described as in following table III and table IV.

Table. 3 Result Data of the Test Engine using petrol

Nominal Load (W)	(kW)	bsfc (kg/kWhr)	bmep (bar)	η_t (%)	(kg/s) $\times 10^{-4}$
400	409.89	1.176	0.91	6.989	1.338
800	846.49	0.6676	1.84	12.31	1.569
1200	1267.29	0.5352	2.83	15.32	1.88
1600	1669.68	0.4575	3.78	17.965	2.123
2000	2100	0.4285	4.85	17.935	2.38

Table.4 Result Dataofthe Test Engineusing CNG

Nominal Load(W)	(kW)	bsfc (kg/kWhr)	bmep (bar)	η_t (%)	$\dot{m}_f$ (kg/s) $\times 10^{-5}$
400	407.47	0.378	0.86	19.2	4.27
800	832.8	0.222	1.8	32.6	5.136
1200	1139.5	0.137	2.48	52.9	4.329
1600	1666.13	0.093	3.75	77.9	4.3
2000	1956.13	0.122	4.51	59.3	6.635

The test engine had been carried out by both of the fuels petrol and CNG with the various load at the constant speed.

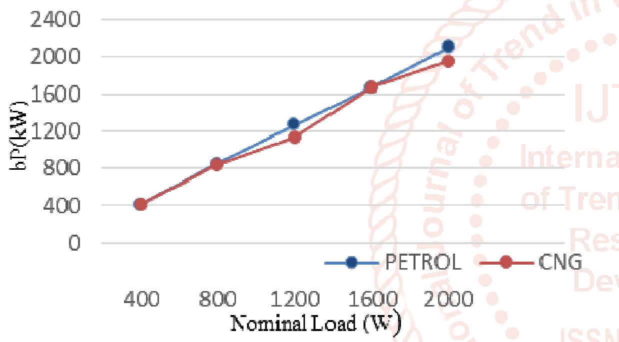

Fig.5 Brake power with various nominal load at constant speed

Figure.5 shows the variation of brake power with the various loads. From the graph, it can be seen that the brake power of CNG fuelled engine is lower than petrol fuelled engine. The maximum difference is about 10.08% at the load 1200W. This is due to the effect of CNG's gas property and its density is very lower than that of petrol.

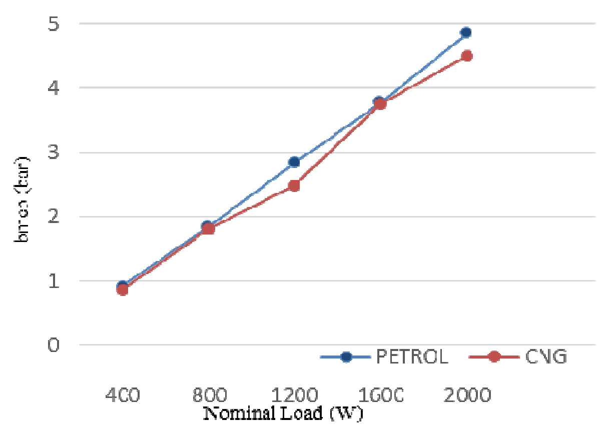

Fig. 6Brake mean effective pressure with various nominal load at constant speed

From figure.6, it can be observed that the BMEP of CNG is lower than that of petrol engine because the BMEP is inversely proportion to the air fuel ratio. At the load of 1200 W, the BMEP of the CNG fuelled engine is 12.36% lower than petrol fuelled engine. The maximum differences of the brake power and BMEP are seen at the nominal load, 1200 W from figure 5 and 6. The higher the load, the lower the fuel consumption due to the consumption is decreased beyond the optimal limit and also the combustion efficiency of the fuel.

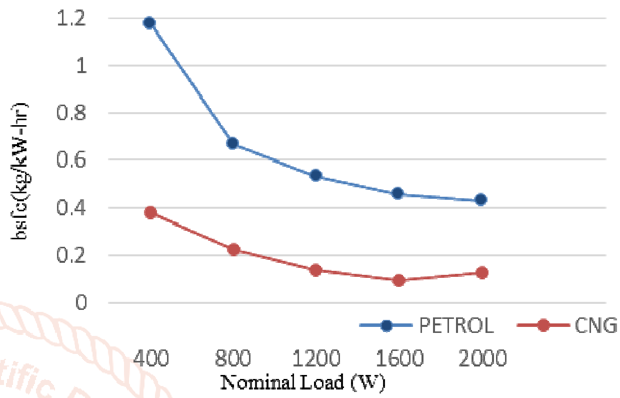

Fig. 7 Brake specific fuel consumption with various nominal load at constant speed

From Figure 7, it can be shown that the variation of the break specific fuel consumption with the various load. The brake specific fuel consumption is decreased with the load increases. And the BSFC is less for the engine with the CNG fuel than the petrol engine and concluded that the maximum difference is about 79.7% at load of 1600 W and the minimum difference is about 66.67% at the load 800 W.

CONCLUSION

A lot of alternative fuels have been introduced to replace the usage of primary fuels that are gasoline and diesel .Among these fuels, the compressed natural gas (CNG) is the best alternative fuel for SI engine. The good emission effects, less fuel cost and many other benefits can also be achieved by SI engine with the using of CNG fuel.

In this study, experimental investigations carried out on a single cylinder, four stroke air cooled SI engine to compare the performance results of this engine with the fuels of petrol and CNG. It can be concluded that the brake mean effective pressures increase as the loads increase, the break specific fuel consumptions decrease with the loads increase, and the thermal efficiency increase with the load increasing for the fuel using of petrol or CNG. The table IV shows the results of bsfc at the load 2000 W is higher than that of 1600W but the thermal efficiency at the load 2000W is lower than that of the load at 1600W.This is due to the converted CNG engine (single cylinder,4 stroke SI engine) cannot operate for a long time and will cause the errors or mistakes near the optimal load of 2000W. Based on the experimental results, except thermal efficiency, the other performance of brake power, brake mean effective pressure and brake specific fuel consumption of the CNG fuelled engine are less than that of the petrol fuelled engine due to the lower volumetric efficiency and lower flame speed of CNG.

For reducing of these problems, one of the improvement methods of the engine performance is to implement the supercharger or turbocharger with this converted CNG engine. As many experimental results of the literatures, the compressed natural gas emits less carbon dioxide, carbon monoxide and has less ozone-forming than petroleum or gasoline fuel which is because CNG burns more completely than petrol. Compressed natural gas is very useful in public transportation sector because it has more cost effectiveness than gasoline and diesel fuel. Therefore, the conversion of the petrol engine to CNG engine is very effective for economy and clean environment. The detail conversion of petrol engine to converted CNG fuel engine and the comparison of the engine performance using the petrol and CNG fuel are presented in this paper. Further research should be conducted to set up the supercharger at the engine inlet to produce higher power output and reduce the air pollution.

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