

Effect of Variable Ignition and Injection Timing on Emission Characteristics of SI Engine Using CNG and HCNG as Fuel

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Abstract

Alternative fuels like CNG have proven advantages over gasoline in lowering emission for IC engine applications. For a CNG engine better benefits can only be derived through engine modifications. For CNG usage, it is imperative to modify and optimize the ignition and injection timing for better performance and reduced emissions. This paper presents the effect of variation of ignition and injection timing on engine performance and emissions. Experiments were performed at constant engine speed of 3000 rpm to determine the engine characteristics and emissions on a twin cylinder genset in which ignition timing was modified from baseline 336° CA to 310, 316, 326, 336, 338 and 340° CA for CNG as fuel for two different injection timings i.e. 300° CA and 270° CA, whereas 310, 316, 320 and 326° CA for HCNG as fuel for 310° CA injection timing. In term of performance, the results showed that the MBT occurred at the ignition and injection timing of 316° CA and 300° CA respectively using CNG as fuel whereas MBT occurred at the ignition and injection timing of 320° CA and 310° CA respectively using HCNG as fuel. In terms of emissions using CNG as fuel, at MBT for 300° CA and 270° CA injection timing respectively CO and HC are observed with decreasing trend whereas CO₂ and NO_x are in increasing trend. Using HCNG as

fuel, at MBT, CO, HC, CO₂, NO_x are observed with similar trends as with CNG.

Keywords: CNG; HCNG; MBT; emission.

1. Introduction

Transportation sector is highly dependent on fossil fuels primarily gasoline and diesel. Spark ignition engines predominantly use gasoline and finds its usage in the passenger segment. But as the emission norms are tightening, developing countries are adopting compressed natural gas as an alternative fuel for transportation sector both for passenger as well as for commercial usage. Experiments have proven that compressed natural gases are cleanest fossil fuel; the exhaust emissions from compressed natural gas spark ignition vehicles are lower than that of gasoline-powered vehicles (Z. D. Ristovski, 2000) (M. V. Prati, 2011).

Properties of compressed natural gas demonstrate its strong potential to be an alternative fuel (Haeng Muk Cho a, 2007). Its high octane number enables use of higher compression ratio in spark ignition engines consequently improving brake thermal efficiency (Rosli Abu Bakar & Mardani Ali Sera, 2002). The option of alternative fuels like CNG becomes all the more attractive primarily due to its lower cost. CNG being gaseous in nature has higher diffusion rate than gasoline and therefore exhibits lower volumetric efficiency compared to gasoline at same operating conditions. Flame velocity of CNG is slightly slower than gasoline hence higher combustion duration is required for complete combustion. Since, the minimum ignition energy of CNG is higher than gasoline; the combustion temperature inside the cylinder is higher as compared to gasoline. All these parameters and properties play a crucial role in deciding the performance of the engine and in turn the design of combustion chamber for improved efficiency and power output. Use of CNG in SI engine offers challenges in the engine design.

Hassan et al. investigated the effect of variation in injection timing on exhaust emission concentrations in a CNG fuelled direct injection engine and observed a decrease in HC concentration with advancement in injection timing as well as retardation in injection timing resulted in increment of NO_x (K. M. Hassan, 2009) (Salah E. Mohammed, 2011). Researches have shown that fuel injection timing had a large influence on the engine performance, combustion and emissions (Zuohua Huang, 2006). The ignition timing played an important role in the improvement of the engine performance (Fanhua Ma, 2012).

Nomenclature	
BTDC Before Top Dead Centre	DOI Duration of Injection
CA Crank Angle	ECM Engine Control Module
CNG Compressed Natural Gas	HC Hydrocarbon
CO Carbon Monoxide	MBT Maximum Brake Torque
NO _x Oxides of Nitrogen	SOS Start of Spark

2. Experimental Details

2.1 Test set-up

A 13 HP, twin cylinder, HONDA engine is used as the test engine as shown in Fig. 1 subjected to the load as shown in Fig. 2. The engine is coupled to an alternator of 5 kW rating. Detail specification is given in Table 1.

Table 1: Engine specification.

Parameter	Description
Engine type	2 cylinder, 4 stroke, water cooled petrol engine
Power output	13 bhp
Bore	58 mm
Stroke	68 mm
Displacement	359 cc
Compression Ratio	8.5:1
Rated Speed	3600 rpm
Alternator rating	5 kW at 3000 rpm
Spark timing	24° BTDC

The gasoline engine was modified to run on gaseous fuels. Gas injectors, cam sensor and crank sensor were fitted to the engine for gaseous fuel operation. Electronic control module (ECM) interfaced with the software has the capability to vary the ignition timing, fuel injection timing and duration. Engine exhaust emissions were measured using portable emission analyzer of model MEXA-584L shown in

Fig. 3. Schematic of the experimental set-up is shown in Fig. 4.



Fig. 1: Test Rig.



Fig. 2: Engine test rig subjected to load (each bulb shown is of 500W).



Fig. 3: Exhaust Gas Analyzer.

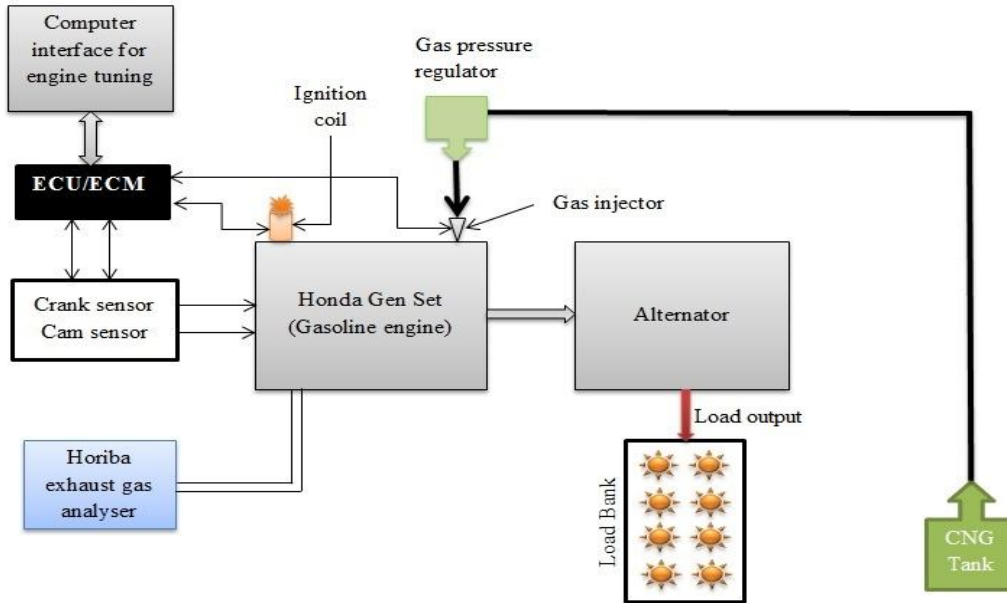


Fig. 4: Schematic of the experimental set-up.

2.2 Test Procedure

Base line engine performance and emission data was generated using CNG. The ignition timing of the engine was advanced as well as retarded from baseline from baseline 336° CA to 310° , 316° , 326° , 336° , 338° and 340° CA for CNG, whereas 310° , 316° , 320° and 326° CA for HCNG as fuel. Performance and emissions tests were performed at constant engine speed of 3000 rpm for all ignition timings. In each test, the load was varied. At each load, parameters such as CO, NO_x, HC etc. were measured.

2.3 Test fuels

Commercial compressed natural gas and 18% hydrogen blended with CNG were used as the test fuels in all the experiments. The specification of the fuels is given in the **Table 2**.

Table 2: Test Fuel specifications.

Component	CNG (%vol.)	HCNG (%vol.)
Methane, C1	89.14	72.5
Hydrogen	0.01	17.8
Ethane, C2	4.05	4.4
Propane, C3	0.83	0.95
Iso-butane, I C4	0.28	0.12
Neo-butane, N C4	0.66	0.21
Iso-pentane, I C5	0.09	0
Neo-pentane, N C5	0.28	0.18

Hexane	0.17	0.12
Carbon dioxide, CO ₂	4.38	3.63
Nitrogen, N ₂	0.11	0.09

3. Results and Discussion

3.1 Power output

Performance of CNG at different ignition timing shows an increase in maximum power when compared to the baseline performance of CNG (Fig. 5). At 336 and 315° CA ignition timing the increase in power is around 20%. However, further advancement in the ignition timing to 310° CA results drop in power about 20%.

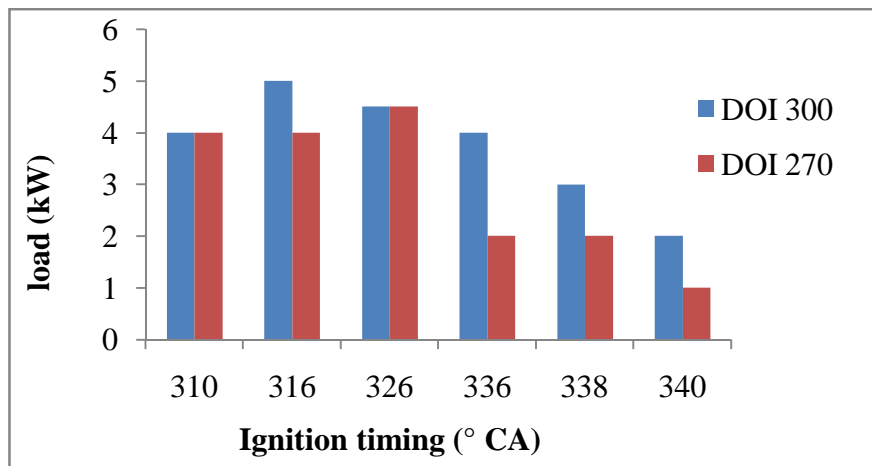


Fig. 5: Max Power using CNG at different ignition and injection timing.

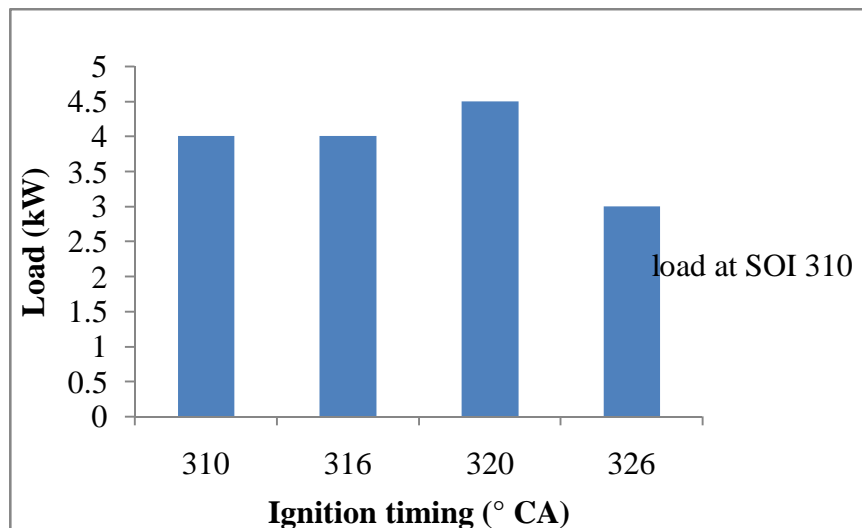


Fig. 6: Max Power using HCNG at different ignition timing.

The drop in power of an engine is reported by researchers when the engine is converted to operate on CNG. This is due to the reduction in volumetric efficiency coupled with slow burning characteristic of CNG. Performance of HCNG at different ignition timing shows an increase in maximum power with advancement in the ignition timing within a limit i.e. 320° CA (

Fig. 6), further advancement in the ignition timing results in decrement in the load carrying capacity of the engine.

3.2 Emission Characteristics

3.2.1 CO emission

CO emission using CNG at different ignition and injection timing is compared with baseline reference value in Fig. 7 and

Fig. 8. Higher CO emission at lower loads from the engine is primarily due to incomplete combustion for reasons such as inappropriate temperatures, air fuel ratio etc. The result shows that with advancing the ignition timing, there is an increment in CO emission indicating inefficient combustion within the cylinder. At max power and ignition timing 300° CA the CO emission is observed lower whereas at 4.5 kW load shows higher emissions using CNG. CO emission with HCNG is decreases with advancement in the ignition timing as in

Fig. 9.

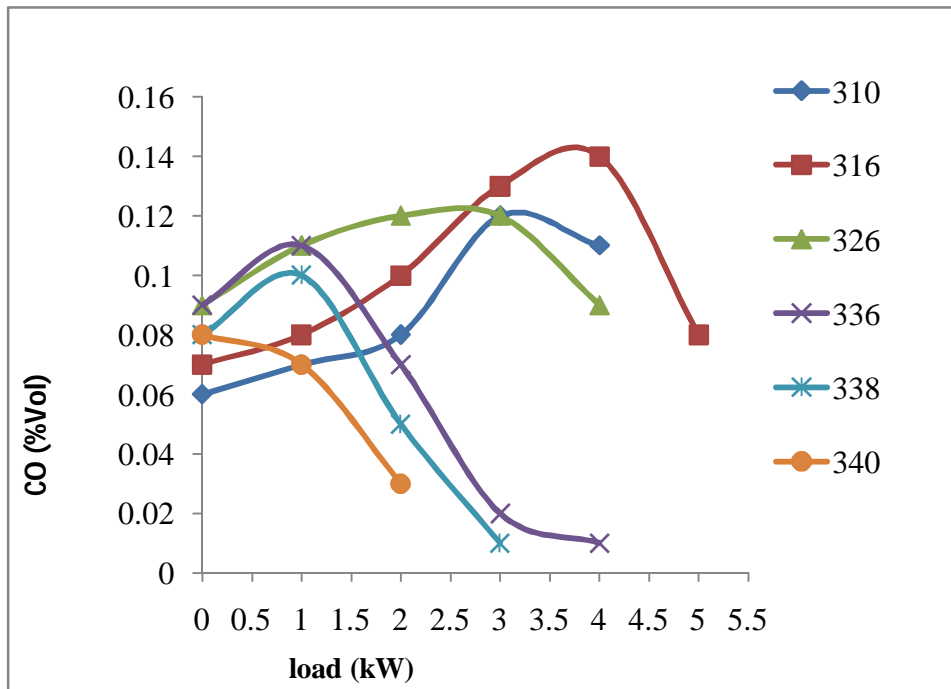


Fig. 7: CO emission at 300° CA injection timing using CNG.

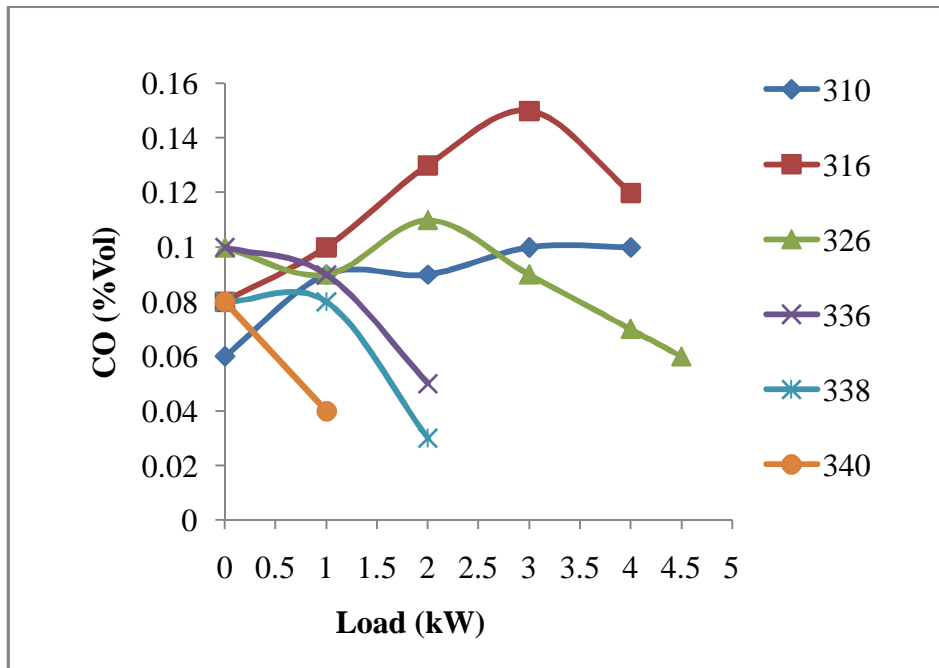


Fig. 8: CO emission at 270° CA injection timing using CNG.

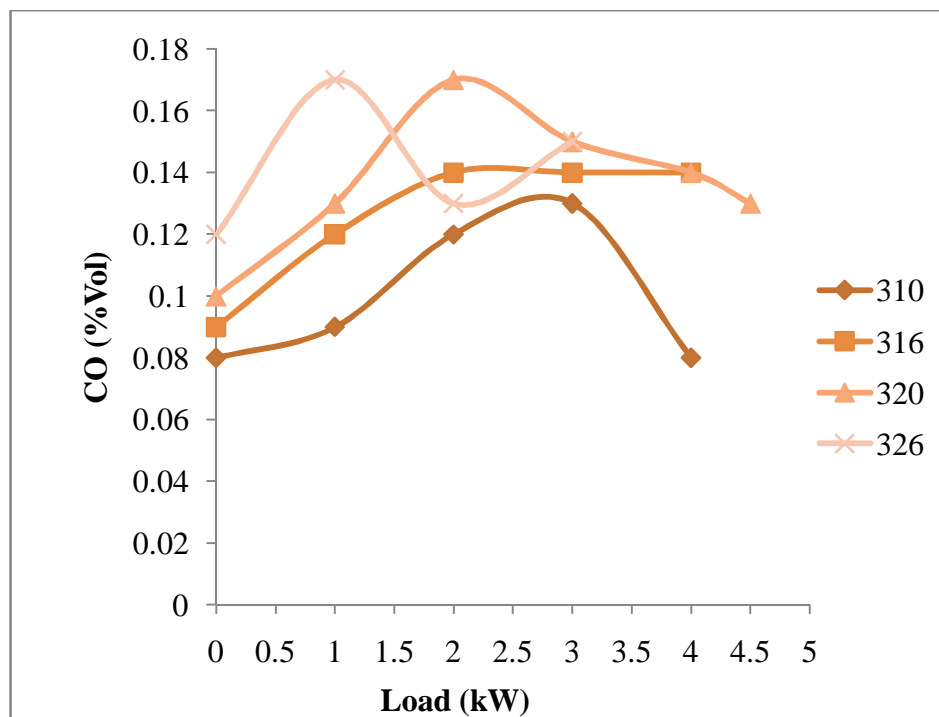


Fig. 9: CO emission at 310° CA injection timing using HCNG.

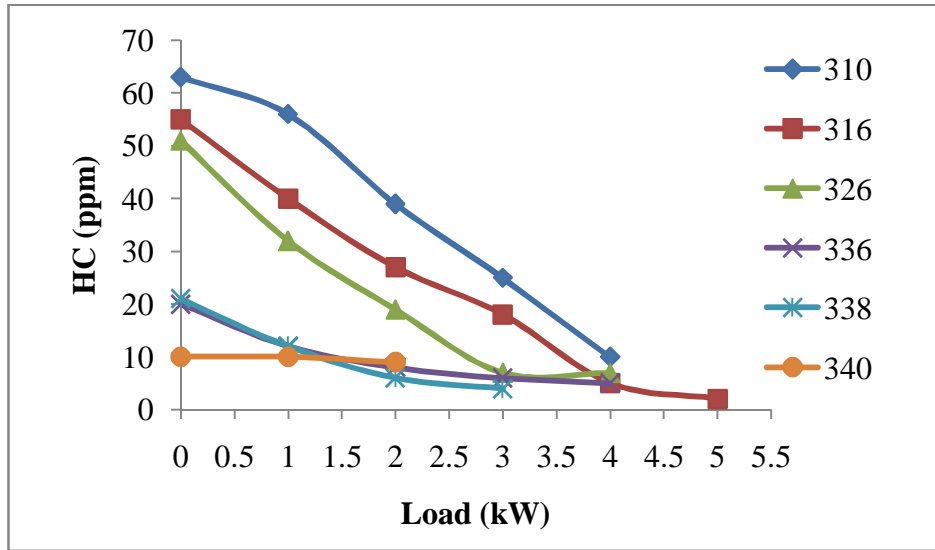


Fig. 10: HC emission at 300° CA injection timing using CNG.

3.2.2 HC emission

The hydrocarbon emission (**Fig. 10**) was low for CNG at higher load. As the load increases HC emission also decreases for CNG as well as for HCNG (Fig. 11 & Fig. 12). In comparison of CNG and HCNG, HC emission for HCNG at lower load was greater than for CNG. HC emissions (at no Load) increased with advancement in ignition timing and decreased as ignition was retarded. Hence it can be seen that advancing the spark timing increases the HC emissions and with the increase in load HC emissions decrease linearly. The reduction in HC emission with the increase in load is observed due to proper combustion at high loads whereas we expect improper combustion at low loads with advancement in spark timing.

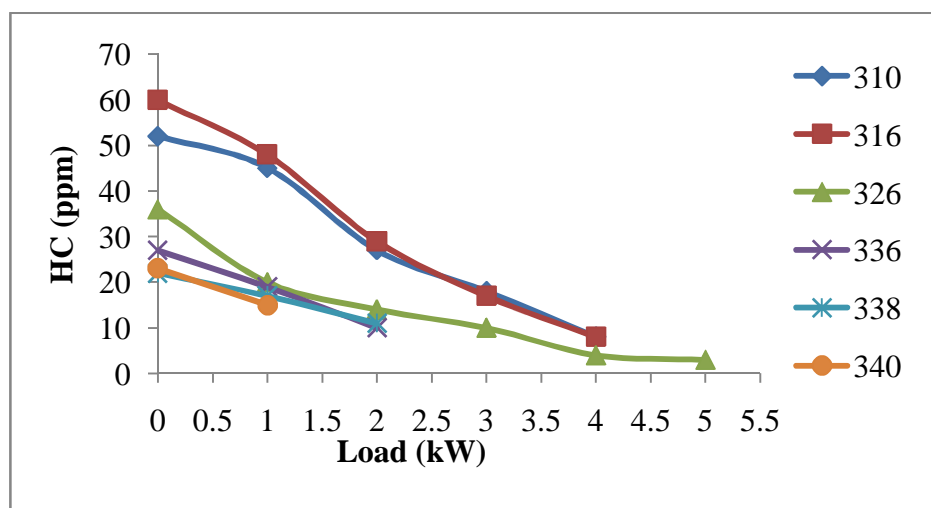


Fig. 11: HC emission at 270° CA injection timing using CNG.

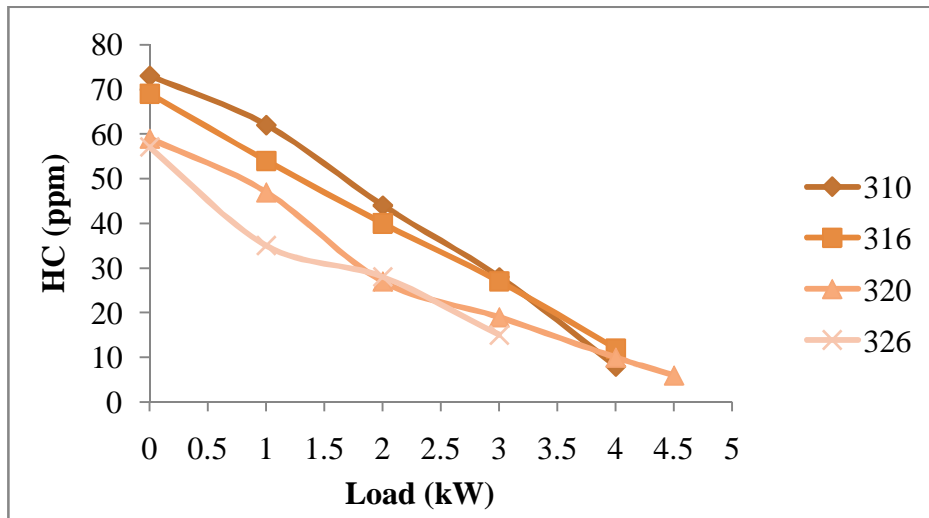


Fig. 12: HC emission at 310° CA injection timing using HCNG

3.2.3 NOx emission

From the results obtained from the experiment it is observed that the NOx increases with increase in load for all spark timing.

Fig. 13 and

Fig. 14 shows the dramatic increment in NOx for ignition timings 316° CA & 326° CA whereas similar pattern is observed for

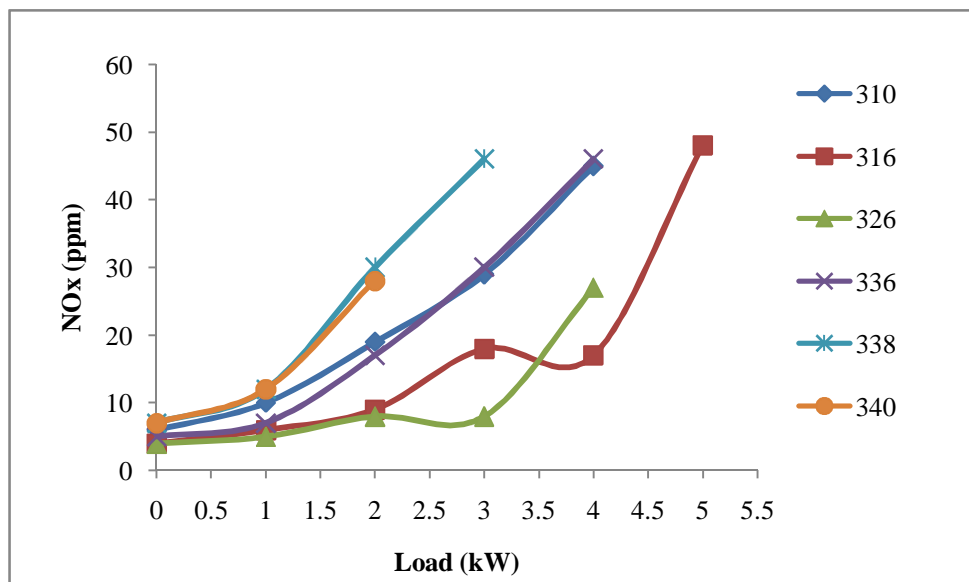


Fig. 13: NOx emission at 300° CA injection timing using CNG.

Fig. 15. at ignition timing 310° CA. The reason for dramatic increase in NO_x has not been understood properly. High NO_x emission while using CNG is due to high combustion temperature inside the cylinder resulting from high auto-ignition temperature of CNG. With the increase in load combustion process occurs faster and with greater rise in cylinder temperature hence more NO_x is emitted through the exhaust. The rise in NO_x with increasing load implies that the combustion at this point is proper which shows presence of rich mixture in the cylinder at this point.

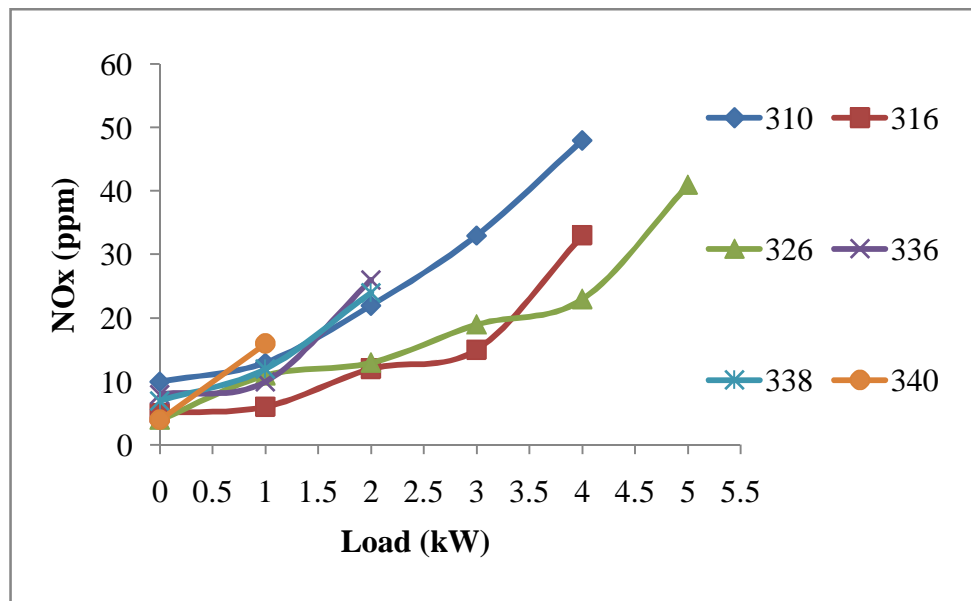


Fig. 14: NO_x emission at 270° CA injection timing using CNG.

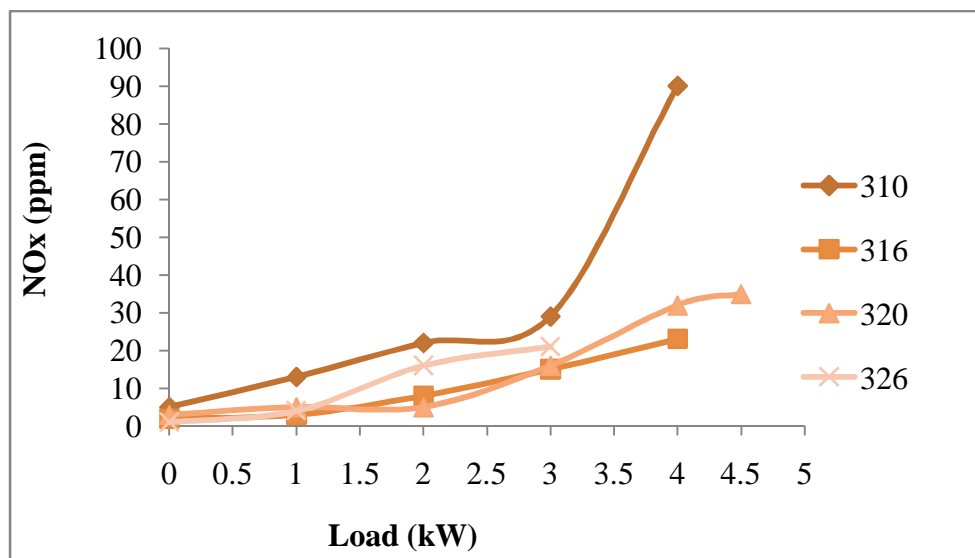


Fig. 15: NO_x emission at 310° CA injection timing using HCNG.

4. Conclusions

This paper presented an experimental study aimed at investigating the effect of variable ignition and injection timing of an SI engine using CNG and HCNG as fuel on performance and emission characteristics. The experimental data was taken for various ignition and injection timings at different loads.

The following main conclusions are drawn from this study:

1. The load carrying capacity of the engine reduces as the ignition timing is advanced and retarded from 320° CA due to increase of flame speed and decrease in its volumetric efficiency.
2. For CNG at 300° CA injection timing, decreasing trend of CO emission is observed at 316° CA and is least i.e. 0.08 % by volume for maximum load.
3. For CNG, HC emission too, is least at 316° CA ignition timing for 300° CA injection timing i.e. 2 ppm.
4. HC and CO emissions are almost similar for CNG and HCNG for load of 4.5kW (maximum could be achieved by HCNG). NO_x emission increases drastically for the same in HCNG. Thus blending Hydrogen to CNG is not a good option.

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