AN INVESTIGATION ON S.I ENGINE USING HYDROGEN AND CNG BLENDS

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ABSTRACT
Continuously decreased in reserves of fossils fuels, foreign exchange expenditure for import of crude petroleum, the unsteadiness of their prices and the increasingly stricter exhaust emission legislation, put forward the alternative fuels as substitute for the vehicles. Much interest has been centered on CNG due to its potential for low particulate and hydrocarbon emissions. To improve low burning velocity and poor combustion stability of Natural gas fueled engine Hydrogen blending with CNG is looked upon as a good alternative fuel. The maximum mean gas temperature and maximum rate of pressure rise increased remarkably when the hydrogen volumetric fraction increase slightly. The burning velocity increases exponentially with the increase of hydrogen fraction in the fuel blends. The optimum hydrogen volumetric fraction in natural gas, is around 20 % to get the compromise in both engine performance and emissions. HCNG reduces exhaust emissions and improves combustion characteristic.
In this paper, the operating envelope, fuel economy, emissions, strategies to achieve stable combustion of HCNG engine, blending methods and world scenario are considered.

Key Words: *Hydrogen, CNG, HCNG blends, Alternative fuels, Emission reduction etc.*

1. INTRODUCTION

The growing sector of transports, rise a big alarm either for the day-by-day increasing number of vehicles and for the sensible contribution to the degradation of air quality in urban areas, as well as for the global pollution. Due to high thermal efficiency and power density, IC engines are widely used for transportation and stationary power source. Kyto protocol calls for a reduction in greenhouse gas emission between 2008 to 2012 to the levels that are 5.2 % below 1990 level in 38 industrialized countries. IC engines exhaust emissions, due to stringent emission norms caused engine manufacturer to examine the potential of alternative fuels. CO_2 reduction in mobility sector is a major challenge for next decade. 30 billion tons of CO_2 is added to atmosphere every year by the entire nation. Non Methane Hydro Carbon (NMHC) is a green house gas with global warming factor. After treatment devices are expensive and have imposed constraint on E-IV.

2. WORLD SCENARIO

The European Union committed to reduce the dependence on import of fossil fuels (oil, natural gas, coal), by using at least 20% of alternative fuels within the year 2020; the corresponding commitment in the reduction of Greenhouse Gases (GHG) is the well-known 8% with respect to 1990 by 2012, as required by the Kyoto Protocol. In Europe the sector of transports is responsible for the 25% of CO_2 emissions, 40% of which is related to the vehicles circulating in urban areas. External costs due to the degradation of air quality related to transports had been estimated in about 11.7% of EU GDP.

- 1million vehicle
  ~ 0.75 million 2&3 wheeler
  ~ 0.15 million car/taxis &
  ~ 0.1 million truck/buses
- 1000 MW power generation
  ~ 50mw stand alone IC engine generators
  ~ 50mw stand alone fuel cell generators
  ~ 900 mw centralized plants.

3. NATIONAL SCENARIO

In India, interest in use of hydrogen as an alternate fuel started in 1976 by setting up a task force under Dept. of Science & Technology (DST) which received a fresh boost in 1983 under Dept. of Non-conventional Energy Sources, when thrust areas were decided for a 15 year period 1985-2000, and small research projects were initiated to look into production (BARC, IIT-M, BHU, Univ. of Madras), storage (ISRO, NPL, IIT-Kharagpur, BHU) and utilization(IIT-M, BHU). However momentum was lost due to stabilization of oil prices. Interest was revived in 2003 by the Planning Commission, by forming a Committee under the chairmanship of its Member (Energy), to prepare plan for various aspects of development of hydrogen energy.

Four sub-committee are formed in 2003 by planning commission for hydrogen energy,

1) Production- headed by secretary, DST,
2) Storage & distribution headed by secretary ministry of petroleum & natural gas (MOP & NG)
3) Application- headed by secretary ministry of non conventional & renewable energy sources (MNRES).
4) Safety standards, security & policy issue -headed by Director General, The energy resource institute (TERI).

Various deliberations took place based on it. various programs & projects were announced including establishment of a Hydrogen Corpus Fund of Rs 100 Crore by MoPNG. The National Hydrogen Energy Board (NHEB) set up in 2003 by MNRES, recently announced 'National Hydrogen Energy Road Map: Hydrogen Vision 2020' under Green Initiative for Future Transport (GIFT) and Green Initiative for Power Generation (GIP).

Need of Hydrogen to reduce emissions: [1]

Those alarming data have to be added to the contribution to the total emissions from the energetic sector (carbon dioxide, natural gas, nitrogen oxides, sulphur, aromatic compounds), which amounts at about 50% of the total contribution. Deaths caused by the smog, due to particulates and other emissions, are more than 10000 per year; on the other side, the global change becomes a "real" problem, with an increasing concern about GHG emissions. Nowadays a last-generation Euro-4 car emits slightly less than 150 gms CO_2/km, with scarce perspectives to be able to reduce, with fossil fuels, that value very much. It had been worldwide agreed that the introduction of hydrogen as a "new" fuel could have contributed to the realization of a sustainable energy system in the long term (2050 and beyond); according to this vision, emissions of both global and local pollutants can be maintained under "safe" values. Even if the transition towards a hydrogen-based economy will be surely very long, its sustainability is achievable since now, also considering the limitations in the substitution of conventional fuels with alternative ones, less polluting. Also the contribution of the introduction of biomass-derived fuels, for a limited quota of total consumption, is counterbalanced by the still growing demand of vehicles in the world. Even if it's difficult to forecast the future concerning the next decades, it has been agreed worldwide that climate change is closely connected with GHG emissions, so we may ask for some important decisions for the beyond-Kyoto years. The stabilization of CO_2 concentration at values not higher than 550 ppm (today's value is 380 ppm) requires a strong emissions reduction: some of the IPCC scenarios aiming at that values shows a required decrease of GHG of 40-60% with respect to 1990, which means a "real" reduction of 70-90% of the emissions with respect to the "business-as usual" forecast. Such a reduction won't ever be achieved by using any actual available sustainable technology. Nevertheless, a "cultural shift" will be necessary, in order to reach that goal: the introduction of hydrogen as an energy carrier seems to be a real contribution to that goal, making possible, in the long term, the realization of a cleaner World.

4. HYDROGEN FINDING FOR COMBUSTION: [10]

Hydrogen is a remarkable light gaseous fuel that requires on volume basis the least amount of air for stiochometric combustion (2.39 verses 59.6 for Isooctane), while on mass basis it require the highest relative mass of air. Its heating value on mass basis is the highest, but on volume basis it is the lowest. Hydrogen is an energy carrier like electricity and not a fuel by itself, and has to be produced from other energy sources. Hydrogen has low mass density per unit volume an order less. Hydrogen has high energy density which is 2.7 times than NG or gasoline. Hydrogen high burning flame velocity (7 times of CNG) helps combustion characteristics. Also since its product of combustion in air is only water, there is significant difference between its higher and lower heating value. However its energy release by combustion per unit mass of stiochometric mixture is one of the highest. The extremely low boiling temperature of hydrogen leads to fewer problems encountered with cold weather operation. The gas is highly diffusive and buoyant which make fuel leaks disperse quickly, reducing the fire and explosion hazards associated with hydrogen engine operation. Hydrogen at 200 bar at atmospheric pressure and temperature has mainly around 5% of the energy of the gasoline of the same volume. H_2 engine gives less power o/p due to LHV of H_2 on volume basis and resorting to lean mixture operation. Uncontrolled pre ignition and back firing into the intake manifold of H_2 engine. The equivalent octane number of hydrogen is rather low in comparison to common gasoline and methane. There are various limitations to the application of the cold exhaust gas circulation for exhaust emission control. H_2 engine may also display some serious limitations to effective turbo charging. More noise and vibrations due to high rate pressure rise resulting from fast burning flame. Also material compatibility is required with H_2 engine. Cold climate, the exhaust emission form poor visibility and increased icing problem. H_2 require low ignition energy, which leads to uncontrolled pre ignition problems. There is an increase potential for undesirable corrosion and lubricating oil contamination due to exhaust water vapor condensations. A hydrogen engine needs to be some 40-60% larger in size than gasoline operations for the same power output. It is preferable to have timed injection of hydrogen whether within the manifold or directly into the cylinder, optimized for injection duration, timing and pressure. This is important especially for the avoidance of pre ignition and back firing. Provision of some water injection when needed can also make. Carefully controlled cooling of EGR can be applied for knock avoidance and control. For lean mixture operation with hydrogen suitably heated EGR can be used. VVT can be incorporated and optimized to affect higher volumetric Efficiency and better control of EGR.

- hydrogen cost at delivery point @ Rs. 60-70/kg
- hydrogen storage capacity 9 w%
- Hydrogen 3 wheeler showed a fuel efficiency of 138 km/kg comparison to 38km/kg on CNG and 25km/kg on gasoline.

CNG characteristic [02]

2.18 % Nitrogen
92.69 % Methane
3.34 % Ethane
0.52 % CO2
0.71 % Propane
0.12 % Iso-butane
0.15 % N-Butane
0.09 % Pentane
0.11 % Hexane
38.59 MJ/m^3 GCV
34.83 MJ/m^3 Net CV
49.80 MJ/m^3 Gross Wobbe number
16.65:1 Stio. A: F ratio

Gaseous fuel mix uniformly with air which burns precisely during combustion than liquid fuels. It has minimum carbon deposition & negligible physical delay. Natural gas is the mixture of methane (99% of total volume) non methane hydrocarbons such as ethane, propane, and butane and in some cases trace of higher hydro carbons as well as inert gases like nitrogen, helium, carbon dioxide hydrogen sulphide, and sometimes water. NG reserves are 5288.5 trillion cubic feet which is larger than crude oil. Petroleum one 1000 billion barrel going to consumed in about 40 years. It is observed that CNG reduces PM by 90 % and NOx by 50 % compare to diesel engine. With CNG 42.5 % reduction in CO compared as gasoline and THC have increased with CNG with marginal decrease in NOx. CNG H/C ratio is approx. in the range of 3.7 to 4.0. CNG due to its potential for low PM and carbon based emissions such as HC, CO, PM, etc is looked as best alternative fuel. It has cleaner combustion characteristic and plentiful reserves. Current gasoline engine can be modified due to (stiochometric mixture, closed looped fuel control and exhaust catalyst) for CNG. More research & development work is going on worldwide to investigate various aspects of CNG in SI engines. CNG has simple chemical structure & wide flammability range and absence of fuel evaporation. Its high octane number (>130) give the engine high anti-knocking capability and allows it to operate at even high compression Ratio. CNG poor lean burn ability leading to incomplete combustion, High misfire ratio and large cycle by cycle variation at Lean Mixture combustion can be improved by adding Hydrogen. Hydrogen is able to burn at ultra lean at an equivalence ratio of 0.1, comparing methane Ø=0.53 and Gasoline Ø=0.7. Hydrogen quenching distance of 0.064 cm is approx 1/3 that of methane or gasoline. With modern technology CO_2 emission reduction of 30 % for small car is possible. New technology use increase in CR, with specially developed turbo-charging strategy and EGR to reduce engine out NOx emission.
As CNG is a dry fuel there is more wear & tear of exhaust & inlet valve & engine parts as compared to conventional fuel gasoline. Also CNG lack latent heat of evaporation. It has slow burning flame velocity & poor combustion stability. In unmodified base engine, torque and power for CNG decreases compares to gasoline**.**

Hydrogen, CNG, HCNG Blends properties comparison:
A good opportunity in the short term can be represented by the utilization of blends of hydrogen with other fuels, first of all with natural gas (HCNG). When used in an Internal Combustion Engine (ICE), even the addition of a small amount of hydrogen to natural gas (5-30% by volume that means ~1.5-10% by energy) leads to many

advantages, because of some particular physical and chemical properties of the two fuels. Hydrogen is an excellent additive to methane or gasoline due to its unique characteristics. Based on an examination of the properties, it is seen that hydrogen is able to burn ultra lean at an equivalence ratio of 0.1. In comparison methane and gasoline are capable of burning at equivalence ratio no lower than 0.53 and 0.70 respectively. Hydrogen mass specific lower heating value, LHV of 120 MJ/kg is nearly three times that of methane or gasoline. However, hydrogen density of 0.08 kg/m^3 at NTP results in a volumetric LHV of 10,046 kJ/m^3 which is lower than methane (32,573 kJ/m^3) or gasoline (1,95,800kJ/m^3 .Although its stiochometric A:F ratio is higher, hydrogen occupy a greater proportion of volume with respect to air (0.095) or gasoline (0.018). This ill effect counters hydrogen low volumetric LHV so that stiochometric mixture of hydrogen and air contains slightly less energy (2913 kJ/m3) than stiochometric methane/air (3088kJ/m^3) and stiochometric gasoline/air (3446 kJ/m^3). An approximate seven fold increase in the burning speed of hydrogen flame (265-325 cm/s) over methane or gasoline results in shorter burn times. This shorter burn time is reflected in less heat transfer from a hydrogen flame compared to that of either methane or gasoline flames; only 17-25% of the thermal energy release during combustion of hydrogen is lost to the environment due to radiation heat transfer compared to 22-33% for methane and 30-42% for gasoline. Hydrogen quenching distance (usually defined as the minimum gap between parallel plates in which a flame will propagate) of 0.064cm is approximate 1/3rd that of methane or gasoline. Hydrogen generally burn hotter (2318k) than gasoline (2470k) based on flame temperature in air.

Literature Review:

Shrestha and Karim [3] investigated proportions of 100/0, 90/10, 80/20, 70/30, and 10/90, CH4/H_2, percentage in different compression rates by varying equivalence ratio. They stated that the addition of some hydrogen to methane in SI engine enhanced the performance, particularly when operating on relatively low equivalence ratio mixtures. The optimum concentration of H_2 in the fuel mixture for producing power gain and avoiding knock appears to be about 20-25% by volume over the range of conditions considered.

T. Thurnheer and P. Dimopoulos [4] carried out performance of gasoline, methane and HCNG blends of 5, 10 & 15% H_2 by volume on 2 liter NA bi-fuel engine with Port fuel injection. At 2000RPM and 2bar BMEP and stiochometric combustion heat release analysis and a loss analysis were performed. It was observed that 15%$H_{2,}$ optimized spark timing retardation by approximately 4.5^{0}CA compared to CNG. Adding hydrogen to methane lead to decreased real combustion losses while the wall heat losses increase. Compared to methane, gasoline has smaller real combustion losses and slightly smaller wall heat losses. However losses due to gas exchanged are larger. Fuel conversion efficiency increased by blending methane with hydrogen. It states that care has to be taken when comparing fuel conversion efficiency among the different fuel as relative error in fuel conversion efficiency for the gasses fuel is 0.2% at most, where it is about, 1% for gasoline.

Janardan Sharma, M.A. Siddiqui [5] the necessary modification and timing of engine for safety and backfire were, flame trap in gas- air mixture, vacuum lock in the secondary pressure regulator, retarded spark timing and lean mixture operation. The tests were carried on 1 cyl. ,173cc,air cooled, 4 stroke engine developing power of 4.4 KW @5500 RPM on CNG and 6 KW @5000 RPM on gasoline. To avoid back fire spark timing was retarded and gas power valve was adjusted for lean mixture operation. Under uniform test condition, hydrogen 3 wheeler showed a fuel efficiency of 138km/kg, in comparison to 38 km/kg in CNG are 25km/l on gasoline. Fuel efficiency in terms of gasoline liter equivalent (GLE) on net energy basis, hydrogen operation has substantially higher energy efficiency (36.4 Km/GLE), 1.3 times the CNG (28.7 km/GLE) and 1.4 times the gasoline operations (25.3km/lit). This is due to H_2 low ignition energy, high flame velocity and wider flammability, resulting complete combustion of lean mixture. The acceleration performance of H_2 vehicle is slower by 30-40% and also the max speed achieved is substantially lower in compression to std. CNG/gasoline 3wheeeler. It is due to under powered H_2 engine, developing only approximate 60% of the maximum power compared to standard CNG. For 1 liter engine cylinder gasoline occupy 17cc of the cyl while H_2 occupies 300 cc ie. Stiochometric mixture of H_2-air is only 0.85 times that of gasoline air. If direct H_2 fed into cyl, the heat released is about 20% greater.

Yujim wang [6] used the combinations of software model simple chemistry model & detailed chemical kinetics model and compared it with experimental results. He used the blends of HCNG & compared the CO & NOx emission for 15% & 20% load. With simulation results performed on modified diesel engine (DCK) model show better agreement with experimental results. CO reduces with increase in HCNG blends where as NOx increases for 15% & 20% load. A simulation model using CFD and detailed chemical kinetics is accomplished by integrating KlVA3V with CHEMKLN-II. The model can take turbulence, thermodynamics and chemistry into account and a turbulent combustion model which balances the effects of turbulence and detailed chemical kinetics is applied to describe the combustion rate. Simulation model are valuable to the engine researcher and designer for two reasons:

1) Experimental cost is always limiting factor and

2) Simulation of in cylinder process can provide information about the various interacting phenomenon taking place

during combustion that cannot be revealed from experimental measurement.
Bauer and Forest [7] studied the effect of H_2 addition to the performance of methane fueled vehicles. They used one cylinder research engine at compression ratio 8.5:1. They analyzed brake power, ITE, spark degree (BTDC), $BSCO_2$, BSCO, BSHC, BSNO, in 100/0,80/20,60/40,40/60 CH_4/H_2 changing equivalence ratio, load and speed (700 and 900 RPM). They concluded that when compared to pure methane hydrogen addition up to 60% volume was shown to lower the partial burn limit from an equivalent ratio of 0.58-0.34. There was a corresponding increase in brake power up to 80% (at Ø=1.0) and decreases in BSfc up to 14% (from Ø =0.58 to 1.0). For pollutant production, hydrogen addition up to 60% volume resulted in a decrease in $BSCO_2$ up to 26% (from Ø =0.58 to 1.0), a decrease in BSCO up to 40% (for Ø >0.95), a decrease in BSHC up to 60% (from Ø =0.58 to 1.0) and a increase in peak BSNO at Ø =0.83 of approximate 30% (for volumetric fraction =40%) .
L. M. Das [8] performed test on single cylinder genset, limit for 10% & 15% H_2 energy basis at const speed . The supply pressure used for CNG & H_2 were 1.5 to 2 bar .TMI system was used .CNG injection was as it is, where as electrically controlled fuel injection system was used for hydrogen. The fuel was delivered at the upstream of intake valve

- Maximum Ø=1.58 at 2500 rpm.
- lean mixture limit was extended from 1.24 to 1.46
- 5 to 10% improvement in BTE compared to CNG.
- 7 to 12% reduction in BSEC.
- 20 to 30% reduction in CO.
- 25 to 30% reduction in HC.

Karim [9] investigated hydrogen as SI engine fuel. He concluded that there were excellent prospects to achieve very satisfactory SI engine operation with hydrogen as the fuel and most of the subject whether hydrogen could be obtained abundantly and economically remained yet to be unused satisfactory.

Modification of CNG Kit for HCNG Blends:

Existing CNG kits can be modified for HCNG blends. The gas air mixture is provided with a flame arrestor up stream to back flash when engine is running. Additionally a vacuum lock is provided downstream the secondary pressure regulator to avoid flooding of the intake manifold when engine was not running. To avoid back fire spark timing was retarded and gas power valve was adjusted for lean mixture operation.1 canister of 1.38 liter wc (6kg) each with capacity to store 0.7 kg hydrogen (99.9% purity) at 35 bar. At statutory pressure of 150 bar storing hydrogen in steel cylinder. Calculation shows that on board CNG tank can store 0.34 kg of hydrogen under normal site conditions. Since refueling could be carried up to 75 bar only as source cylinder stored hydrogen at 150 bar as expected only 0.17 kg hydrogen could be stored. If hydrogen refueling could be carried out at 250 bar or more in similar capacity , specially designed high pressure cylinder (carbon fiber wrapped polymer) hydrogen storage would be 0.54 kg and higher that could be comparable to metal hydride storage. (Mg NiH4) magnesium nickel hydride and lanthanum nickel hydride (LaNi5H6) have hydrogen storage capacity of 3.59 and 1.37 mass percentage respectively. However like many other known metal hydride such as $Li_3Be_2H_7$and $BaReH_9$ which can store H_2 up to 9 mass%. (US DOE targets are 6.5 mass % and 62 kg hydrogen per cubic meter)

Property Table:

Sr. No	Property	Units	H_2	CH_4	C8H18
1.	Limits of flammability in air	Vol %	4-75	5.3-15	1-7.6
2.	Laminar Burning velocity in air	Cm/s	200-230	37-43	37-43
3.	Minimum energy for Ignition in air	mJ	0.02	0.29	0.24
4.	Auto Ignition temp.	K	858	813	501-744
5.	Quenching gap in air	mm	0.64	2.03	2
6.	Diffusion coefficient in air	cm^2/s	0.61	0.16	0.05
7.	Density (Gas)	Kg/m^3	0.0838	0.7174	5.11
8.	Flame temp. in air at λ=1 (adiabatic)	K	2318	2148	2470
9.	Lowest Heating value	MJ/Kg	120	53	44
10.	Research Octane Number		>130	>120	90-100
11.	Normal boiling Point	K	20.3	111.6	310-478
12.	Equivalence Ratio Ignition Lower Limit in NTP air		0.10	0.53	0.70
13.	Volumetric LHV at NTP	KJ/m^3	10046	32573	195800
14.	Stiochometric A:F ratio	Kg/Kg	34.2	17.19	15.08
15.	Volumetric Fraction of Fuel in air Ø=1 at NTP		0.290	0.095	0.018
16.	% thermal Energy radiated from flame to surrounding		17-25	23-33	30-42
17.	Density (Liquid)	Kg/lit	0.071	0.42	0.73
18.	Molar C/H ratio		0	0.25	0.44
19.	Quenching distance in NTP air	(cm)	0.064	0.203	0.2
20.	Higher Heating value	MJ/Kg	141.7	52.68	48.29
21.	Higher Heating value	MJ/m^3	12.10	37.71	233.29
22.	Lower Heating value	MJ/m^3	10.22	33.95	216.38
23.	Combustion Energy per kg of Stoichometric mixture	MJ	3.37	2.56	2.79
24.	Kinematic Viscosity at 300 K	Mm^2/s	110	17.2	1.18
25.	Diffusion coeff. into air at NTP	cm^2/s	0.61	0.189	0.05
26.	Energy of stiochometric mixture	MJ/m^3	3.6	3.5	3.9
27.	Thermal Conductivity at 300 K	mW/mk	182	34	11.2

Properties of HCNG Blends:

Sr No	Properties	Gasoline	CH_4	5 vol%	10 Vol%	15 Vol%
1.	Volume fraction H_2 (Vol %)	--	0	5	10	15
2.	Volume fraction CH_4 (Vol %)	--	100	95	90	85
3.	Mass Fraction H_2 (mass %)	--	0	0.705	1.377	2.169
4.	Mass Fraction CH_4 (mass %)	--	100	99.29	98.62	97.83
5.	Energy substitution(H_2 %)	--	0	1.652	3.242	5.053
6.	Stoichometric air Fuel ratio	15.08	17.19	17.23	17.26	17.28
7.	L.H.V (MJ/Kg)	44.01	53.12	50.49	50.96	51.51
8.	Mass fraction H (mass %)	13.23	25.13	25.62	26.16	26.75
9.	Mass fraction C (mass %)	86.77	74.87	74.38	73.84	73.25
10.	Vol. L.H.V (MJ/m^3)	3.578	3.170	3.167	3.164	3.160

Acceleration performance of 3- wheeler:

Fuel	Time taken to cover 1 km in best possible manner, Sec		Maximum speed achieved km/hr
	with pay load	without pay load	
H_2	155	142.5	35
CNG	123.5	108.5	55
gasoline	102	99	60

Heat Losses with HCNG Blends:

Sr No	Properties	Gasoline	CH_4	H_2 5 vol%	H_2 10 Vol%	H_2 15 Vol%
1.	ηcv	51.47	50.60	50.53	50.51	50.48
2.	Real Cylinder charge losses :Δcc	1.63	0.98	0.94	0.90	0.85
3.	Incomplete combustion losses : Δic	1.78	1.06	0.98	1.15	1.03
4.	Real combustion Losses : Δrc	3.68	4.16	3.97	3.42	3.32
5.	Heat Losses through cylinder wall : Δwh	7.64	7.83	7.94	8.22	8.31
6.	Leakage Losses : Δle	0.28	0.31	0.31	0.31	0.31
7.	Real Gas exchange losses : Δge	7.08	6.88	6.79	6.67	6.71
8.	Mechanical losses : Δme	9.30	9.31	9.38	9.45	9.48
9.	ηe	20.08	20.07	20.22	20.39	20.47

Methane-Hydrogen Mixture emissions for vehicle :

	NMHC (gm/mile)	**CO (gm/mile)**	**NOx (gm/mile)**
Gasoline	**0.59**	**14.1**	**2.2**
ULEV	**0.04**	**1.7**	**0.2**
Natural Gas	**0.01**	**2.96**	**0.9**
HCNG	**0.01**	**0.7**	**0.2**

OBSERVATIONS FROM HCNG:

There was a reduction in CO_2, CO & HC due to direct displacement of carbon based fuel with H_2. NOx increase with increase in H_2 % due to higher combustion temperature of Hydrogen. Ultra Lean burn combustion can be achieved due to inherent nature of H_2. Reduction in power output was observed due to lower volumetric heating value. Indicated Thermal Efficiency was decreased due to decreasing ratio of BP to FP and increasing heating value of the fuel. Spark retardation i.e. optimum spark timing was used due to increase in flame burning velocity.

10^o BTDC (Ø=0.25)___H_2
17^oBTDC (Ø=0.6)__ CNG
18^oBTDC (Ø=0.7)___Gasoline

Reduction in equivalence ratio i.e. up to 0.1 can be achieved due to higher burning speed & flammability of H_2. There was reduction in knocking due to increase in octane number which helps to increase Compression Ratio. The chances of backfire are increased due to low quenching gap of hydrogen. There is increase in onboard storage volume due to low density of hydrogen. It is observed that ignition timings, the combustion duration, the coefficient of variation (COV), the indicated mean effective pressure (IMEP) and engine out emissions are dependent on the overall air fuel ratio, spark timing, throttle position and fuel injection timing. With the increase of the A: F ratio, the ignition delays and combustion duration increases. The change in the fuel injection timing reduces the engine out CO, total hydrocarbon (THC) emissions. Lean Burn can significantly reduce NOx emission but it results in high cyclic variation. With optimal combinations of spark timing (ST) and EGR rate the achievements are significant. Efficiency increases with substantially lower engine out NOx emissions while total unburned HC or CO engine out emissions are not affected. It is observed that Gas Injection system has more potential compared to gas Mixture system and 10 % improvement at higher speed is observed. Late fuel ignition by timing manifold injection system reduces decrease of back fire. A spark advance reduction of only 3 degree (which means little retard compared to the case of pure methane) brings to a large decrease of NOx emissions, without torque reduction. Exhaust HC and CO_2 concentrations increased with the increase of Hydrogen fraction at high engine load.

Blending Methods of HCNG and findings:

- Bi-fuel (shifting from one fuel to another),
- Duel fuel (mixing of fuel).
- Bi-fuel vehicle emissions are not as clean when they are run on gasoline.
- 2 cat-con; a close coupled and under floor three way catalytic converters.

The Stoichometric A:F ratio for pure H_2 is 34.2:1, thus an Ø ratio of 0.55 represents an operating A:F ratio of 62.2:1 . H_2 flame velocities of 2.37m/s compared to 0.415 m/s for gasoline, results in ignition timing that is significantly more retarded than the gasoline Engine. PCV (pressure controlled valve) coalescing oil separator was added to prevent recirculation of oil into the combustion chamber reducing the potential for pre-ignition or back flash. 46 liter tank of H_2 at 278.2 bar and nominal operating pressure of 248.2 bar can be used. steel tank are not rated for H_2. H_2 tank have isolation solenoid valves with internal check valve, thermal pressure relief device vent port (PRD) and a pressure transducer all located at one end. A single stage pressure reducing regulator set at 5.2 bar with an emergency diaphragm vent port. A pressure relief valve (PRV) downstream of the pressure regulator set at 8.6 bar. An over pressure burst-disk downstream of the pressure regulator set at 31 bars. A fuel rail isolation solenoid valve located in the engine compartment feeding the port injector fuel rail. Fill station electrical connector for temp & pressure information during filling. The system supplies gaseous H_2 to the port fuel injectors at a nominal pressure of 5.2 bar. A fuel rail solenoid valve located in the engine compartment allows the flow of H_2 from a single stage regulator to the fuel rail when enabled to avoid leakage in to the engine compartment. A second control valve located in the fuel tank manages the high pressure flow from fuel tank to the regulator. This valve open while the engine runs but is closed when the engine is stopped in response to a hydrogen leak or vehicle crash. 87 liter of gaseous H_2 at 248.2 bar holds 1.5 kg of fuel. On an energy equivalent basis these tank carry an equivalent of 5.7 liter (1.5 us gallon) of gasoline. Alarm condition are triggered at H_2 concentration of 0.6%, 1% and, 1.6 % (15%, 25% and 40% of lower flammability limit for Hydrogen). H_2 is less dense than air; it will rise and disperse if it is not trapped. Co produced in H_2 vehicle was 0.4% of gasoline vehicle which are from burned oil in CC. Ø greater than 0.55 can produce large increase in exhaust NO_x concentration. H_2 powered vehicle delivered a 17.9% fuel economy improvement relative to the gasoline powered vehicle over the city cycle. Though reduced emission & improvement in fuel economy, the const equivalence ratio control resulted in unacceptably poor acceleration performance.

PRECAUTION FOR HCNG:

Pressure regulator should be away from the most heated zone in engine compartment. The Pipe outing at inlet and outlet should be easy to avoid bending. Flame arrestor and flame trap should be provided to avoid backfire and accident. Hydrogen cylinder should be kept in well ventilated area away from the building. EMER NZS CNG filler valve is used for CNG filling in the vehicle, but this valve is not compatible for the HCNG filling. For filling HCNG blend in a tank special type of receptacle is used OPW (LK360 P36). For HCNG blending dispenser air used, which are equipped with hydrogen gas leak detector unit, break away hoses and nozzle etc.

5. SUMMARY AND CONCLUSIONS:

Hydrogen has strong effects on the combustion of natural gas that can be used to reduce emissions of nitrogen oxides and hydrocarbons. Hydrogen requires more compressed storage tank volume than natural gas for the same energy content by a factor of nearly. At the small Hydrogen percentages recommended for HCNG, the extra fuel volume is modest. The extra volume has no significant effect on stiochometric engine power. This surprising result is because Hydrogen produces more heat than methane per unit of oxygen consumed. In the lean burn range, HCNG has a power advantage over natural gas, as well as improved fuel economy. Fuel storage volume (or shortened vehicle range with the same tanks) and added cost are carefully weighed against the advantages of HCNG in designing HCNG fuel mixtures and engine controls to properly burn them. Among the effects of

Hydrogen on the combustion properties of natural gas are safety-related effects. Flame speed, flame temperature, flammability limits, ignition energy, quenching distance and ignition temperature affect fire safety.

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