MATTER: International Journal of Science and Technology
*ISSN 2454-5880*

*Yadav et al., 2017*

*Volume 3 Issue 2, pp. 64 - 79*

*Date of Publication: 06th September, 2017*

*DOI-https://dx.doi.org/10.20319/mijst.2017.32.6479*

*This paper can be cited as: Yadav, B., Soni, S., Sharma, D., & Sharma, P. (2017). Performance and Emission Analysis of Constant Speed SI Engine Operated on Hythane (HCNG). MATTER: International Journal of Science and Technology, 3(2), 64-79.*



# PERFORMANCE AND EMISSION ANALYSIS OF CONSTANT SPEED SI ENGINE OPERATED ON HYTHANE (HCNG)

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## Abstract

*Energy is the basic need of human to survive in this dynamic world. The whole world is toiling hard to meet its energy demands. Every country in this world has high energy demand owing to its increasing population which is posing a threat to energy sustainability. Generally, Energy is consumed in Agriculture, Residential and Transportation sector in which transportation sector* *has a high percentage of energy consumption. Conventional fuels which are used to power vehicles are having limited reserves. In the present scenario, Petroleum reserves are depleting at a faster rate and causing environmental pollution. It has inspired the researchers to develop new alternate fuels. Alternate fuels are having significant energy content and lower emissions as compared to conventional fuels. Alcohol, Biodiesel, Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG) and Hydrogen are the alternate fuels which are being used today. CNG is being used extensively all over the world. CNG is having low laminar burning velocity which makes it more prone towards knocking. Hydrogen has high laminar burning velocity which makes it a better supplement to CNG. The blend thus obtained by mixing Hydrogen and CNG is known as Hythane or HCNG. Hythane has the advantages of both the parent fuels which make it a promising fuel for automotives. This paper includes the effect of Hydrogen addition to CNG which is tested on a single cylinder, four-stroke, water cooled SI engine. Determination of optimum percentage of Hydrogen in CNG and emissions analysis is also included in the paper.*

**Keywords**

Alternate Fuel, CNG, HCNG, BSFC, BSEC, Hydrogen, Hydrocarbon

## 1. Introduction

Energy sustainability is hard to achieve without using renewable energy sources or alternative sources. Alternate fuels are playing a vital role in transport sector to meet its continuously increasing energy demands. Rapidly increasing population of vehicles is causing too much air pollution and stringent emission norms are also fostering to look for new fuels. Hythane can be a futuristic fuel for automotives due to its characteristics. Hythane is a mixture of Hydrogen and CNG. Hydrogen has lower minimum ignition energy (0.02 mJ), high burning rate, high diffusivity, high heating value, high octane number and wide flammability range (4-75%) which makes it a perfect partner of CNG (Nanthagopal, 2011). Hydrogen has wide flammability range which makes Hythane to be lean burning and it subsequently reduces HC emissions. This paper contains results of an experiment which is done on a stationary SI engine. It includes Performance and Regulated emissions analysis of CNG and three blends of HCNG. Used three blends of HCNG contain 5%, 10% and 15% of Hydrogen which are termed as HCNG5, HCNG10 and HCNG15 respectively. It is observed that increasing Hydrogen fraction to CNG would increase the brake thermal efficiency of the engine. It was found in the experiment that HCNG10 has the highest efficiency among all blends. HCNG15 has low efficiency as compared to HCNG10. Fuel Consumption is almost similar for HCNG10 and HCNG15. By considering efficiency and BSFC it is concluded that HCNG10 can be used in tested engine without any modifications. $No_x$ emissions and Exhaust Gas Temperature (EGT) are higher for Hythane (HCNG).

## 2. Literature Review

Lot of research work has been carried out by different researchers in the field of alternate fuels for past many years, HCNG is one of them**.** K R Patil (2010) carried out an experiment on neat CNG and 5% blends of hydrogen with CNG. It is found by the experimental work that HCNG engines are better than CNG engines from power output, fuel economy and emission point of view. The power is improved by 3 -4%, torque is improved by 3% and fuel consumption is reduced by 4% in comparison to neat CNG engine. Kapadani (2014) performed an experiment on 4.50 kW, single cylinder, 4 stroke, variable speed, water cooled gasoline engine. The researcher used Gasoline, Compressed Natural Gas and HCNG5 as fuels. Hydrogen is produced by electrolysis of water and CNG is supplied from a cylinder. A Hydrogen electronic control unit (HECU) has been designed for regulating the rate of hydrogen production according to the engine load condition to ensure 5% Hydrogen mixture with compressed Natural gas. It was observed from the experiment that the Air-Fuel mixture for HCNG5 has comparatively lean for nearly all range of operating conditions. The engine combustion pressure increases by addition of 5% Hydrogen in Compressed Natural gas. The HCNG5 fuel improves power gain 14 % in comparison to gasoline and around 8% more than Compressed Natural gas. HC emissions are reduced up to 15% for CNG and up to 20% for gasoline. The engine component embrittlement phenomenon does not occur with addition of 5% hydrogen in Compressed Natural gas. Mariani (2012) suggested that to obtain maximum braking torque (MBT) in HCNG engine, ignition timing should be lower as compare to Compressed Natural Gas. For low brake mean effective pressures (bmep) high efficiency can be achieved by increasing the hydrogen amount reducing throttling losses. HCNG blend improves engine efficiency and reduces $CO_2$ emissions because of the reduced C/H ratio and fuel consumption. $NO_x$ emissions are higher than CNG due to the higher in-cylinder temperature attained for a given equivalence ratio. The good combustion patterns of HCNG help to maintain low Hydrocarbon (HC) emissions. Suryawanshi (2011) reported that existing CNG kits can be modified for Hythane or HCNG. Spark retardation i.e. optimum spark timing was used because of increase in laminar flame burning speed. The possibility of backfire increases owing to low quenching gap of hydrogen. Goyal (2014) suggested that the addition of hydrogen to CNG will increase the lean operation limit and decreases maximum brake torque (MBT) which clearly shows relation among hydrogen ($H_2$) fraction, spark timing and excess air ratio.

## 3. Experimental Set-up

### 3.1 Engine

A single-cylinder, 4-stroke, S.I engine coupled to a dynamo (generator) is used to study the effect of Hydrogen addition to CNG. Dynamo converts mechanical shaft work of engine into electrical output with the help of alternator. The engine used in experiment, is a modified diesel generator. It utilizes gaseous fuel to produce shaft work which is converted into single phase A.C as explained above.


**Figure 1:** *Engine*

**Table 1:** *Specification of the Engine*

| S. NO. | SPECIFICATION | RATING |
|---|---|---|
| 1 | Engine type | Water cooled |
| 2 | KVA | 3KVA |
| 3 | No. of cylinder | ONE |
| 4 | R.P.M. | 1450-1500 |
| 5 | Bore | 114 mm |
| 6 | Stroke | 116 mm |
| 7 | Cylinder Volume | 1200 cc |
| 8 | Spark Plug | MICO 10X1 mm |
| 9 | Fuel | Gaseous fuels |
| 10 | Lubricating Oil sump Capacity | 3.5 Liter |
| 11 | Lubricating Oil | SAE –30 |
| 12 | Weight | 600 Kg |
| 13 | Alternator | 3KVA |
| 14 | Power Factor | Unity |
| 15 | Output Voltage | 220V AC |
| 16 | Frequency | 50 Hz |
| 17 | Max. Current | 13.0 Amp |
| 18 | Phase | Single Phase |
| 19 | Voltage Regulation | ± 10% |

### 3.2 Flame Trap and Flame Arrestor

Flame trap and Flame arrestor are safety devices which are placed in between the gas cylinder and inlet manifold of engine which allows gas to flow under normal operating conditions but prevent the transmission of a flame (backfire).

### 3.3 Exhaust Gas Temperature measurement

Exhaust gas temperature was measured with the help of a thermocouple. K type thermocouple was placed in the exhaust manifold of engine to measure the temperature of exhaust gases. The K type thermocouple is cheaper as compared to others and a wide variety of probes are available in the market for −200 °C to +1350 °C range. Exhaust gas temperature gives an indication of the potential available in the exhaust gas from heat recovery point of view.


**Figure 2:** *Flame Trap and Flame Arrestor* **Figure 3:** *Temperature Indicator*

### 3.4 Load Arrangement

30 bulbs of rating 100 watt each was installed on the load bank. Arrangement was made to vary the load from zero to full at 3000 W.

### 3.5 Gas Analyzer

The gas analyzer is used to find out the exhaust gas emissions. Carbon monoxide (CO), Carbon dioxide, Oxygen, $NO_x$ and Unburned Hydrocarbon are measured with the help of Gas Analyser. CO is measure in vol %, HC in ppm vol. Hex., $CO_2$ in vol %, $O_2$ in vol %, $NO_x$ in ppm.

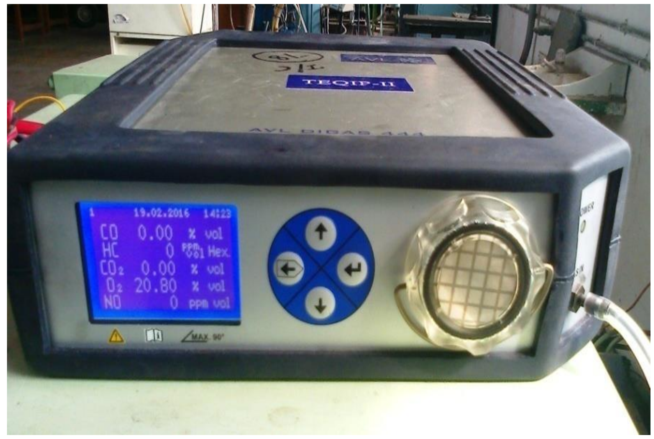


**Figure 4:** *Connection of bulbs on load bank*

**Figure 5:** *Gas Analyzer*

### 3.6 Auxiliary Devices

Many auxiliary devices were used in the research work some of them are - Pressure Regulator, Tachometer for RPM measurement of engine, NRV (Non return Valve), pipe connector and Reducer.

## 4. Experimental Technique for testing engine

CNG and HCNG were used and study was done to measure the performance of engine. A sequence of experiments was done by varying the load on engine to compare the performance of neat CNG and blends of CNG. During the experiment exhaust gas temperature and emissions were recorded at each load after allowing the engine to warm up and stabilize.

### 4.1 Variation of Load

The rated power output (full load) of the engine was 3KW. The different loads applied to the engine for all fuels (Neat CNG, HCNG5, HCNG10 and HCNG15) were 0.5 kW, 1.0 kW, 1.5 kW, 2.0 kW, 2.5 kW and 3.0 kW. The loads were increased by switching on bulbs of appropriate wattage.

### 4.2 Variation of Fuel

First engine was made to run on neat CNG only to have a baseline data. Subsequently, it was made to run on various blends. The fuels for experiments were CNG, HCNG5, HCNG10 and HCNG15.

**Table 2:** *Range of investigation*

| Sr. No. | Parameters | Range |
|---|---|---|
| 1. | Fuel | CNG, HCNG5, HCNG10 and HCNG15 |
| 2. | Load | 0-3 kW |
| 3. | Engine Speed | 1500 rpm |

## 5. Engine Performance Parameters

These parameters are used for comparison of various engines. It includes Brake thermal efficiency, Brake specific fuel consumption and Brake specific energy consumption.

### 5.1 Brake Thermal Efficiency

Brake thermal efficiency (BTE) is a measure of net power developed by the engine which is readily available for use at the engine output shaft. Brake thermal efficiency (BTE) for all fuels increased with increase in load and reached its maximum at 2.5 kW load and then it dropped slightly at full load. Brake thermal efficiency in case of neat CNG was 17.63% which occurred at 2.5 kW load. As hythane was used as a fuel in engine then its efficiency started increasing. For HCNG5 maximum brake thermal efficiency obtained was 19.48% at 2.5 kW load. For HCNG10 maximum brake thermal efficiency obtained as 20.95% which was at 2.5 kW load. So by increasing hydrogen percentage in hythane, break thermal efficiency tends to increase up to 10% of hydrogen but as hydrogen content was increased to 15% or HCNG15 then efficiency was decreased.

For HCNG15 efficiency was lower than HCNG10 at all loads. Hydrogen has high burning flame velocity as compared to CNG so when its fraction is increased then ignition timing should be set according to it. Ignition timing should be retarded as hydrogen fraction is increased. Due to this engine efficiency was decreased as combustion took place before time so peak pressure and temperature were not occurring on designed point. Increasing hydrogen fraction will increase peak pressure and temperature so it may also cause knocking so decrease in efficiency can be understood. Figure 6 shows the variation of brake thermal efficiency with respect to load for all fuels used.

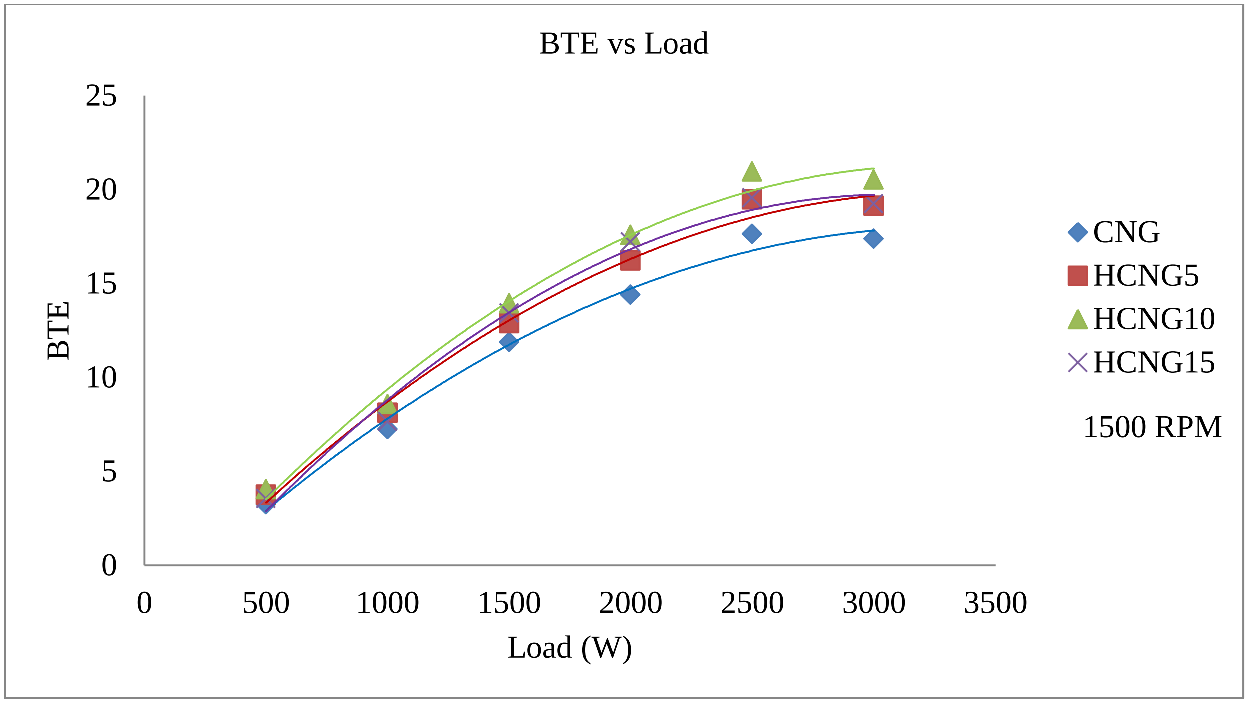


**Figure 6:** *BTE variations with Load*

### 5.2 Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption is defined as the rate of fuel consumed per unit of brake power developed by the engine (Wikipedia). It is a measure of the fuel efficiency of engine which burns fuel and produces shaft power. In the present research work, minimum Brake specific fuel consumption was found as 0.509 kg/kW-hr at 2.5 kW for CNG which was decreased by addition of hydrogen content to it. By adding 10% hydrogen to CNG, it reached a minimum value of 0.357 kg/kW-hr at 2.5 kW.

For HCNG15, minimum value of brake specific fuel consumption was 0.354 kg/kW-hr at 2.5 kW engine load. BSFC was minimum for HCNG15 which was almost equal to HCNG10. Efficiency was lower for HCNG15 in comparison to HCNG10 but BSFC was almost same for both the fuels, this conflict would be clear by studying BSEC (brake specific energy consumption) curves of the fuels. A graphical representation of brake specific fuel consumption (BSFC) with respect to varying engine load for various fuels is shown in figure 7.

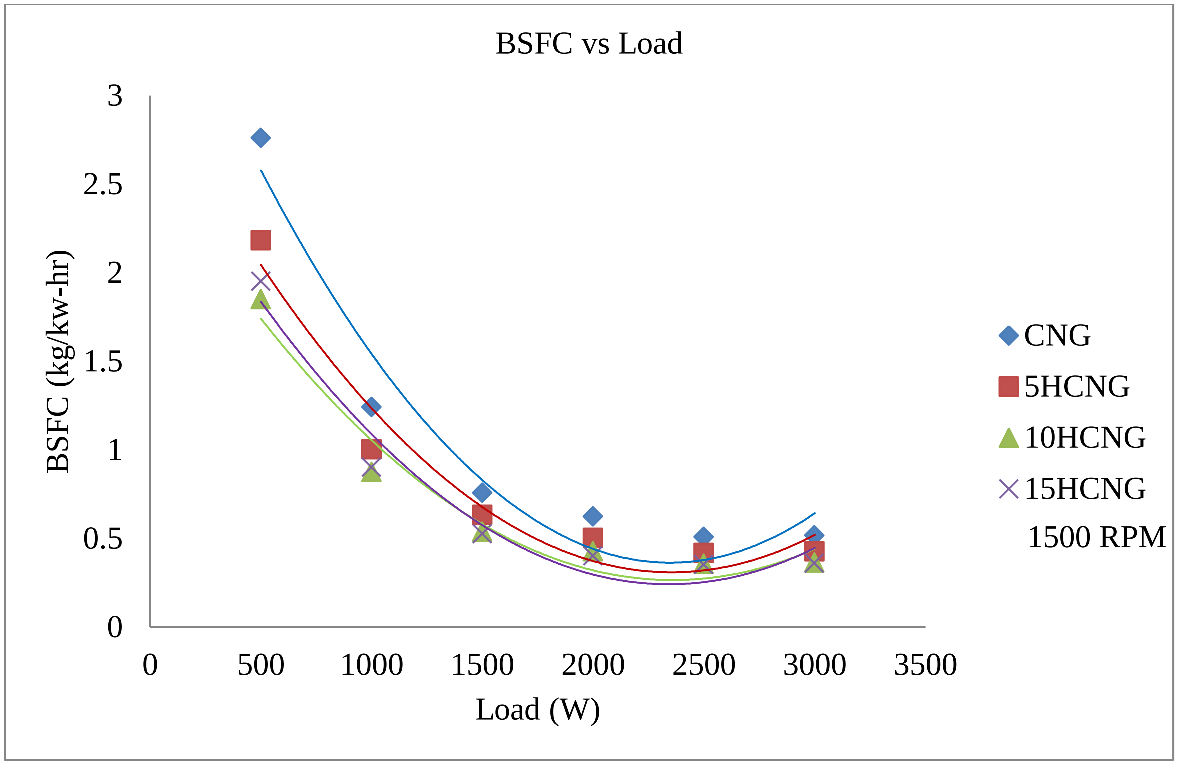


**Figure 7:** *BSFC variation with Load*

### 5.3 Break Specific Energy Consumption (BSEC)

It is defined as a product of BSFC and Calorific value (CV) of fuel. BSEC for all fuels found to be the highest at low load which decreased with increasing load and found to be minimum at 2.5 kW load and again increased at full load. In the present research work, minimum Brake specific energy consumption was obtained as 20,360 kJ/kW-hr at 2.5 kW for CNG which was decreased by addition of hydrogen content to it. By adding 10% hydrogen to CNG, it reached a minimum value of 17,136 kJ/kW-hr at 2.5 kW. For HCNG15, minimum value of brake specific energy consumption was obtained as 18,408 kJ/kW-hr at 2.5 kW engine load. BSEC is higher for HCNG15 as compared to HCNG10 because HCNG15 has high hydrogen content. Minimum BSEC was obtained for HCNG10. A graphical representation of brake specific energy consumption (BSEC) with respect to varying engine load for various fuels is shown in figure 8.

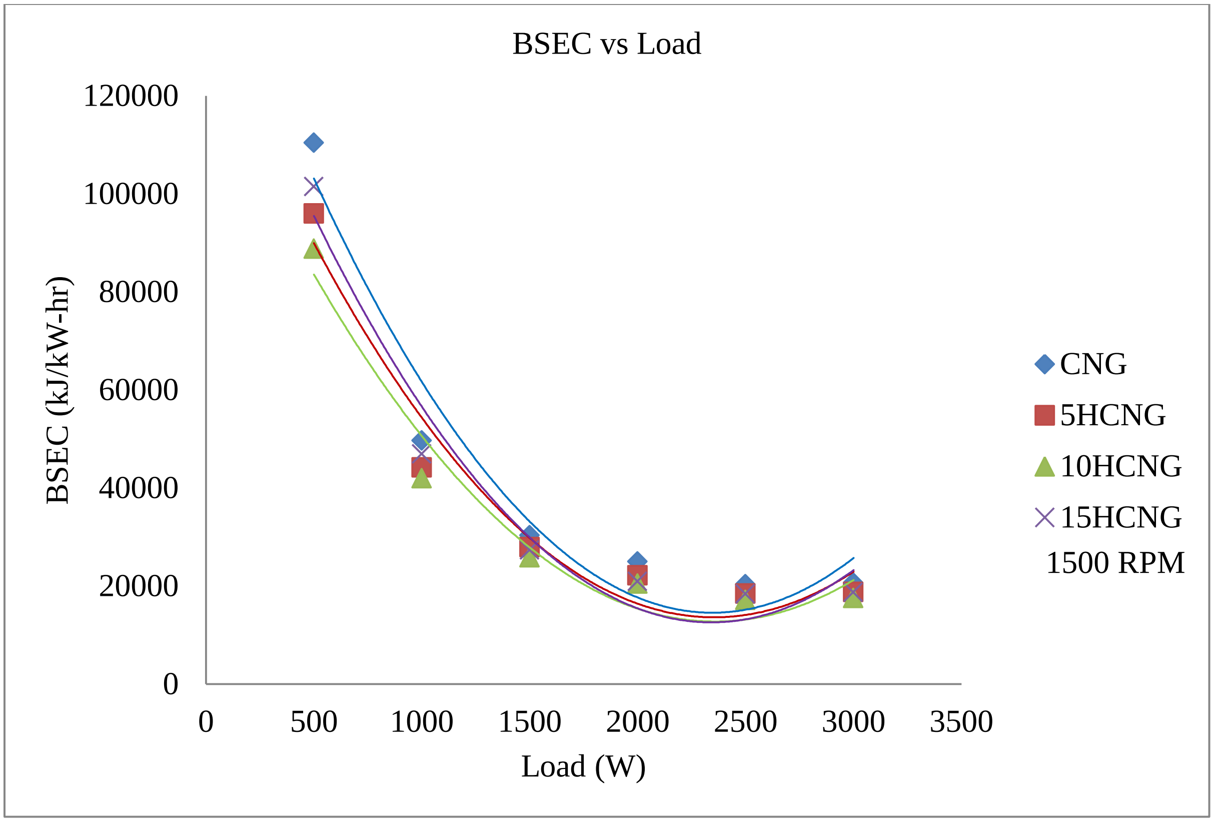


**Figure 8:** *BSEC variations with Load*

### 5.4 Hydrocarbon (HC) Emissions

Un-burnt hydrocarbons (UBHC) are the direct consequence of incomplete combustion (I.C. Engine book by Sharma 2012). UBHC variation with respect to load for all fuels is represented in the figure 9. By the experiments it was found that hydrocarbon emission was higher at low load conditions and then at the moderate load condition it was decreased and again rose slightly at higher load conditions. This might be due to the improper mixing of fuel which resulted in incomplete combustion of fuel giving high hydrocarbon emissions.

UBHC emission are higher for neat CNG as compared to all HCNG fuels, it is due the more carbon content in CNG as compared to Hythane. As hydrogen fraction was increased in the fuel, HC emissions were reduced as HCNG allows lean operation. In case of HCNG15 there was slight increase in HC emissions as compared to HCNG15 at higher load conditions, it might be because of knocking which is likely to be occurred at higher hydrogen percentage. Besides that hydrocarbon emissions from the engine depend on induction system design and combustion chamber design (I.C. Engine book by Sharma 2012).

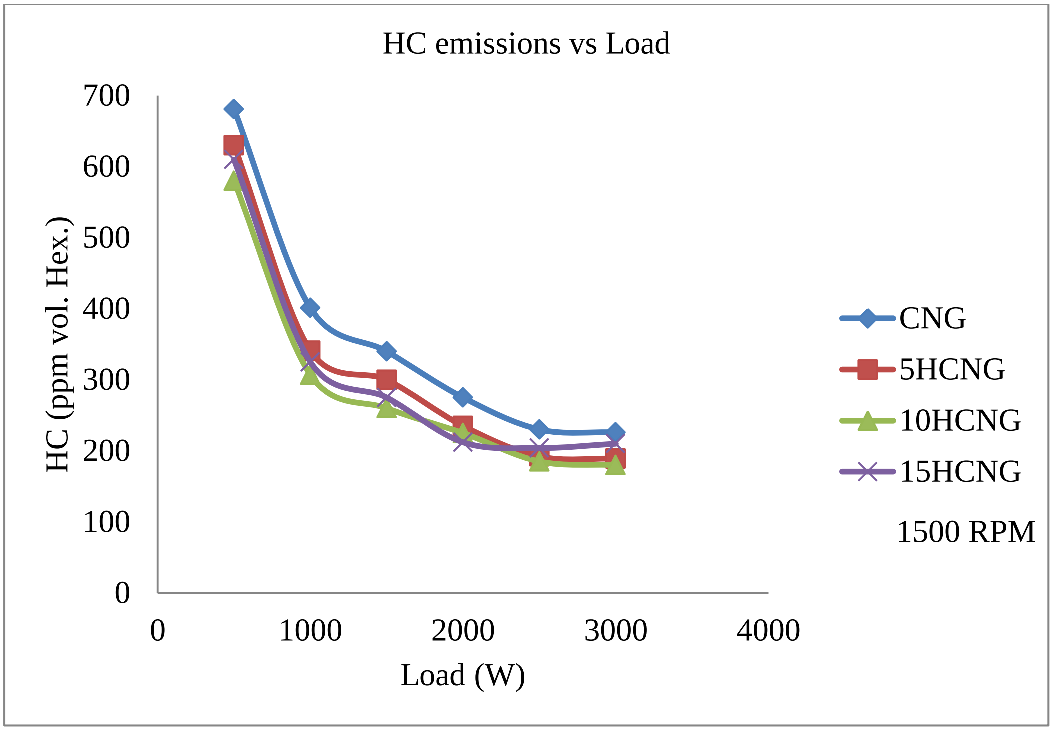


**Figure 9:** *HC emissions vs. Load*

### 5.5 Carbon Monoxide (CO) emissions

Carbon monoxide (CO) occurs only in the exhaust of engine. It is a product of incomplete combustion because of inadequate amount of air in fuel-air mixture or inadequate time in the cycle for complete combustion of fuel. Carbon content of fuel oxidized with Oxygen available in the air to CO and then to $CO_2$. Carbon which is not converted to $CO_2$ will come out as CO in exhaust (I.C. Engine book by Sharma 2012).

As addition of hydrogen to CNG makes it possible to operate engine on very lean conditions so it means more air is available in case of HCNG so lower CO is obtained in case of HCNG. CO variation with respect to load for all fuels is represented in the figure 10.

### 5.6 $NO_x$ emissions

Nitrogen and Oxygen react at relatively high temperature. $NO_x$ formation in an engine depends on-

a) Reaction temperature

b) Oxygen availability and

c) Duration of availability of oxygen

$NO_x$ emissions are increasing by increasing load as increasing load will cause more fuel to enter in the combustion chamber due to this more $NO_x$ emissions will be formed. $NO_x$

emissions were found to increase in all HCNG blends in comparison to pure CNG it is due to more calorific value of hydrogen as compared to CNG so higher in cylinder temperature were observed in case of HCNG blends so more $NO_x$ emissions were obtained. $NO_x$ emissions variation with respect to engine load for all fuels is represented in the figure 5.6.

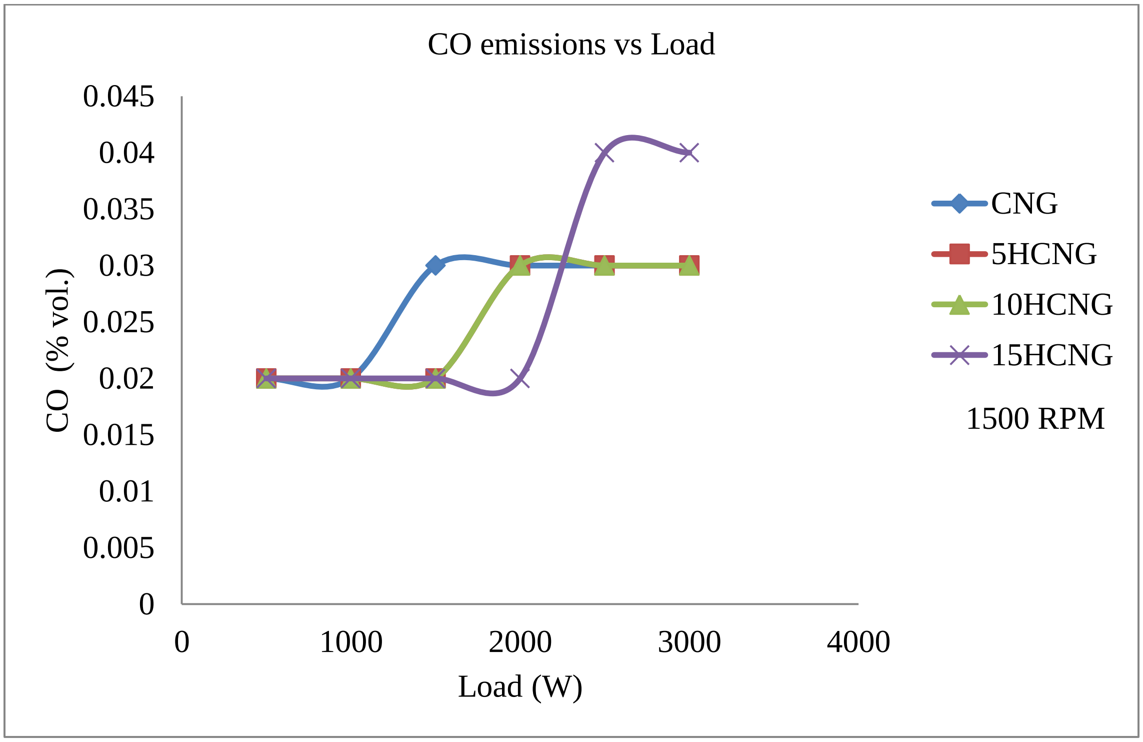


**Figure 10:** *CO emissions vs Load*

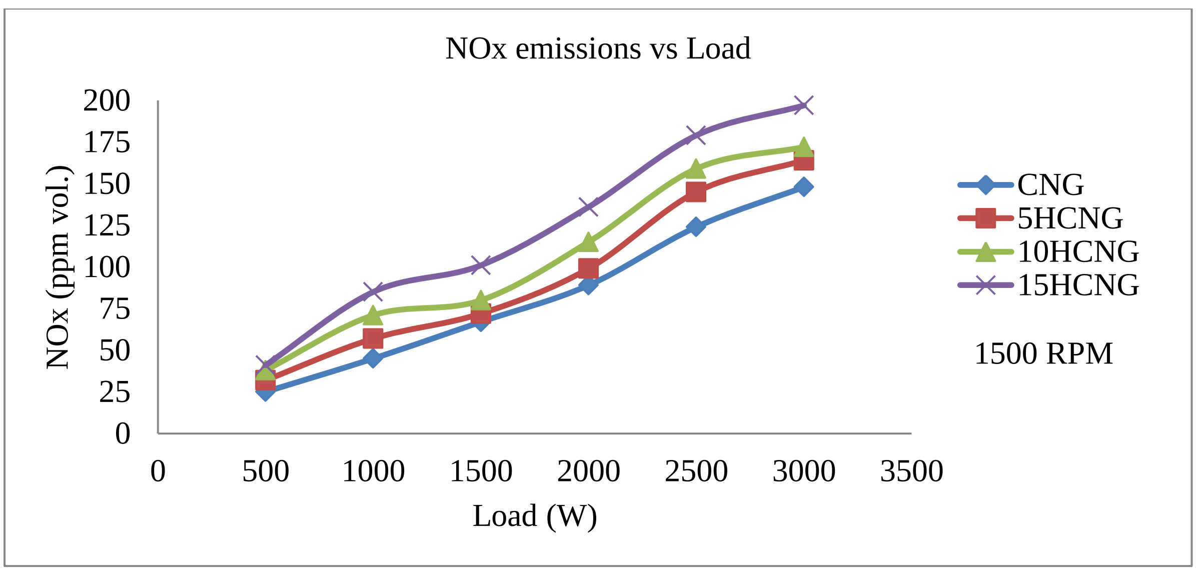


**Figure 11:** *$NO_x$ emissions vs Load*

### 5.7 Exhaust Gas Temperature

The exhaust gas temperature was measured during all the experiments. Figure 5.7 shows the variation of exhaust gas temperature at various engine loads. It also shows the effect of hydrogen substitution percentage on exhaust gas temperature. In the experiment, exhaust gas temperature increased with addition of hydrogen fraction because hydrogen has more energy as compared to CNG. Effectiveness of utilization of heat energy produced by combustion of fuel can be known with Exhaust Gas Temperature.

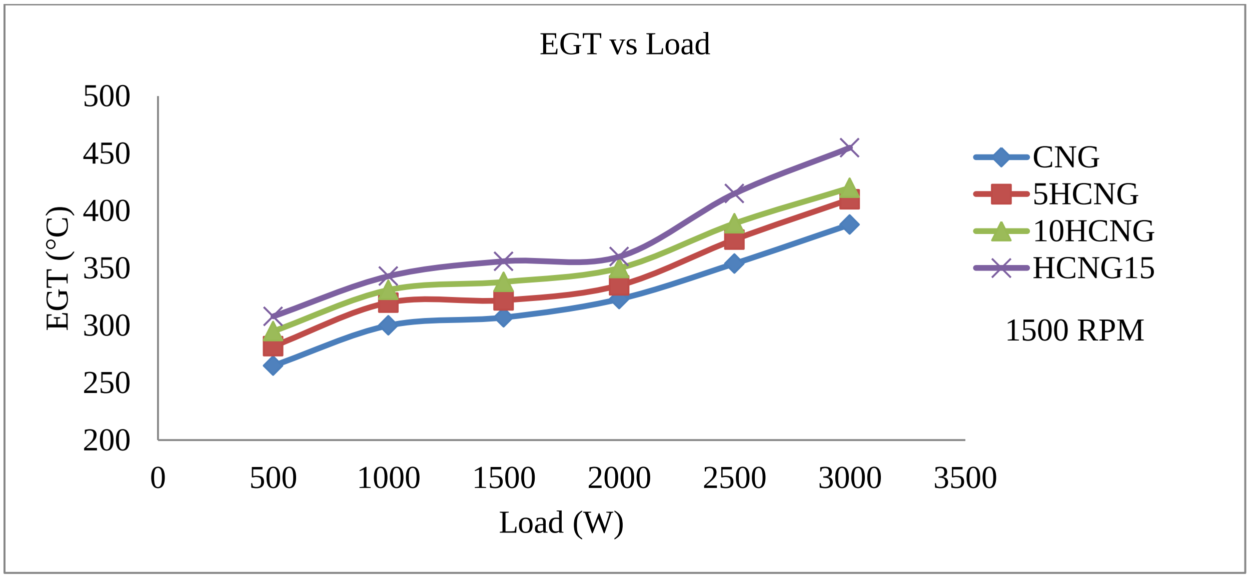


**Figure 12:** *EGT vs Load*

## 6. Conclusion

Increasing hydrogen fraction in compressed natural gas (CNG) increases the brake thermal efficiency of the engine and the optimum percentage of Hydrogen, is limited to 10% in compressed natural gas (CNG). So HCNG10 can be used in the presently tested engine without any modifications. HCNG15 has low brake thermal efficiency as compared to HCNG10 because of presently set ignition timing which is to be retarded when hydrogen fraction is increased. Efficiency of HCNG10 is found to be highest among all fuels. Neat CNG has highest efficiency as 17.63% while HCNG10 has highest efficiency as 20.95% so efficiency is increased by 3.32%. BSFC is found to be minimum for HCNG10 and HCNG15 which is almost similar. But HCNG15 has high BSEC (Brake Specific Energy Consumption) as compared to HCNG10. Hydrogen has wider flammability limits (4-75) as compared to methane (5-15) so it provides lean operation so HC and CO emissions are reduced (Nanthagopal 2011). $No_x$ emissions are higher for HCNG10 as compared to CNG. Exhaust gas temperature (EGT) has an increasing tendency with increasing hydrogen content, it is found maximum in case of HCNG15. EGT is lower in case of neat compressed natural gas (CNG).

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