Experimental Investigation of the effect of Compression Ratio on the performance of a dedicated CNG engine

Anand Ramachandran[1], Prof. A.V Waghmare[2]

[1]Student, M.E Automotive, AISSMS COE, Pune
[2]HOD, Mechanical Engineering Department, AISSMS COE, Pune

Abstract - *The compression ratio is a factor that influences the performance characteristics of internal combustion engines. This work is an experimental investigation of the influence of the compression ratio on the engine performance, brake thermal efficiency, and specific fuel consumption of a variable compression ratio CNG fueled engine.*
Compression ratios of 8, 9, 10, 11, 12 and 13 and engine speeds of 1200 to 1800 rpm, in increments of 100 rpm, were utilized. In the present study, the effect of different compression ratios was studied and optimum compression ratio was established for a dedicated CNG engine. The results show that with the increase in compression ratio, the performance characteristics viz. power, torque, brake thermal efficiency and brake specific fuel consumption are improved. The emission characteristics except nitrogen oxides are found to be better for CNG.

***Key Words*: Compression Ratio, Thermal Efficiency, Dedicated CNG, VCR Engine**

1. INTRODUCTION

Compressed Natural Gas (CNG) engine has proved itself to be worthy replacement for diesel in heavy commercial and passenger transport application. Development of CNG distribution infrastructure and stringent emission regulations has increased the efforts by Original Equipment Manufacturers (OEM) to concentrate on development of CNG vehicles across all the segments. Indian cities are facing air quality degradation due to high vehicle density and since contribution of light commercial vehicles in intra city application is enormous, application of CNG vehicle has been made mandatory in some cities.

As a fossil fuel, natural gas is formed from the decaying remains of pre-historic plant and animal life. It has higher octane number (120) than petrol (91-97). The use of CNG in internal combustion engines yields higher thermal efficiency and better fuel economy compared to gasoline. This is due to mainly the higher octane rating which permits greater engine compression ratio without the occurrence of knock.

CNG fueled engines have been used in automotive field, in all combination as an alternate fuel. The advantages of CNG are – clean burning fuel because it produces lower reactive hydrocarbons, improved efficiency because it allows higher compression ratio due to high octane rating, and lower CO_2 emission, due to high H/C ratio.

2. BACKGROUND

In recent years, CNG has been promoted as a promising clean fuel alternative to spark ignition engines because of its relatively higher octane level. It also offers much lower greenhouse gas emissions than those from the burning of other hydrocarbons as a result of its very simple carbon chain structure and higher hydrogen to carbon ratio.

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 and 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. High ratios place the available oxygen and fuel molecules into a reduced space along with the adiabatic heat of compression, causing better mixing and evaporation of the fuel droplets. Thus, they allow increased power at the moment of ignition and the extraction of more useful work from that power by expanding the hot gas to a greater degree.

3. COMPRESSION RATIO AND ITS SIGNIFICANCE

Compression ratio is the ratio of the total volume of the combustion chamber when the piston is at the bottom dead center (BDC) to the total volume of the combustion chamber when piston is at the top dead center (TDC). Theoretically, increasing the compression ratio of an engine can improve the overall efficiency of the engine by producing more power output. The ideal cycle analysis for SI engine show that indicated thermal efficiency increased continuously with compression ratio according to Equation 1

$$\eta_T = (1 - \frac{1}{r_C^{\gamma-1}}) \quad \text{...... (1)}$$

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

Higher CR increases the combustion efficiency of CNG engines. With the higher compression ratio, the lean burn limit increases because of the reduction in initial combustion period. Under part load conditions, the fuel economy can be improved with higher compression ratio. However, this is often associated with problem of knocking and roughness. Knocking, however, is a limitation for increasing the compression ratio.

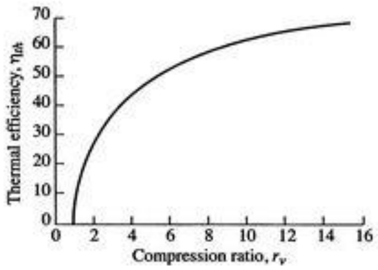

Fig-1: Thermal efficiency vs. Compression ratio for Otto cycle

The ideal Otto cycle efficiency is shown as a function of the compression ratio in Fig-1. As the compression ratio, r, increases, efficiency of Otto cycle increases.

4. FUEL PROPERTIES

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

Table-1: Fuel Properties

PROPERTY	GASOLINE	CNG
Chemical formulae	C8H18	CH4
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

5. EXPERIMENTAL SETUP

Fig-2: Experimental Setup

Table-2: Technical Specifications of test engine

Description	Specifications
Make	Kirloskar TV1
Type	Single Cylinder, Four-Stroke, Vertical, Water-Cooled, Naturally Aspirated Variable Compression Ratio Multi-Fuel Engine
Power in Diesel Mode	Diesel mode: 3.5 KW @ 1500 rpm
Power in Petrol Mode	Petrol mode: 4.5 kW @ 1800 rpm
Number of Cylinders	One
Compression Ratio	5:1 - 20:1 (Variable Compression Ratio)
Bore X Stroke	87.5 mm X 110mm
Swept Volume	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.

6. 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 at speed of 1200 to 1800 rev/min. The optimum compression ratio is decided based on maximum brake thermal efficiency and emissions.

The parameters which are 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

Chart-1 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.

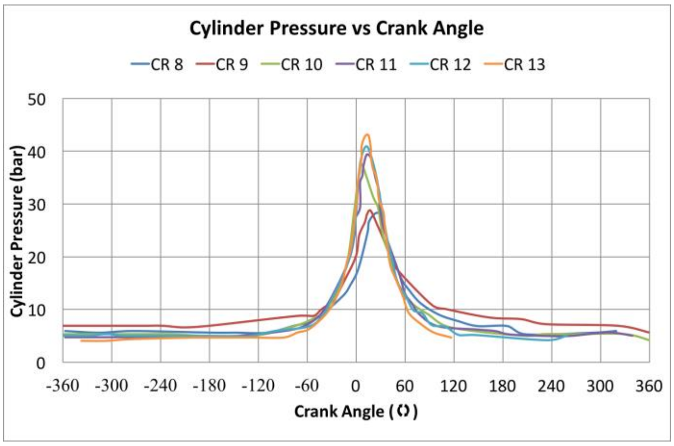

Chart-1: P-Theta comparison for various CR

Chart-2 shows variation of Torque with respect to 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.

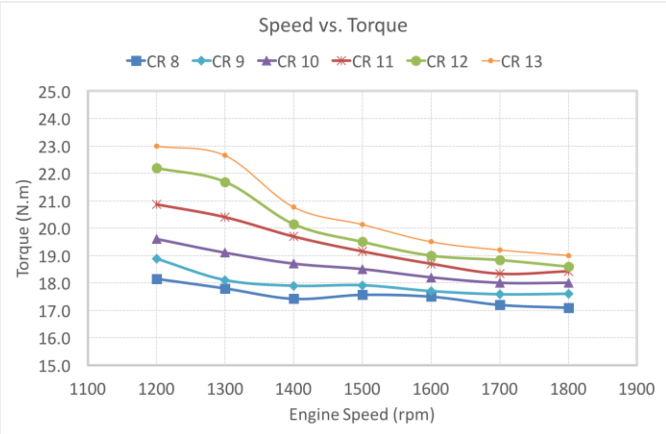

Chart -2: Variation of Torque with Engine Speed

Chart-3 shows variation of Brake Power with respect to speed. It can be clearly seen that the CR and Power are directly proportional inline 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).

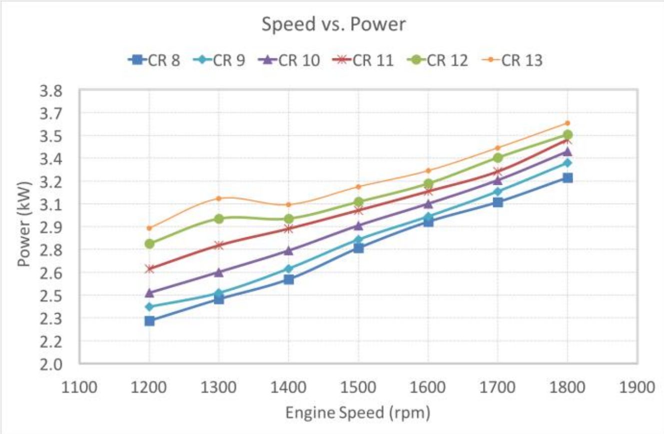

Chart-3: Variation of Brake Power with Engine Speed

Chart-4 shows variations 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 the 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.

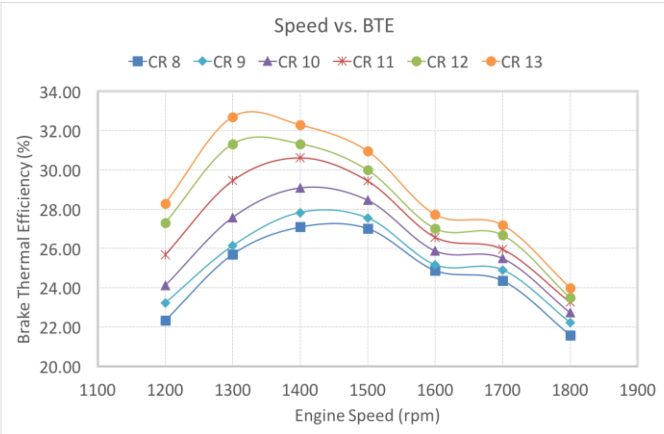

Chart-4: Variation of Brake Thermal Efficiency with Engine Speed

Chart-5 shows the plot of BSFC with respect to speed. CR 12:1 and 13:1 shows SFC values around 235 gms/kWhr.

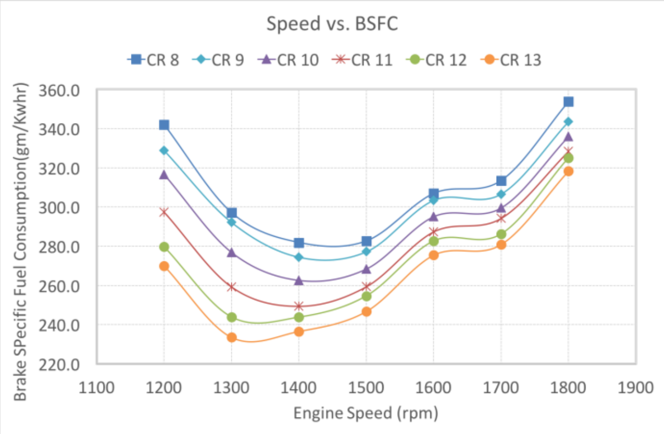

Chart-5: Variation of Brake Specific Fuel Consumption with Engine Speed

Chart-6,7,8 shows 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.

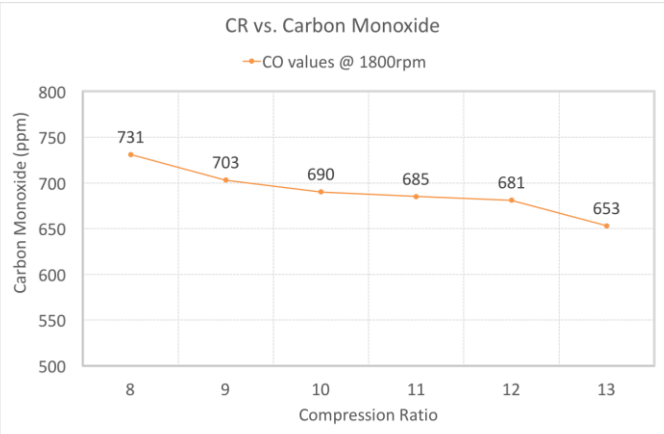

Chart-6: Comparison of CO emissions at 1800rpm

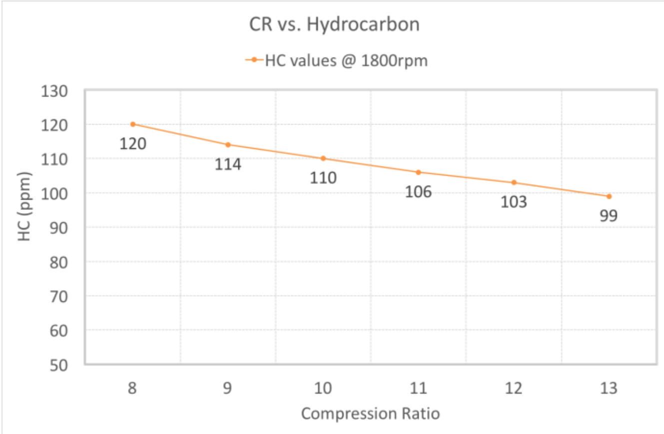

Chart-7: Comparison of HC emissions at 1800rpm

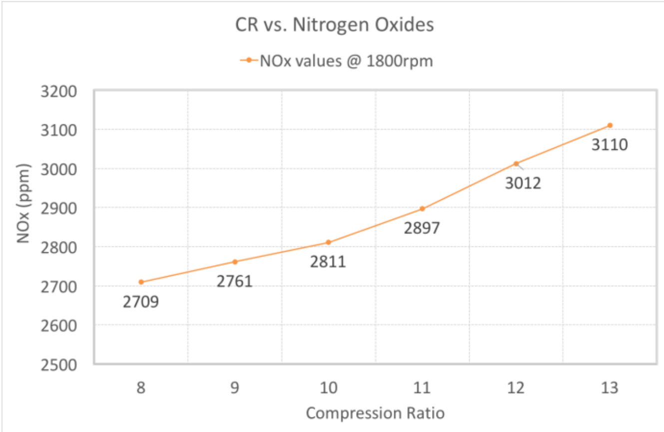

Chart-8: Comparison of NOx emissions at 1800rpm

7. CONCLUSIONS

1. Increase in compression ratio increases the brake power, torque, brake thermal efficiency, brake mean effective pressure and decreases the specific fuel consumption.
2. The overall performance of the CNG engine was very good and also showed performance equivalent to base diesel engine.
3. Exhaust CO and HC decreases while NOx increases with increase in compression ratio.
4. Below table shows the comparison of performance parameters at compression ratio 12:1 and 13:1.

Table-3: 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

5. It is clear that performance parameters are marginally better with compression ratio 13:1. Whereas the NOx emission has gone up significantly.
6. 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.
7. 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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