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Experimental Investigation of the Effect of Compression Ratio on the Performance of a VCR CNG Engine

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Abstract – Environmental degradation is on the rise due to increased motor vehicle population. One of the strategies adopted to curb deteriorating environmental quality is the use of alternative fuels. Compressed Natural Gas (CNG) has the potential to provide a good compromise in efficiency, cost, and emission when used in Internal Combustion (I.C.) engines. Due to its higher-octane number, engine efficiency can be increased through higher compression ratios. It also produces lower emission of pollutants and is available in abundance in many parts of the world.

Higher compression ratio increases the pressure, temperature, mixture concentration of the compressed gases which results in high thermal efficiency and improved fuel economy in I.C. engines, whereas if the compression ratio is higher, the fuel will pre-ignite causing knocking which leads to engine damage.

This work is an experimental and theoretical investigation of the influence of the compression ratio on the brake power, brake thermal efficiency, brake mean effective pressure, specific fuel consumption and emissions of a Variable Compression Ratio CNG fueled engine.

Keywords— Compression ratio, VCR Engine, CNG, brake power, brake thermal efficiency, specific fuel consumption, emissions.

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INTRODUCTION

Emission concerns related to engines and the adverse effects brought on human and environmental health along with the search for alternate sources of energy continue to be two important issues of discussion in the automotive industry. Emission standards on engines will become even more stringent in the next couple of years. For these reasons, extensive research works were performed on alternative fuels such as methanol, ethanol, butanol, Compressed Natural Gas (CNG), and Liquefied Petroleum Gas (LPG). Compressed Natural gas has an important position among alternative fuels and a potential for low emission of pollutants when used in I.C. engines. Its abundance, low cost, and good emission characteristics make it an important alternative fuel for some applications.

CNG AS A FUEL

Natural gas consists mainly of methane with small amount of ethane, propane, and butane. Very small concentrations of inert gases such as N_2 and CO_2 are also present. Methane exists in natural gases in percentages of up to 90 to 95%.

In gaseous state, it is lighter than air, colorless, and odor free. If odor is present, it is due to impurities such as mercaptans and other products which are added in very small amounts as a safety precaution, especially in city areas as it can provide a warning signal should it leak.

Natural gas is an excellent fuel for Otto-cycle engine because as a gas, under normal condition, it readily mixes with air in any proportion, thus eliminates the existing difficulties of fuel-air mixing and distribution in gasoline-fueled engines.

Also, it does not require vaporization before burning, hence cold-engine starting is easier and cold-start enrichment is not required. Cold-start fuel enrichment is a major source of CO emission in gasoline-fueled vehicles.

One of the major advantages utilizing natural gas in engines is its cleaner combustion characteristics than most other fuels currently available. The major pollutants from natural gas combustion are unburnt hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx) and small amount of other pollutants such as particulates, sulfur dioxide, and aldehydes.

Due to the low density of natural gas, a stoichiometric mixture of natural gas and air occupies about 10% more volume than a stoichiometric gasoline/air mixture with the same energy content. Therefore, for a fixed engine displacement, the amount of input chemical energy per stroke is about 10% less for a CNG-fueled engine as compared to a gasoline one.

The reduction in what is called as volumetric efficiency because of natural gas utilization is significant. The volumetric efficiency of a CNG-fueled engine is 0.78, whereas that of a gasoline engine is 0.85. This is commonly cited as one of the important reasons that CNG vehicles have less power than the gasoline ones. In dedicated natural gas engine, this can be overcome by increasing the compression ratio. The higher efficiency due to the increased compression results in more work output for each unit of mixture inducted, thus offsetting the reduced volumetric efficiency.

BACKGROUND

Current CNG engines are predominantly bi-fuel (Petrol + CNG) and are run at compression ratio around 9:1. But now CNG is easily available in cities and hence dedicated CNG engines can be thought of more aggressively. CNG has higher octane rating so it can run at higher compression ratios compared to petrol. A high compression ratio is desirable because it allows an engine to extract more mechanical energy from a given mass of air-fuel mixture due to its higher thermal efficiency.

Theoretically, increasing the compression ratio (CR) of an engine can improve the overall efficiency of the engine by producing more power output. The ideal cycle analysis for SI engine shows that indicated thermal efficiency increases continuously with compression ratio according to Equation 1

$$\eta_T = \left(1 - \frac{1}{r_C^{\gamma-1}}\right) \quad \ldots\ldots (1)$$

Where, γ is ratio of specific heats (for air γ = 1.4).

Higher CR increases the combustion efficiency of CNG engines.

FUEL PROPERTIES

Important fuel properties of gaseous fuels such as octane number, calorific value etc. is given below:

TABLE I Fuel Properties

PROPERTY	GASOLINE	CNG
Chemical formulae	C_8H_{18}	CH_4
Carbon, % composition	85-88	75
Hydrogen, % composition	12-15	25
Density, kg/m3	750	0.72
Octane Number	89-94	120+
Auto-ignition temperature, °C	230	540
Latent heat of vaporization, kJ/kg	9.94	12.79
Stoichiometric air/fuel, weight	14.7	17.2
Calorific value, kJ/kg	44000	45000

EXPERIMENTAL SETUP

Fig. 1 Experimental Setup

TABLE II Specifications of Test Engine

1) Description	2) Specifications
3) Make	4) Apex Innovations Pvt. Ltd., Sangli.
5) Type	6) Single Cylinder, Four-Stroke, Vertical, Water-Cooled, Naturally Aspirated Variable Compression Ratio Multi-Fuel Engine
7) Power in Diesel Mode	8) Diesel mode: 3.5 KW @ 1500 rpm

9) Power in Petrol Mode	10) Petrol mode: 4.5 kW @ 1800 rpm
11) Number of Cylinders	12) One
13) Compression Ratio	14) 5:1 - 20:1 (Variable Compression Ratio)
15) Bore X Stroke	16) 87.5 mm X 110mm
17) Swept Volume	18) 661 cc

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Research engine connected to eddy current dynamometer. It is provided with necessary instruments for combustion pressure, crank-angle, airflow, fuel flow, temperatures and load measurements. These signals are interfaced to computer through high speed data acquisition device. The set-up has stand- alone panel box consisting of air box, manometer, fuel measuring unit, and transmitters for air and fuel flow measurements, process indicator and piezo powering unit. Rotameters are provided for cooling water and calorimeter water flow measurement.

RESULTS AND DISCUSSIONS

In order to determine optimum compression ratio for variable compression engine fueled with CNG, tests were carried out at full load and compression ratios of 8, 9, 10, 11, 12 and 13 respectively at speed of 1200 to 1800 rpm. The optimum compression ratio is decided based on maximum brake thermal efficiency and emissions.

The parameters under consideration are

Performance Parameters-

- Power & Torque
- Brake thermal efficiency
- Specific fuel consumption

Emission Parameters-

- Carbon Monoxide (CO) Emissions
- Unburned Hydro Carbon (HC) emissions
- Nitrogen Oxides (NOx) Emissions

Fig.2 shows the P-Theta graph at Compression ratio of 8:1 to 13:1, it can be seen that no knocking tendency was observed throughout the operating range. 43 bar pressure was observed at CR 13:1.

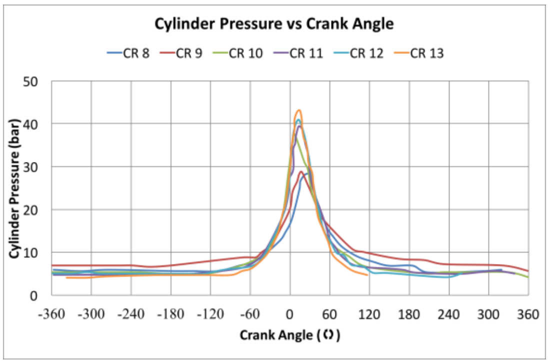

Fig. 2 P-Theta comparison for various CR

Fig.3 shows comparison of Torque w.r.t. speed. Max torque of 23Nm@1300rpm is achieved at CR 13:1. By increasing the compression ratio, the cylinder gas pressures and peak burned gas temperatures increase. This causes gas motion to increase, resulting in faster and better combustion.

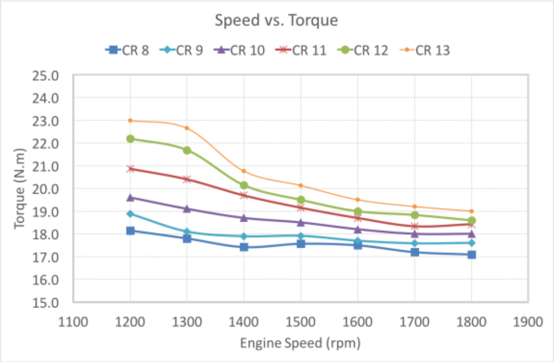

Fig. 3 Variation of Torque with Engine Speed

Fig.4 shows comparison of Brake Power with respect to speed. It can be clearly seen that the CR and Power are directly proportional in line with the empirical formula.

At CR 13:1, 3.6kW@1800rpm was achieved with CNG as fuel which is comparable to the performance value with Diesel (3.5kW) and Petrol (4.5kW).

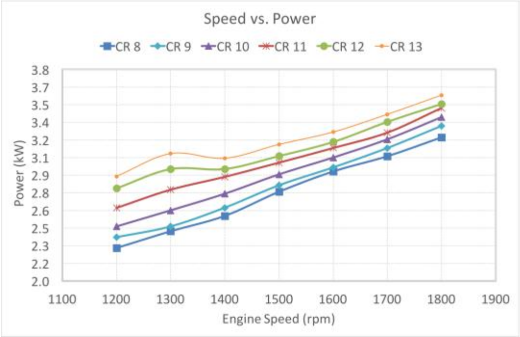

Fig. 4 Variation of Brake Power with Engine Speed

Fig.5 shows comparison of brake thermal efficiency with respect to load at different compression ratios. The thermal efficiency increases with increase in CR. The maximum brake thermal efficiency is obtained at a compression ratio of 13:1, due to superior combustion and better intermixing of the fuel. The brake thermal efficiency at compression ratio 12:1 is also very close to that of maximum brake thermal efficiency.

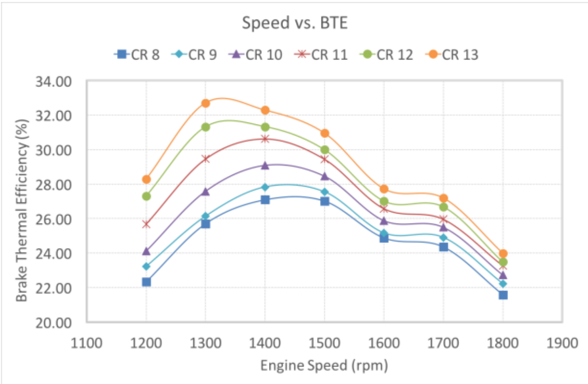

Fig. 5 Variation of Brake Thermal Efficiency with Engine Speed

Fig.6 shows the plot of BSFC w. r. t. speed. CR 12:1 and 13:1 shows SFC values around 235 gms/kwhr. It can be clearly seen that Fuel consumption reduces with increase in compression ratios.

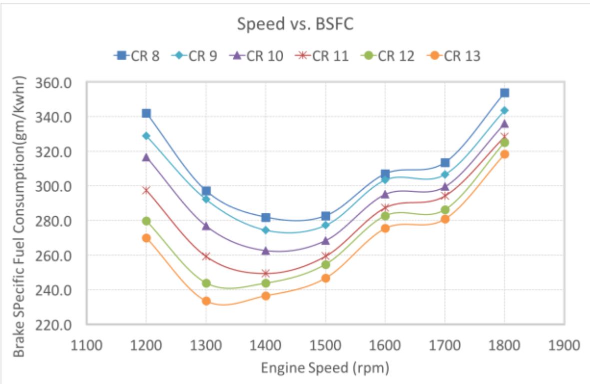

Fig. 6 Variation of Brake Specific Fuel Consumption with Engine Speed

Fig. 7, 8, and 9 show the plot of CO, HC and NOx emissions at 1800 rpm for various compression ratios. It can be seen that CO and HC emissions reduce with increasing CR due to improvement in quality of combustion and NOx increases with increase in CR. Higher CR with increase in temperature is favourable for emission of NOx.

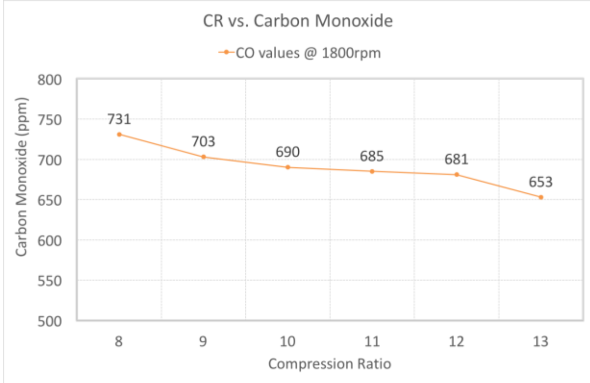

Fig. 7 Comparison of CO emissions at 1800rpm

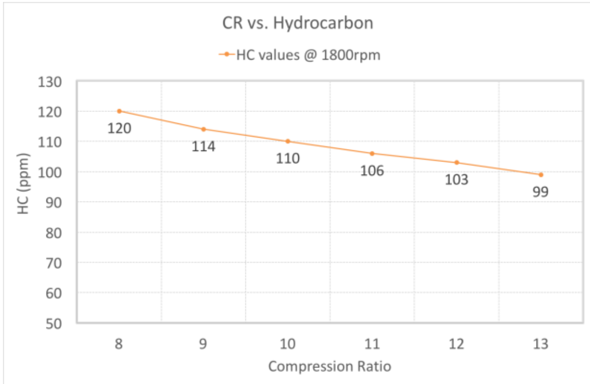

Fig. 8 Comparison of HC emissions at 1800rpm

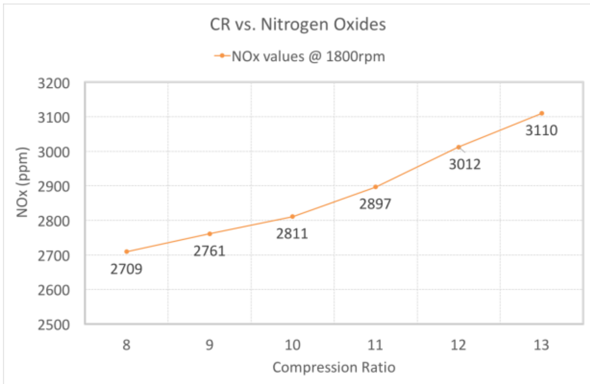

Fig. 9 Comparison of NOx emissions at 1800rpm

CONCLUSIONS

a. Increase in compression ratio increases the brake power, torque, brake thermal efficiency, brake mean effective pressure and decreases the specific fuel consumption.

b. The overall performance of the CNG engine was very good and also showed performance equivalent to base diesel engine.

c. Exhaust CO and HC decreases while NOx increases with increase in compression ratio.

d. Below table shows the comparison of performance parameters at compression ratio 12:1 and 13:1.

TABLE III Performance comparison of CR 12:1 and 13:1

Sr. No	Parameter	Compression Ratio 12:1	Compression Ratio 13:1
1	Max Power	3.5 kW	3.6 kW
2	Max Torque	21.7 Nm	22.6 Nm
3	Brake Thermal Efficiency	31.31%	32.7%
4	Brake Specific Fuel Consumption	243.9 gm/kWhr	233.5 gm/kWhr
5	CO Emission	681 ppm	653 ppm
6	HC Emission	103 ppm	99 ppm
7	NOx Emission	3012 ppm	3110 ppm

e. It is clear that performance parameters are marginally better with compression ratio 13:1. Whereas the NOx emission has gone up significantly.

f. Common strategy used for NOx reduction is Exhaust Gas Recirculation (EGR). Adding EGR on the engine calls for performance penalty and the performance with EGR would be similar to that of compression ratio 12:1 or 11:1. Also, EGR adds to the cost of the engine.

g. Based on the test results, compression ratio 12:1 is proposed as an optimum compression ratio for dedicated CNG engines since the performance parameters are at par with compression ratio 13:1 and 12:1 also has the advantage in NOx emissions.

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