Use of Hydrogen Enriched Compressed Natural Gas for IC Engines – Review Paper

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***Abstract*– Enriched hydrogen enriched CNG fuel is going to be promising fuel in near future potentially replacing CNG. The most important advantage is present fuel developed can be retrofitted without any modifications in present CNG engines. With addition of 20% of hydrogen to CNG Carbon emissions are claimed to be 20 % lesser as per testing results by IOCL, India [1]. Very commonly Steam Methane Reforming units (SMR) are used to produce hydrogen required for HCNG fuel. However it has been found that due o high temperatures during combustion NOx levels are not much reduced with used on enriched HCNG fuel. In some cases NOx level are also found reduced drastically with no after treatment needed for the exhaust gases. The paper focuses on methods of producing hydrogen, characteristics of HCNG, and some measures for improving thermal efficiency and power, with reduction in emissions. Many counties like China, US, Canada, Brazil along with India are promoting used on HCNG fuel. Since use of hydrogen in near future is not possible HCNG blends can be very useful.**

Keywords – CNG – Compressed natural gas
HCNG – Hydrogen Compressed Natural Gas
NTP – Normal Temperature & Pressure
LHV – Lower Heating Value
EGR – Exhaust Gas Recirculation

I. INTRODUCTION

Many fuels are being tested as alternatives to hydrocarbonfuel. CNG is the most widely used and popular alternative fuel in many nations. CNG can be regarded as a "clean" fuel. The octane number of natural gas is 130 which is comparatively good. This automatically increases highest useful compression ratios for these gas engines thereby increase in thermal efficiency. Methane is a greenhouse gas on the contrary. Also due high lean flammability it is difficult to achieve stable combustion with natural gas. In spite of that running engine using natural gas with excess air can result in high ignition temperature and low flame propagation speed. This calls for need to improve combustion rate. It is found that adding small amount of hydrogen has resulted in improving combustion of methane. [1]

Effect of hydrogen concentration on HCNG performance was studied. As the hydrogen concentration increases above a certain limit, pre-ignition can be observed along with knocking as well as backfire. The process of combustion become hotter thereby increased heat transfer to cooling water. So appropriate concentration selection is important aspect in HCNG fuelled vehicles. [2]

TABLE I
COMPARATIVE PROPERTIES OF CNG & HCNG[3]

Parameter	CNG	HCNG 5
Limits of flammability in air, (Vol. %)	5-15	5-35
Stoichiometric composition in air, (Vol. %)	9.48	22.8
Auto ignition temperature, (K)	813	825
Flame temperature in air (K)	2148	2210
Burning velocity in NTP air (cms^{-1})	45	110
Methane number	80	76
Minimum energy for ignition in air, (kJ)	290	210
CNG - CH4 - 90.2% , C_2H_6 = 8.5%, C_3H_8 – 0.6%, butane – 0.1% NTP – 293.15 K, 1 atm.		

The volumetric LHV is the fuel energy per unit volume. It indicates fuel energy that can be stored in the fuel tank. It can be observed from Table 2, that volumetric LHV is 7%, 14% and 21 % lower than NG for HCNG10, HCNG20 and HCNG30 respectively. It is also noted that value of $LHV_{stoich,mix}$, remains unaffected by percentage of the hydrogen added to CNG. [8]

TABLE II
PROPERTIES OF HCNG BLENDS WITH DIFFERENT HYDROGEN CONTENT[4]

Properties	**CNG**	**HCNG 10**	**HCNG 20**	**HCNG 30**
H_2 [vol. %]	0	10	20	30
H_2 [mass %]	0	1.21	2.69	4.52
LHV [$MJkg^{-1}$]	46.28	47.17	48.26	49.61
LHV_{vol}(MJ/Nm^3)	36.9	34.3	31.7	29.2
AFR $_{(stoich)}$	15.6	15.8	16.1	16.4

As hydrogen percentage increasesit gives shorter combustion duration at a given excess air ratio. More NOx generation occurs due to this. This can be avoided by retarding spark. This causes decrease in compressor work as well as combustion temperature. This further reduces NOx formation. Therefore spark timings affect largely on power produced and emissions when hydrogen percentage increases. [3,4,5]

II. STORAGE of HYDROGEN

Hydrogen has been familiar as an ideal energy carrier but it has not yet been widely used in the transportation sector. The absence of an efficient storage prevents its application, in particular as fuel for transportation. Because of the low density of hydrogen at ambient conditions, it is a dare to store enough energy on-board to allow for an acceptable vehicle range. The density hydrogen can be increased by pressurizing or liquefying hydrogen. Gaseous hydrogen having high pressure up to 700 bars, is considered a potential safety hazard due to problems of material resistance. For vehicle application, cylinders are made of composite fiber due to weight considerations. Also tanks add a significant weight to the vehicle which is much greater than the stored fuel. It is 3% of the total weight (cylinder plus fuel) for a 700 bars approved system (Sørensen, 2005).

Storage of Liquid hydrogen requires refrigeration to a temperature of about 20^0 K, and the liquefaction process requires at least 15.1 MJ/kg. T 6 bars the storage pressures for the liquid hydrogen are only slightly above the atmospheric. The container for storing liquid hydrogen consists of several metal layers which are separated by highly insulating materials. The main disadvantage is the hydrogen boil-off from the storage therefore venting valves are required to control tank pressures. Boil-off generally starts after a latency period and then proceeds at a level of 3% − 5% per day (Sørensen, 2005).

There are more challenging options have been proposed and investigated as an ilternative. Maximum attention is given to the storage in solid materials and particularly for metal hydrides. Here, hydrogen gas is breast-fed to a tank containing a metal powder and is absorbed as hydrogen atoms in the metals crystal lattice to form a metal hydride. In metal hydrides, hydrogen can be stored with energy densities up to 15000 MJ/m^3 , which is higher than that of liquid hydrogen (8700MJ/m^3). The main drawback is the weight of the storage alloys. Furthermore refueling times are affected by absorption rates. Now a days other storage options are under investigation and still at prototypal stage (Bakker, 2010).

III. REVIEW of EARLIER WORK - HYDROGEN as ENGINE FUEL

It is important to note that up to 30% blends of hydrogen by volume with CNG the phenomenon of hydrogen embrittlement does not occur with respect to engine components.So no major change is expected in fuel system and engine components. Moreover, it improves the engine efficiency, which lowers fuel consumption and hydrocarbon emissions. To increase the flame speed of HCNG engines,the ignition timing needs to be retarded; this results in reduction of NOx emissions.[3]

Significant change is performance was marked when HCNG is used as IC engine fuel. With increase in hydrogen percentage the maximum cylinder pressure and maximum heat release rate was on rise. The rise was more prominent when richer air-fuel mixture was supplied. At leaner mixture increase in hydrogen percentage results in more NOx emissions. When excess air used with respect to stoichiometric air requirements, NOx level are found to be reducing. For 65% increase in excess air ratio (from 1.2 original), extremely low NOx was recorded. If ignition advance was reduced from 30 degree to 20 degree before TDC maximum cylinder pressure as well as NO_X was found decreased. At 50 % increase in excess air ratio (from 1.2 original) maximum cylinder pressure and maximum heat rise were significantly high. So spark timing can be optimized with lean mixture combustion in order to get better thermal efficiency and lower emissions as same time.[4]

The brake thermal efficiency of IC engines using HCNG was found greater than using CNG provided excess air ratio was same. As excess air ratio increases brake thermal efficiency also increases. Using higher excess air ratio results in reduced NOx emissions. [5]

The testing was carried out on 4 cylinder 3.0 Ltr. engine fitted with CNG kit using CNG and 5% blends of Hydrogen by volume with CNG. Increase in 11 % rise in power and reduction of 8 % in fuel consumption was recorded in HCNG over CNG. The H/C ratio increases in HCNG over CNG which considerably reduces CO, CO2 and HC which are emissions based on carbon. [6]

Experimentation was carried out using various bled of hydrogen and CNG, ranging from 5 to 50 %. Port injected SI engine was used. Results indicated that maximum brake torque was reduced with increase in hydrogen percentage. However indicated thermal efficiency got increased. As hydrogen percentage increase duration of combustion found reduced. As the ignition advance was increased with increase in hydrogen percentage emissions (CO, HC & NOx) all were found reduced. Similar results obtained for heavy duty vehicles.

Parket al. [14] analyzed the influences of hydrogen on the performance and emission features of a heavy duty natural gas engine. He explained that, 80% NO_X reduction is possible by retainingdelayed spark timing with the addition of 30% vol. hydrogen gas with natural gas under the best thermal efficiency conditions.

IV. CONCLUSION

Natural gas is used as fuel since it is the cleanest fossil fuel.The exhaust emissions from natural gas vehicles lower than those of gasoline-powered vehicles. Some of its limitationscan be alleviated by enriching it with hydrogen to produce the so called hydrogen-natural gascombinations. EGR can be used to reduce NOx emissions resulting out from lean combustion of HCNG. Finally, the use of HCNG fuel can inspire the development of the hydrogen technologies and market which are, nowadays, the main concrete problems preventing it to beimplemented.

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