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Combustion and Error Analysis of Hydrogen and CNG Blends for Multi cylinder SI Engine

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A B S T R A C T

CNG engine emits higher NOx as compared to gasoline engine at stoichiometric condition. Lean burn combustion reduces NOx emission and gives higher thermal efficiency but increases tendency of misfire and increase cycle by cycle variation. Hydrogen addition extend lean limit,increase thermal eff., combustion speed and reduces combustion duration. This paper shows the effects of hydrogen and CNG blends on Multi-cylinder SI Engine. The combustion and error analysis is done for optimum blend of 5% hydrogen by energy with CNG. All trials are performed at MBT spark timing with WOT conditions. Sequential injection system shows improvement in performance and combustion characteristics of engine.

Keywords:HCNG blends, MBT Spark Timing, WOT, COVpmax etc.

1. Introduction

HCNG is promising alternative fuel. Blends (5, 10, 15, 20 ---- 80%) of H2 by vol in CNG can be used in single as well as multi-cylinder SI engine. Port Fuel Injection reduces fuel consumption and improves performance and emission characteristics. H2 addition extend lean operation limit. Hydrogen addition increases thermal efficiency and improves combustion stability. The CPmax, IMEP and maximum rate of pressure rise increases while burn duration and cycle-by-cycle variation decreases with increase in hydrogen addition at lean operation. Hydrogen addition leads to higher NOx if spark timing is not optimized. HC, CO, and CO2 emission values decreases with increase in hydrogen addition. At lean condition power of HCNG is found to be higher than CNG. Backfiring and pre-ignition are needed to be addressed. In naturally aspirated CNG engine NOx emission increases with increase in equivalence ratio NOx emission increases with the increase in combustion temperature, duration of high temperature combustion period and the availability of oxygen. HCNG blends with EGR rate has potential to increase brake thermal efficiency of engine with reduction in NOx emission compared to CNG engine. Increase in EGR rate slows down combustion with reduction in pumping work and in-cylinder peak temperature.

Hydrogen addition is used to enhance combustion of CNG for improvement in performance and emission of CNG engine. We can also improve the performance and emission characteristic of CNG engine by increasing compression ratio. Higher compression ratio increases brake thermal efficiency due to high octane number of CNG fuel. Dedicated CNG engine of CR=13:1 are more efficient. It is difficult to increase compression ratio of on-road SI engine but can be decreased by removing material from piston surface in case of diesel engines. With slight modification in cylinder head of existing diesel engine, dedicated CNG engines can be prepared. Injectors are replaced by spark plug and compression ratio is reduced from 22:1 to 13:1. Now days these are run at stoichiometric condition giving higher power output. As CNG has slow flame speed lean burn is not possible as it emits NMHC emissions. The only method to reduce NMHC emissions and improvement in thermal efficiency is to enhance it with high burning velocity fuel i.e. hydrogen.

CNG engines give higher in-cylinder pressure only if it is dedicated CNG engine with compression ration 13:1 to 15:1 at stoichiometric condition. The experimentation done on engine is dedicated gasoline stoichio. burn engine with compression ratio 9.2:1. The lower mass density of CNG (0.717) compared to gasoline (5.11) in gaseous form reduces mass intake charge which reduces in-cylinder pressure. Volumetric efficiency of gaseous fuelled engine is less. As CNG is gaseous fuel volumetric efficiency is less and it further decreases with increase in speed which reduces in-cylinder pressure. Liquid Gasoline has higher density than CNG which increases charge intake by mass increasing in-cylinder pressure. Compared to above effect the high octane number and higher calorific value of CNG does not show much improvement in rise in in-cylinder pressure.

2. Experimental Setup:

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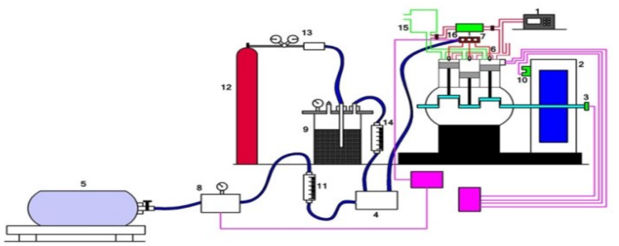

Fig.1 Experimental rig: 1: Exhaust Gas Analyzer, 2: Eddy current Dynamometer, 3: Crank Angle Sensor & rpm sensor, 4: CNG & Hydrogen Mixer, 5: CNG Cylinder, 6: CNG Rail with 3 Injectors, 7: CNG ON/OFF valve, 8: CNG 2 stage regulator, 9: Hydrogen flame trap, 10: Load Cell, 11: CNG Flow meter, 12: hydrogen cylinder, 13: Hydrogen 2 Stage Regulator with Flame Arrestor, 14: Hydrogen Flow-meter and regulator, 15: Air Box with Water Manometer, 16: Oxygen Sensor.

3. Results and Discussions

Combustion Analysis (*MBT, WOT, CR=9.2, ϕ=1.0)*

Cylinder peak pressure increases with increase in H_2 addition. Hydrogen fast burn speed advance the time of maximum pressure towards TDC.

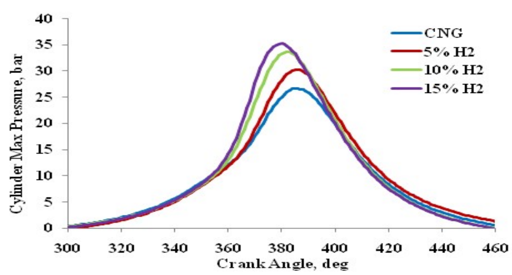

Fig 2: Cpmax of HCNG Blends for Speed

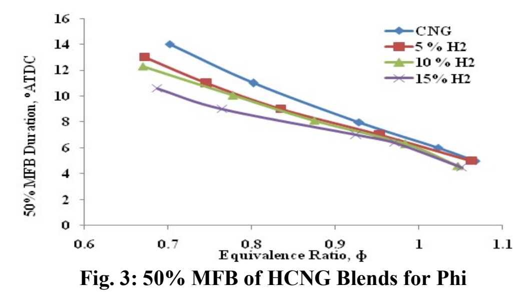

Fig. 3: 50% MFB of HCNG Blends for Phi

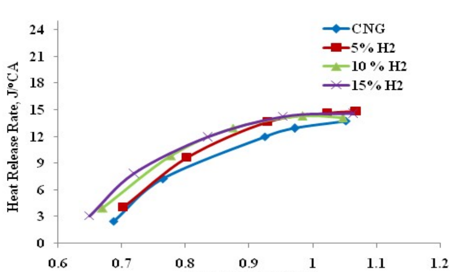

Fig. 4: CPmax of HCNG Blends for Phi

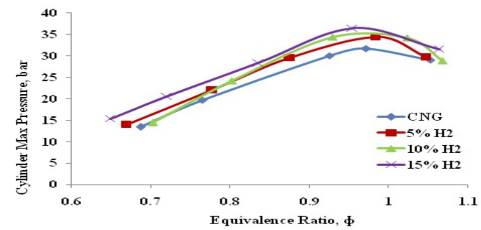

Fig.5: HRR of HCNG blends for Phi

At 3000 rev/min and ϕ=1.0, the maximum peak pressure for 15% hydrogen addition is observed to be 35.17 bar occurred at 19 ° ATDC. Knocking and pre-ignition never occurred in sequential port fuel injection system (SPFIS) till 15% hydrogen addition. Cylinder pressure decreased with increase in speed. Cylinder peak pressure increases with increase in equivalence ratio. For 5% hydrogen addition and equivalence ratio 0.98 maximum peak pressure of 34.42 bars is observed at 2500 rpm. Combustion duration is the duration in crank angle between 10 to 90 % mass fraction burnt at 2500 rpm.

Combustion duration decreases with increase in equivalence ratio and hydrogen addition. For 5% H2 addition and ϕ=0.73, 50% MFB occurred at 9°ATDC and 4000 rpm. Heat release rate increases with increase in speed and increase in hydrogen addition. HRR is minimum at lean condition.

4. Measured Data Repeatability and Accuracy

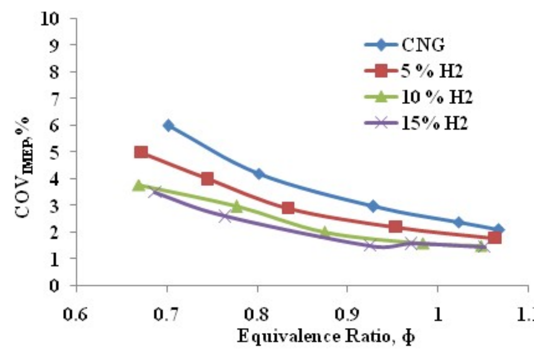

Fig. 6: COVIMEP % of HCNG Blends

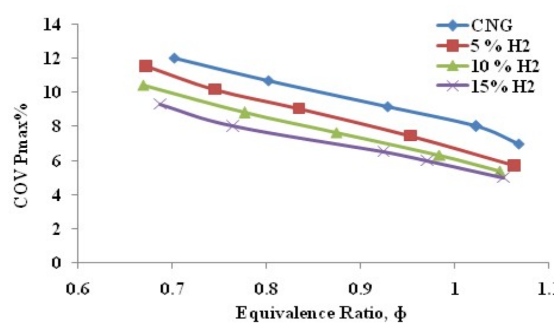

Fig.7: COVPmax% of HCNG Blends

It is the standard deviation of measured magnitude as a percentage of its mean value. COV_{IMEP} is minimum at stoichiometric and relatively rich mixture and suddenly increases as the lean limit is approached. The

COV_{IMEP} and COV_{Pmax} are calculated from the P-ɵ diagram for 10 average cycles. The decrease in COV_{IMEP} of HCNG blends shows engine lean burn stability is greatly improved by hydrogen addition. COV_{IMEP} is less than 10 % for equivalence ratio of 0.6.COVPmax is better in HCNG blends compared to CNG. COV_{IMEP} decreased with increase in speed and increase in hydrogen addition and maintained low level at ϕ=1.0. The decrease in COV_{IMEP} and COVpmaxshows engine stability is greatly improved by hydrogen addition. At higher speed & WOT condition and equivalence ratio 1.0 due to rich fuel air mixture the combustion temperature increases which increases detonation. This gives rise to COVpmax at higher speed. Minimum COVpmax of 6% is observed at 2500 rpm for gasoline & CNG. Higher COVpmax is observed for gasoline than CNG due to higher charge by mass. COVpmax for gasoline is observed 12.8% and CNG 11.27% at 4000 rpm.

5. Error bar for COVpmax is done by doing uncertainty analysis:

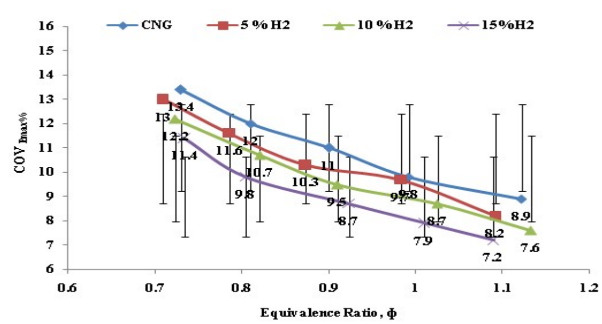

Fig. 8: Coefficient of Variance of Pmax as a function of Equivalence Ratio at a constant speed of 4000 rpm for different fuel blends

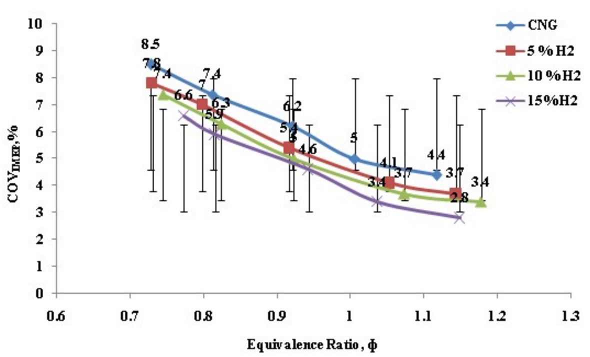

Fig. 9: Coefficient of Variance of IMEP as a function of Equivalence Ratio at a constant speed of 4000 rpm for different fuel blends

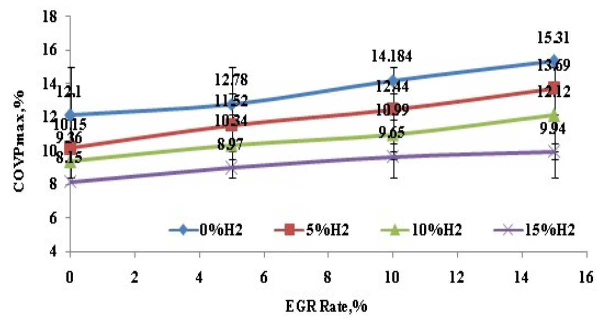

Fig 10: Coefficient of Variance of Pmax as a function of EGR rate at 3500 rpm and equivalence ratio 1.0

Table 1. CNG

CNG						
Equivalence Ratio	**Dev Pmax**	**COV Pmax**	**Dev IMEP**	**COV IMEP**	**Dev RPR**	**COV RPR**
0.727033	1.44	0.31	0.1	**23**	0.01	2.75
0.822405	0.7	4.4	1.43	**21.7**	0.0097	2.64
0.909091	2.63	11.55	0.4	**5.48**	0.084	14.81
1	3.32	12.02	0.399	**5.06**	0.186	22.73
1.190595	3.54	10.28	0.325	**3.47**	0.307	21.04

6. Conclusion

From the present investigation it is found that sequential injection system proved to be more efficient for HCNG operation for reduction in backfire and increase in brake thermal efficiency. 5% hydrogen addition by energy is observed to be optimum blend for improvement in performance and reduction in emission. Lean burn combustion is easily achieved with hydrogen addition for improvement in brake thermal efficiency. Existing on-road S.I engines can be easily converted to HCNG sequential port fuel injection system (SPFIS) with slight modification.

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