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ENHANCEMNT OF A FOUR CYLINDER HCNG MIXED FUEL ENGINE WITH CONTROL OF NOX EMISSION USING LEAN BURN CONCEPT

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ABSTRACT

The most recent numerous decades have seen raised dependency on petroleum as the world's main power source for transportation. However the rapid growth of vehicle population, concerns about the air pollution from automobile emissions and the decreasing reserves of fossil fuels has motivated researches to use alternate fuels. Alternative fuels such as Bio-Diesel, Biogas, Hydrogen, Ethanol, Methanol, and producer gas, CNG, HCNG, LPG, and LNG have been tried worldwide. Hydrogen as a future fuel for IC engines is also being considered. For example if we consider one of the alternate fuels like CNG which has low carbon to hydrogen (H_2) Ratio burns very clean and thus making it cleaner fuel due to this CNG is gaining wide popularity as an alternate fuels for Internal combustion(IC) engine in the field of mobility. However the use of Hydrogen fuel for internal combustion (IC) engine is also being considered as a future fuel due to its simple carbonless structure. But several obstacles have to be overcome before commercialization of Hydrogen as an internal combustion(IC) engine fuel for mobility. A strategy has been worked out for converting the developed CNG engine to run on HCNG. The testing is carried out for the neat CNG and 5% blends of Hydrogen by volume with CNG. It is observed in the experimental work that the HCNG engines are more superior to CNG carbureted engines from fuel economy, power output and emission compliance point of view. The HCNG engine increases the H/C ratio of the fuel, which drastically reduces the carbon based emissions such as CO, CO_2 and HC. To increase the flame speed of HCNG engines, the ignition timing needs to be retarded; this results in reduction of NO_x emissions. This paper explains how CNG is the best route to ensure an early entry of hydrogen fuel into our energy infrastructure.

Keywords: HCNG, Internal Combustion Engine, Pollution, Emission.

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1. INTRODUCTION

With the increasing concerns over the environmental protection and the shortage of crude oil supplying, much effort has been focused on the utilization of alternative fuels in IC engines. The present trend of alternative fuel utilization shows that gaseous fuels promise a more reliable future for IC engines. The gaseous fuel like natural gas is an imminent alternative fuel due to its higher octane number, low emissions, low price, and abundant reserve. Over the past six decades researches have demonstrated that the use of natural gas as engine fuel as well as power generation. Most of the initial interest in alternative fuels started after the oil crisis in the 1970s.The fuels such as CNG, HCNG, LPG, Bio-Diesel and Biogas are the most promising alternative fuels for India. Natural gas is a fossil fuel, clean burning, cheap and abundant in many parts of the world. For this research work the diesel engine with compression ratio of 16:1 is selected as a baseline engine and is converted to CNG SI engine with compression ratio of 11.3:1 by making suitable changes in piston bowl and cylinder head. Also new ignition system and CNG fuel feed system with carburetion technology is fitted. Initially, the tests are carried out with neat CNG fuel and it is observed that this engine is compliant with BS-II emission norms. Then, by making suitable changes and modifications in engine systems the engine parameters are optimized to achieve BS-III emission norms as predetermined goal.

PAST WORK EXPERIENCE AND FACTS FOR MOST SUITABLE HCNG BLEND

F.Lynch and S.R. Munshi [1-2] studied that the a typical blend ratio for HCNG fuel mixture is about 20 %(H_2) volume (3%by mass (or) 7% by energy). A natural gas vehicle fuel system is generally compatible with HCNG and natural gas engine can be recalibrated to operate with HCNG with small modification to the engine. This strategy used during the HCNG calibration was to the lean the air fuel mixture and retard the spark timing. In order to get best NO_X reduction while maintain torque, fuel efficiency and other emissions similar to the natural gas base line. The fuel economy on a diesel equivalent basis was reduced for HCNG compared to NG.Increasing H_2 content beyond 30 volume% can provide diminishing returns in terms of NOx reduction but with associated penalty in terms of engine performance existing hardware limitation as well as fuel storage and cost. S.S.Thipse [3] explained strategy for HCNG operation that H_2 and CNG blend (HCNG) is viable fuel for the SI engine to achieve Euro IV norms. A mixture of CNG and H_2 gives good improvement in the engine efficiency which lowers fuel consumption and hydrocarbon emissions stoichimetric operation is recommended for the HCNG engine as lean mixtures results in power drop. The ignition timing needs to be retarded for HCNG engine as compared to CNG operation due to increased flame speed thereby reducing NOx emissions. S.R. Munshi [4] reviewed that the directed injected hydrogen methane mixtures in a heavy duty compression ignition engine a diesel pilot ignited high pressure direct injection of natural gas heavy duty single cylinder engine was fuelled with both natural gas and blends of 10% and 23% by volume hydrogen in methane. Due to this the use of 10% H_2 was found to be slightly reduce PM, CO and THC emissions while improving combustion stability. 23% H_2 was found to substantially reduce CO and THC emission, while slightly increasing NOx. S.S.Thipse [5] observed that the chosen of Blends of

HCNG ranging from 15to30% extend the lean operating limit ensures complete combustion on which reduces HC and CO gains in NOX formation are compromised higher thermal efficiency can also be obtained. The compression ratio chosen for HCNG engines identical to that of CNG is 12:1. Kirk collier and Neal Mulligan [6] explained that the emission results from the development of dedicated hydrogen –enriched natural gas heavy duty engine. Hydrogen blend rations of 30 to 40% have been employed. In addition to the work has demonstrated that a fuel consisting of a mixture of 30% H_2 and 70% natural gas combined with a properly designed engine can result in a practical solution to heavy duty transportation application that require much lower NOx emissions that are commercially achieved.

PRESENT WORLD SCENARIO OF HYDROGEN BLENDING WITH CNG (HCNG)

HCNG is a Blending of Hydrogen and CNG.HCNG has been used as a fuel in Internal Combustion Engines for decades. Hythane building alternative fuel station in India and a Littleton Company will build and supply the first public hydrogen fueling station in India. Hythane Co. LLC, a wholly owned subsidiary of Australian company Eden Energy Ltd., said Monday it expects the station to be completed in the fall of 2008. The station will be in Delhi. Indian Oil Corp. picked Hythane for the project. The station will produce, store, blend and dispense Hythane in addition to hydrogen to fuel vehicles running on natural gas. Hythane is a mixture of hydrogen and natural gas that reduces nitrous oxide emissions. India is attempting to have at least 20 percent of all vehicles run on hydrogen-based fuel by 2020. The hydrogen blends in CNG can range from 5 to 30% by volume. Hythane is 15% blend of hydrogen in CNG by energy content, which is patented by Frank Lynch of Hydrogen Components Inc, USA [2]. A typical 20% blend of hydrogen by volume in CNG is 3% by mass or 7% by energy. An overall comparison of properties of Hydrogen, CNG, 5 % HCNG blend by Energy and Gasoline is given in Table- I.

2. EXPERIMENTAL SET-UP

The engine is mounted on the bed in the test cell. The Dynamometer shaft is connected with the engine flywheel with the help of a drive plate in the flywheel and dynamometer flange coupled with the shaft. The engine is mounted on mounting jacks in the engine bed. The drive plate in the flywheel is used because the flywheel cannot be directly connected with the dynamometer shaft. After the engine is being mounted on the bed the other components like the sensors and other fuel system components are mounted. The baseline engine used for this research work at ARAI, Pune is 4 cylinder, 3 liters naturally aspirated diesel engine which is converted into a CNG engine by addition of a suitable CNG fuel-system kit, an electronic ignition system etc. The selection of suitable piston geometry was done to obtain a reduced compression ratio of

11.3:1. The specification of the Tata CNG Engine is shown in table-II.

Table I Overall Comparison of Properties of Hydrogen, CNG, HCNG and Gasoline.

Properties	H2	CNG	HCNG	Gasoline
Limits of Flammability in air, vol%	4-75	5-15	5-35	1.0-7.6
Auto Ignition Temp, K	858	813	825	501-744
Flame Temp in air (K)	2318	2148	210	2470
Stoichimetric air to fuel ratio, vol%	34.3	17.2	22.8	17.6
Minimum energy for ignition in air (mJ)	0.02	0.29	0.21	0.24
Flame speed (Cm/s)	237	42	120	190
Burning velocity in NTP air, (cm s-1)	325	45	110	37-43

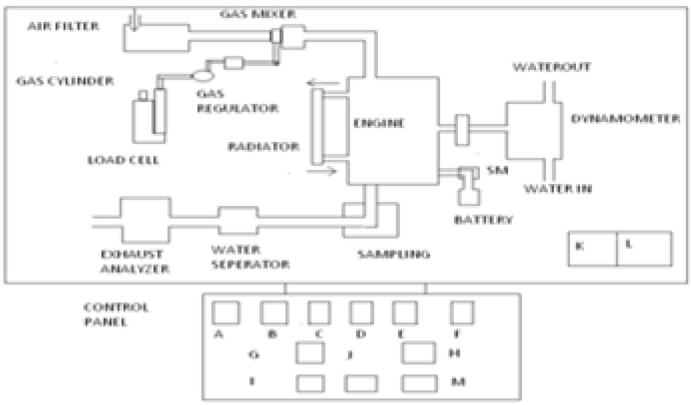

Fig 1: Schematic diagram of the experimental setup.

Table-II The speciifcation of the Tata 4SP NA CNG Engine.

Parameters	Specification
No. of Cylinders	4
Bore x Stroke	97 mm x 102 mm
Displacement	2955 cc
Compression Ratio	11.3:1
Aspiration	Natural Aspiration
Type of Operation	Four Stroke
Rated Speed	3200 rpm
Cooling System	Water Cooled
Idle Speed (rpm)	900-950
Max oil Temp	130 0 c max
Fuel Injection system	Carburetion

The various sensors used in the system are Temperature sensors for water, oil fuel and air, pressure sensors, Lambda sensors, RPM sensor, Throttle Position sensor etc. Here in the control panel A indicates Water Temperature, B oil temperature, C Air Temperature, D Fuel Temperature, E Exhaust Temperature, F Fuel Consumption, G Smoke Number, H Oil Pressure, I Engine speed, J Engine Load, K Dry Bulb Temperature, L Wet Bulb Temperature and M is the mode selector. The schematic diagram of the experimental setup is shown Fig1.

3. ENGINE TESTING

Initial CNG Engine Test

The initial test is carried out on the baseline CNG engine by conducting the 13-mode Engine Steady-State Cycle (ESC) for the compliant of BS-II emission norms. With a view to minimizing development and manufacturing costs, along with development time, it was decided to retain the principal parts of the baseline CNG engine, including the cylinder head, piston, the combustion chamber, and the valve train. In order to achieve the desired objectives of reduction in emissions and improvement in performance, the development work therefore focused only on optimization of the fuel-system, the ignition system, and after treatment. The idea was to achieve the required stringent control over the air-fuel ratio by improving the combustion process inside the combustion chamber, and to have effective treatment of the engine out pollutants. The initial CNG test results compliant with BS-II emission norms are shown in Table- III.

Table- III: Initial CNG test results compliant with BS-II norms

Pollutant	BS-II Norms	Initial CNG test results
CO (g/kWh)	4.0	2.95
HC (g/kWh)	3.66	0.05
NMHC (g/kWh)	1.1	0.017
NOX	7.0	1.52
Idling CO (% by volume)	3.0	0.48
Idling NMHC (ppm)	NA	NA

4. ENGINE OPTIMIZATION

Several optimization steps were undertaken to upgrade the existing baseline four cylinder BS-II CNG engine to obtain improvements in the performance and fuel economy of the engine and achieve compliance with BS-III emission norms to finalize the CNG engine configuration.

a. Exhaust System

The diameter of the exhaust pipe is increased, which helped to reduce the vehicle's pass-by noise to ensure compliance with the current noise norms. Also the increase in the diameter of the exhaust piping resulted in a reduction in then exhausts back pressure from 160 mbar to 105 mbar. This boosted the full-throttle torque output of the engine and helped to improve the specific fuel consumption.

b. Selection of Suitable Spark Plug

The non-resistive type spark plug is used in the baseline BS-II CNG engine. During the vehicle- level Electromagnetic Interference (EMI) tests, unacceptably high levels of EMI are recorded, which are attributed to the use of the non-resistive type spark plug. To reduce the EMI levels to acceptable values, resistive type spark plugs are selected for the present development, which successfully reduced the EMI to acceptable levels of BSIII norms.

c. Optimization of Ignition timing

Ignition timing curve of the baseline engine was 15° BTDC to 21° BTDC from idling speed to rated speed (950 rpm to 3200 rpm). To achieve the power and torque performance and to meet 13 mode ESC mass emission test of CNG engine, ignition timing was optimized for each speed and load. The optimized ignition timing is 7° BTDC to 35° BTDC which has resulted into a flat torque curve at FTP.

d. Optimization of ECU Control Map

The ECU minutely controls the instantaneous output pressure of the CNG from the low pressure regulator and thus the instantaneous air-fuel ratio of the gas–air mixture supplied to the engine. This ECU is selected from the point of view of calibration access to individual load and speed. ECU is calibrated in such a way as to achieve the targeted performance of power and mass emission.

e. Optimization of Low Pressure Regulator

The output pressure of the CNG from the Low Pressure Regulator can be adjusted by varying the spring preload of the secondary diaphragm. Based on the recommendations from the fuel system manufacturer, the setting is selected to obtain a pressure 120 to 140 mm of water-column at engine idling conditions.

h. Lambda Variation

After carrying extensive trials, it is observed that route cause of problem for non meeting stringent emission norms is variation in lambda is due to improper mixing. Variation in lambda in closed loop system was found to be minimal in elbow mixing tube resulting in sufficient margins (more than 50%) than any other configuration tested. Due to lambda variation with original configuration which has resulted in to CO 0.85 to 1.27 gm/kW-hr.

5. TEST RESULTS AND DISCUSSION

For ESC 13-mode cycle, conditioned air at pressure of 100 kPa with relative humidity of 50% is fed to engine. several engine tests are conducted on engine dynamometer. CNG flow of the engine has been optimized for maximum power and idle operation of the engine. It was decided to run the engine from 1200 rpm to 3200 rpm, at the interval of 200 rpm, for full throttle condition. A strategy has been worked out for converting the developed CNG engine to run-on HCNG. The testing is carried out for the neat CNG and 5% blends of Hydrogen by volume with CNG. The power improvement of 11% and fuel consumption reduction of 8% is observed in HCNG engine than the CNG engine. The HCNG engine increases the H/C ratio of the fuel, which drastically reduces the carbon based emissions such as CO, CO_2 and HC. To increase the flame speed of HCNG engines, the ignition timing needs to be retarded; this results in reduction of NOx emissions. It is observed in the experimental work that the HCNG engines are more superior to CNG carbureted engines from fuel economy, power output and emission compliance point of view. It is important to note that 5% blends of hydrogen by volume with CNG the phenomenon of hydrogen embrittlement does not occur with respect to engine components, hence no major change is anticipated in fuel system and engine components. Moreover, it improves the engine efficiency, which lowers fuel consumption and hydrocarbon emissions. The optimized CNG engine test results with BS-III emission norms in Table IV.

Table-IV: Optimized CNG engine test results with BS-III emission norms.

Parameters	Optimized CNG Engine Test Results		BS-III Norms
Mass Emissions as per ECS on Engine Dyno (gm/Kw-hr)			
CO	0.57	0.99	2.1
NHMC	0.042	0.066	0.66
Nox	1.88	1.09	5
Idling Emissions			
CO (% Vol)	0.1		0.5
NMHC (ppm)	100		750
Cold stability	-10o C		--
Exhaust Temp	725 o C max		--
Oil Temp	110 o C max		--

6. CONCLUSIONS

The following conclusions may be drawn based on the present experimental research work:

HCNG gives good improvement in the engine efficiency, which lowers fuel consumption and drastically reduces HC, CO, CO_2 and NOx emissions. The lean-burn capability and flame burning velocity of the natural gas engine is improved by blending it with fast burning velocity fuel such as hydrogen. The CNG engines have easily met Euro- III norms with carburetion technology and Euro-IV norms with injection technology. Moreover, the HCNG engines have the potential to meet the toughest Euro-V norms yet to be enforced. Further experimental optimization is in progress at ARAI on HCNG engine and there is lot of scope for research work on various blends of HCNG with different C.R., A/f ratios, ignition timings, swirl effects etc.

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