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Performance analysis of a 4-stroke SI engine using CNG as an alternative fuel

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Abstract

The research on alternative fuels has become essential due to depletion of petroleum products and its major contribution for pollutants. In the present work, Compressed Natural Gas (CNG) has been introduced as an alternative fuel to overcome the above problems. Of the higher compression ratio, higher octane number, the CNG is used to allow the combustion without knocking. The emission characteristics of HC and CO are better for CNG compared to petrol. In this work experimental investigations have been carried out pertaining to the engine performance and exhaust emissions of a single cylinder 4-stroke air cooled type Bajaj-Kawasaki engine

Keywords: Compressed Natural gas (CNG), SI engine, alternate fuel,4-stroke, emission.

Introduction

Compressed natural gas (CNG) has been used as an alternative fuel. The advantages of CNG compared to petrol are: Unique combustion and suitable mixture formation; Due to high octane number of CNG, engine operates smoothly with high compression ratios without knocking; CNG with lean burning quality will leads to lowering exhaust emissions and fuel operating cost; CNG has a lower flame speed; Engine durability is very high. The flame speed of Natural gas is lower compared to petrol (Aslam *et al.,* 2006). This lower flame speed causes the total combustion duration prolonged compared with petrol fuel. Kawabata and Mori's (2004) studies were based on the principle of using squish motion to generate a series of jets directed towards the center of the chamber just prior to ignition. The chamber in this study referred to as the UBC squish jet. The faster burning rate of UBC chamber lead to an average three percent reduction in brake-specific fuel consumption, five percent increase in BMEP, and an increase in the lean limit of combustion (Jay K. Marti *et al*. 1988). The exhaust emissions were lower for the UBC chamber than those for a conventional Bowl-in-piston (BIP) chamber: brake-specific total unburned hydrocarbon (BSTHC) and BSNOx were lower by 20% to 50% and BSCO were 15% lower. Liu Bing *et al.* (2008) have studied the effects of hydrogen addition on the natural gas engine operation. According to their results, the combination of hydrogen and CNG/air mixture had injurious effect on the combustion delay and increased the burning rate. Performance and emission characteristics of a bi-fuel SI engine have been compared by Al-Baghdadi and Al-Janabi (2000). According to their results, the engine power and exhaust emissions are very lower in CNG fuelled engine. Das and Reddy (2000) conducted the experiment on CNG bi-fuel passenger car and predicted the engine performance, fuel consumption and emission to reduce system calibration time as well as the cost of testing. According to their result, the carbon monoxide (CO) on CNG is very lower compared to petrol engine. Manivannan *et al*. (2003) has studied the reducing of emissions with lean burn strategy for natural gas and also evaluated the emission characteristics with respect to their performance in spark ignition engines. For the CNG Chiodi *et al*. (2004) have studied using a fast response simulation to analyses mixture formation and combustion process. A mathematical model was developed to compute a combination of thermodynamics relations and dynamical characteristics of the CNG engine.

In the present work, the experimental investigations are carried out 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 the results have been compared.

Table 1. Bajaj-Kawasaki engine specifications

Engine Type	Four stroke, Petrol engine
Induction	Air cooled type
Number of cylinders	Single cylinder
Bore (mm)	51
Stroke (mm)	48.8
Displacement volume (cm^3)	99.27
Compression ratio	8.4
Max. power	8.2bhp/ 6.03 kw at 7500 rpm
Max.torque	8.05 Nm at 5500 rpm
No of revolutions/ cycle	2

Experimental setup

The experiments are carried out at full load conditions of a engine with variable speed operation to compute performance parameters and exhaust Emission characteristics of the bifuel engine. The particulars of various components pertaining to the test facility are: Single cylinder petrol engine; Eddy current dynamometer. Model AG10; Exhaust gas analyzer; Fuel temperature control device; CNG mass flow meter; Petrol mass flow meters; Fuel consumption device; Data acquisition system; CNG conversion kit; CNG storage cylinder.

The engine and dynamometer specifications are listed in Tables 1 and 2. The test engine is converted from a

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petrol engine(Bajaj-Kawasaki) to CNG mode and modified with a suitable bi-fuelling system.

Table 2. Dynamometer specifications

Dyno. Type	Eddy current, AG10
Max. speed (rpm)	1500
Max. power (kw)	7.5

Tests have been carried out for both petrol and CNG fuels under standard conditions. The following calibrations were done for both fuels: (a) Air mass flow rate; (b) Manifold temperatures; (c) Engine torque; (d) exhaust emissions.

Table 3. Petrol composition

Component	Symbol	Mass fraction * 100
Carbon	C	85.34
Hydrogen	H	13
Oxygen	O	1.4
Sulphur	S	0.00

Experimental analysis has been done for both CNG and petrol fuels under engine steady state conditions. For CNG operation the engine fitted with a fully loaded CNG kit. The composition and properties of petrol and CNG are listed in Tables 3 -6.

Table 4. Thermodynamic properties of petrol

Stoichiometric ratio	14.2
Octane number	96
Higher heating value (MJ/kg)	45
Lower heating value (MJ/kg)	42.2
Density @ 25^o C (kg/m^3) (DIN 51757)	749
Molecular weight (kg/kmol)	106.2

Table 5. Thermodynamic properties of natural gas

Stoichiometric ratio	15.7
Higher heating value (MJ/kg)	50.3
Lower heating value (MJ/kg)	45.9
Molecular weight (kg/kmol)	17.74
Octane number	120
Methane number	69-99

Results and discussion

The experiments have been carried out for both fuels (CNG and petrol) at engine speed ranging from 1500-5500 rpm. The experiments have been carried out at full load conditions and the various parameters pertaining to performance and emissions are calibrated. Fig. 1 shows a graph plotted between volumetric efficiency and engine speed for both fuels. From the graph, it is observed that the volumetric efficiency of CNG fuelled engine is lower than petrol engine, as the CNG engine occupies more volume of inlet air. The volumetric efficiency for CNG is decreases about 13.3% and it has occur at engine speed 4000 rpm and its average value is about 12.3% through out the engine speed range. From the Fig. 2 and 3, it is learnt that the engine torque and brake power of CNG fuelled engine are considerably lower than that of petrol engine. This is due to lower volumetric efficiency of CNG fuelled engine. From the Fig. 4 and 5, it is drawn that the BMEP is inversely proportional to Engine air/fuel ratio for CNG fuelled engine and petrol fuelled engine with respect to engine speed. From the Fig. 4, it can be observed that the BMEP of CNG is lower than petrol fuelled engine and also from the Fig. 5, it can be shown that CNG has high level integration than petrol management system. Fig. 6 shows that about 19% of BSFC is less for the CNG engine than petrol engine for the engine speed range of 1500 - 5500 rpm and also it is concluded that the maximum difference is about 24% at lower speed of 2000 rpm.

Table 6. Natural gas composition

Component	Symbol	Volumetric %
Methane	CH_4	89.4
Ethane	C_2H_6	4.6
Propane	C_3H_8	1.0
Butane	C_4H_{10}	0.3
Pentane	C_5H_{12}	0.0
Hexane	C_6H_{14}	0
Carbon dioxide	CO_2	0
Nitrogen	N_2	4
Oxygen	O_2	0

Variation of engine performance characteristics

Engine performance parameters viz. engine torque, power, brake mean effective pressure and volumetric efficiency for a wide range of engine speeds have been listed In Table 7.

Variation of engine emissions characteristics

From Fig. 7 it has been concluded that the CO_2 emissions are same for both engines at higher speeds range that is 3500-5000 rpm and also the produced CO_2 in CNG engine is less than petrol and is maximum of about 12.5% at engine speed 2500 rpm.

It is know that the air/fuel ratio of CNG fuelled engine is very much closer to stoichiometric conditions. Hence CO emissions of CNG fuelled engine is much lower than petrol engine as shown in Fig. 8. The BSCO in exhaust gases for CNG fuelled engine is decreased and is of about 64.28% compared to petrol engine.

Fig. 9 compares the brake-specific total hydrocarbon (BSTHC) emissions for operation with CNG and petrol fuels. The lean mixtures and exhaust gases temperature of CNG fuelled engine are responsible for reduction in HC emissions compared to petrol engine.

Conclusion

Experimental investigations carried out on a single cylinder, four stroke, air cooled, Bajaj-Kawasaki petrol engine in the current study to evaluate the performance parameters and Emissions characteristics. In the present work, individual engine tests have been carried out in steady state and at full load condition for both fuels. Therefore, engine operation with CNG has been compared with petrol fuelled and the key observations made are: For all range of speeds, the volumetric efficiency is reduced and various between 10-1 4%;Except thermal efficiency the other performance parameters viz BMEP, Torque, Power and BSFC are decreased for CNG fuelled engine compared to petrol fuelled engine; Except NOx the other emission characteristics such as CO, CO_2, and HC are decreased.

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Fig.1 Variation of volumetric efficiency against engine speed

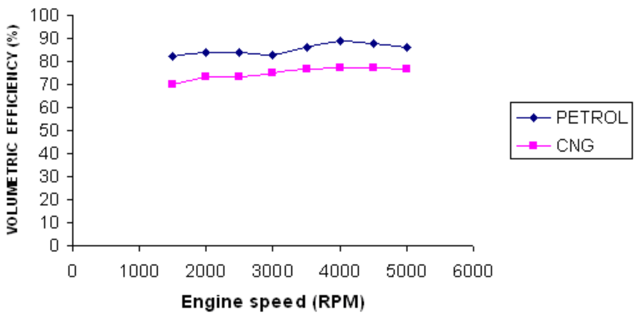


Fig. 2. Variation of torque against engine speed

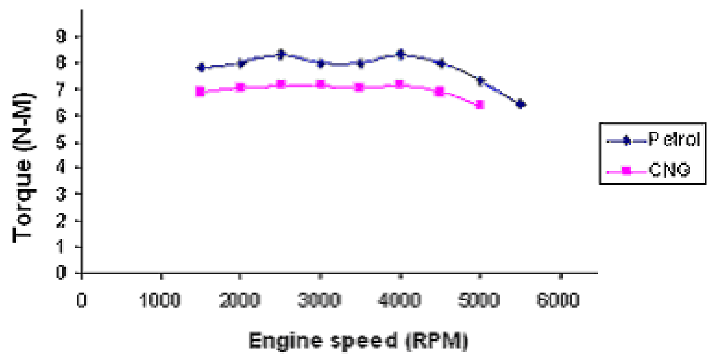


Fig. 3. Variation of power against engine speed

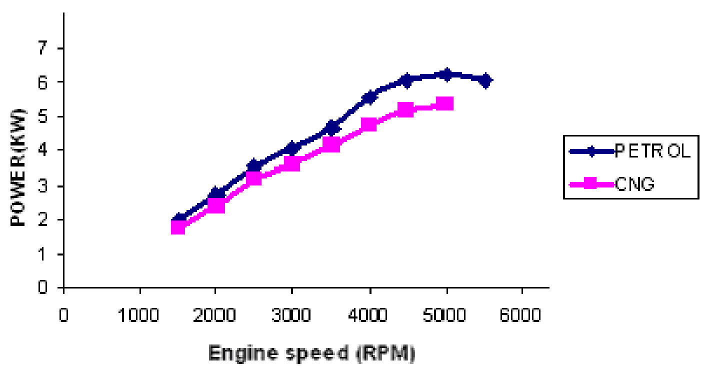


Fig. 4. Variation of BMEP against engine speed

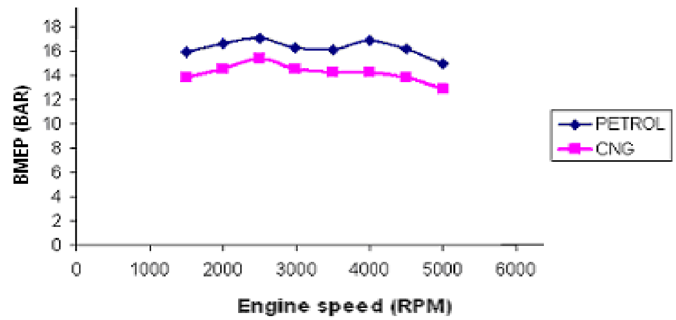


Fig. 5. Variation of Lambda against engine speed

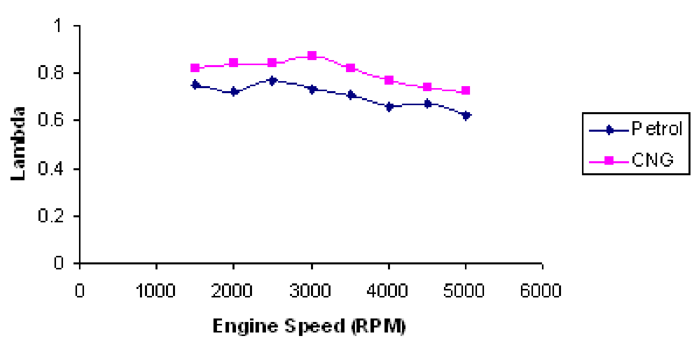


Fig. 6. Variation of BSFC against engine speed

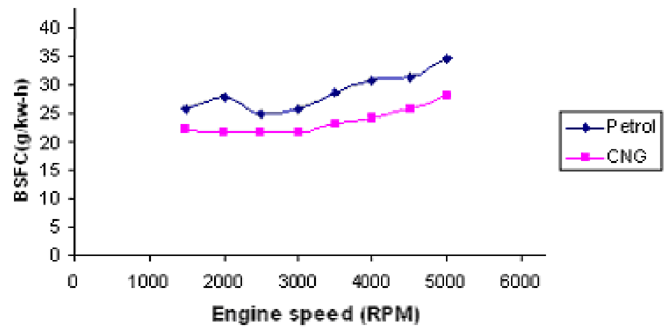


Fig. 7.Variation of CO_2 against engine speed

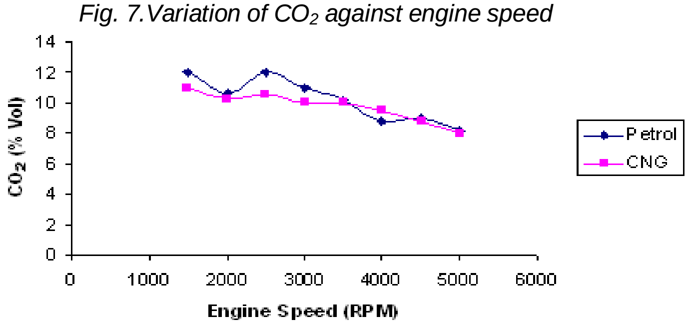


Fig. 8. Variation of CO_2 against engine speed

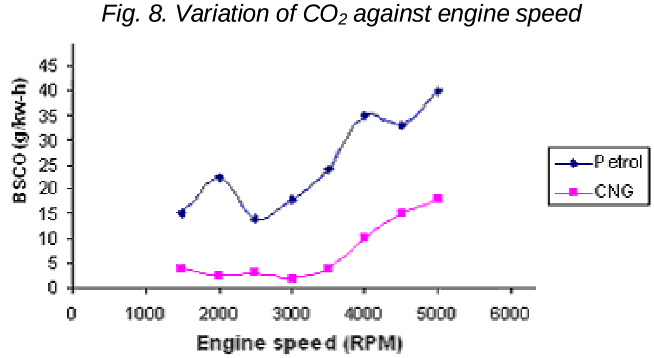
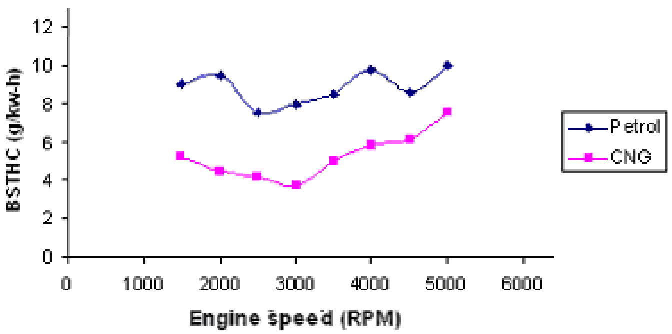


Table 7. Variations of engine performance parameters

Items	Petrol	CNG	Deviation %
Max.power (kw)	6.20@ 5000 rpm	5.34 @ 5000 rpm	13.88
Max.torque (N.m)	8.35@ 2500 rpm	7.13 @ 2500 rpm	14.62
Max.volumetric efficiency	89.51@4000rpm	77.59%@4000rpm	13.3
Max.BSFC (g/kw.h)	34.45@5000rpm	27.99 @ 5000 rpm	18.75
Max.BMEP (bar)	17.06@2500rpm	15.37 @ 2500 rpm	9.91
Max. thermal efficiency %	34%@ 2500 rpm	98 % @ 2000 rpm	--

Fig.9. Variation of CO_2 against engine speed



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