SAE Number 2008-28-0119

Hydrogen-CNG Blend Performance in a Three Wheeler

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ABSTRACT

Refueling of Natural Gas Vehicles (NGVs) with hydrogen blended CNG (H-CNG) fuel is being considered as initial step towards hydrogen economy. Small percentage of hydrogen mixed into CNG is known to improve emissions performance of IC engine powered NGVs. In this study, hydrogen-CNG refueling of a standard CNG 3-wheeler was carried out with an objective to test small percentages hydrogen blended CNG for safety, reliability and performance in terms of fuel efficiency, acceleration i.e. power performance and exhaust emissions of such systems. Hydrogen mixing was directly into the on-board gas cylinder and was based on partial pressures of hydrogen and CNG. The ratio of hydrogen varied from 1.1-6.6 wt % (12-48 vol %). The vehicle performed adequately with H-CNG, showing very low emissions of CO, HC and NOx in relation to CNG/gasoline, measured under no-load conditions at low (1300 rpm) and high (4000 rpm) engine speeds. There was a distinct improvement in fuel efficiency with H-CNG blends primarily due to improvement in combustion with small amounts of hydrogen addition into CNG. This is also indicated by better acceleration performance of the vehicle with H-CNG in relation to standard CNG operation. No safety or operational problems were encountered during refueling or running of the vehicle. The ability to tune a CNG vehicle for refueling with low level blends of hydrogen in CNG, presents the possibility of dispensing hydrogen to in-use NGVs without having to modify them.

INTRODUCTION

In a natural gas engine under lean-burn conditions, to improve flame-burning velocity and lean-burn capacity, traditionally we increase charge flow density in the cylinder. This measure always increases the heat loss to the cylinder wall resulting into poor thermal efficiency, and also increases the combustion temperature leading to high NOx emission. One effective method for solving the problem of the slow-burning characteristics of natural gas is to mix the natural gas with a fuel that possesses a fast-burning velocity. Hydrogen is regarded as the best gaseous candidate for natural gas because of its very fast burning velocity; the laminar burning velocity of hydrogen is seven times that of natural gas; hence this combination is expected to improve the lean-burn characteristics and decrease engine emissions.

Combustion in spark ignition (SI) engines relies on an electric discharge between two electrodes of the spark plug to establish an initial burning kernel in a pre-mixed homogeneous air/fuel mixture, with an overall air/fuel ratio close to stoichiometric. After the air/fuel mixture has been ignited, the burning flame front propagates through the combustion chamber and separates the entire chamber into burned, burning and unburned zones. The pressure and temperature of the unburned gas then naturally increases as a consequence of the heat release from the unburned gas. Another fundamental problem- knock, which is due to the self ignition of unburned "end gas", occurs. Severe knock can cause physical damage to the engine, and it can only be avoided by suppressing the end gas pressure and temperature. The primary method is to reduce the engine compression ratio, which further reduces SI engine efficiency. Additionally, emissions continue to be a problem- NOx due to high burning temperature, CO due to relatively low oxygen availability and unburned HC due to incomplete combustion. The Hydrogen (H-CNG) mixture in certain low compositions of H_2 is known to resolve the above mentioned inefficiencies [1-5]*. The above technical feasibilities are experimentally analyzed with different H-CNG blends on a standard CNG three wheeler.

EXPERIMENTAL

TEST VEHICLE -The test vehicle used for the study is a factory dedicated popular make of CNG/gasoline three wheeler. Its brief specifications are mentioned in Table-1. Some optimization in the fuel-air mixture settings were carried out to achieve similar level of performance to a standard CNG vehicle.

HYDROGEN-CNG FUELING - H-CNG blends of four different compositions were prepared on-board the vehicle into the standard gas cylinder based on partial pressure of hydrogen and CNG and their PVT-Z correlations. Hydrogen and CNG were filled independently in terms of pre- attuned accurate gas calculations based on volume, mass or energy equivalence [6]. At first, required quantity of hydrogen was filled from a commercial hydrogen cylinder having

*Numbers in the parentheses designate references at the end of paper gas at 150 kg/cm^2 pressure. Similar probe as at CNG filling stations was used for hydrogen too (Fig.1). Additionally, source cylinder was weighed on an electronic weighing balance for cross check of quantity filled. Thereafter, CNG was filled to the required proportion at regular refueling station. Fuel properties of hydrogen, CNG and their blends are given in Table-2. The hydrogen quantity in the H-CNG mixture that could be achieved are: 1.1 wt% (12 vol%), 2.2 wt% (22.5 vol%), 3.7 wt% (33.5 vol%) and 6.6 wt% (48 vol%). The test fuels were inducted into the engine through the standard CNG kit system.

FIELD TRIALS - The vehicle was subjected to field trials for fuel consumption, acceleration performance and emissions with the blended fuels. The operational safety and reliability of the system during the trials and normal road driving was observed. The fuel consumption of the vehicle was measured under uniform test conditions (pay load 150 kg, route length 25 km) and also for regular driving from tank fill to tank fill. On the test route, amount of hydrogen consumed was calculated from measurement of initial and final cylinder pressures and ambient temperatures using the above mentioned PVT-Z correlations.

The acceleration performance was evaluated by measurement of time taken from stand still to maximum speed in best possible manner on a 1 km flat stretch. Acceleration is primarily a function of power and inertia of the vehicle. Hence, acceleration time and max speed achieved was considered as a good indication of power developed by the H-CNG engine in relation to standard CNG/ gasoline operation.

Emissions were measured under no load conditions at engine speed of 1300 rpm and 4000 using a portable AVL DiGas 444 analyzer.

RESULTS AND DISCUSSION

VEHICLE PERFORMANCE - The engine did start easily and run smooth on H-CNG blends without any incidence of backfire. The vehicle performed somewhat better than CNG alone operation. The results are discussed in the subsequent sections.

FUEL EFFICIENCY - The result of fuel efficiency H-CNG blends is compared with that of CNG in terms of km/kg in the Table-3. The medium range blend of hydrogen-CNG has shown superior performance and when compared in terms kilometer per kg CNG equivalent, a thermal efficiency improvement of about 20-25%. There are certain important findings from these results. In one aspect, as the intake of fresh air is invariable at fixed engine speed, the addition of hydrogen into CNG will increase the excess air ratio (*mixture dilution effect*) of the mixture and this decreases the burning speed of the mixture. On the other hand, the addition of hydrogen in to natural gas leads to *enrichment of fuel* mixture and this increases the burning speed of the mixture. This indicates that there exists an optimum percentage range of hydrogen at which H-CNG blend give best results of fuel efficiency. This optimum percentage of hydrogen varies between 2 -4 wt% (20-35 vol%).

ACCELERATION AND POWER - The acceleration performance of the vehicle with various fuels is given in Table-4. The acceleration performance of the vehicle has improved to some extent with blending of hydrogen in CNG for the reasons explained above. The enhancement in acceleration was clearly evident in the case of the medium range (3.7 wt% H_2) H-CNG blend and the magnitude of enhancement is about 15%. However the maximum speed achieved is comparable to that of standard CNG fueled three wheeler.

The improvement in acceleration is attained due to efficient propagation of combustion flame inside the combustion chamber resulting in fast heat release and completeness of combustion. For specific induction duration, the total combustion duration has decreased with increase in hydrogen fraction due to burning velocity enhancement by hydrogen addition. But the acceleration performance seems to diminish at higher proportions of hydrogen in H-CNG due to power loss arising from lower energy density of hydrogen rich CNG mixture.

Power produced is maximum near stoichiometric equivalence ratio. A lean burn engine, when full power is needed, such as during acceleration or hill climbing, reverts to a stoichiometric (14.7:1) ratio or richer than its normal air/fuel ratio (about 22:1). Hydrogen addition may reduce the power due to lower volumetric LHV but at the same time increase the power due to improvement in combustion efficiency. Thus it maintains an optimum power output at a particular range of concentration of hydrogen in H-CNG [7-10].

EFFECT ON EMISSION LEVELS - Dependence of the tail gas emissions (CO, HC & NOx) on the concentration of hydrogen in the fuel blend is shown in Figs. 2-5. The concentrations of NOx, CO and HC in exhaust emissions under no-load, have shown a declining trend with increase in the concentration of hydrogen in CNG.

CONCLUSIONS

A reliable performance and safe operation with enhanced fuel efficiency, better acceleration and lower exhaust emissions was achieved with Hydrogen-CNG fueling of a CNG three wheeler. There exist an optimum percentage of hydrogen; 2-4 wt% (20-35 vol%) at which H-CNG blend shows best performance in a vehicle.

Fuel efficiency of the H-CNG fueled engine is about 20-25% higher than that of CNG engine. Acceleration i.e. power performance of the vehicle has got better by about 15% compared to a standard CNG fueled three wheeler.

Emissions of CO, HC and NOx show a diminishing trend with increasing proportion of hydrogen in H-CNG mixture.

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Table-1 Specifications of CNG Three Wheeler

Engine type	Single cylinder, 4 stroke, spark ignition, air cooled
Bore x stroke	57 x 68 mm
Engine displacement	173.52 cm3
Compression Ratio	9 :1
Max. net power	6.53 HP at 5000 rpm
Max. net torque	1.05 kg.m at 4000 rpm
Carburetor	Side draft, 18mm equivalent venturi

Table-2 Properties of Hydrogen and CNG

Item	Hydrogen	CNG	H-CNG			
			1.1 wt%	2.2 wt%	3.7 wt%	6.6 wt%
Molecular wt.	2.02	19.34	17.79	16.31	14.67	12.37
Low Heat Value, kcal/kg	28670	11150	11343	11536	11800	12309
C/H ratio	0	0.2514	0.228	0.2074	0.1838	0.1503
Stoichiometric air-fuel ratio (% by mass)	34.3	15.1	26.85	27.94	29.45	32.02
Laminar burning velocity (m/s)	2.9	0.38	--	--	--	--
Density, kg/Nm3	0.084	0.81	--	--	--	--
Maximum flame speed in NTP air, cm/s	265	33.5	--	--	--	--
Auto ignition temperature, oC	585	540	--	--	--	--

Table-3 Fuel Efficiency of the Three-wheeler on various H-CNG Blends under uniform Test Conditions (with payload of 150 kg and route length 25 km)

Fuel		Distance traveled on test route, km	Fuel consumed, Kg	Fuel efficiency, km/kg	Fuel efficiency km/kg CNG equivalent*
CNG	0% H2	26	0.72	36.1	36.1
H-CNG	1.1% H2 (12 vol %)	26.4	0.79	33.4	21.9
	2.2 wt% H2 (22.5 vol%)	31.4	0.73	43.01	27.8
	3.7 wt% H2 (33.5 vol%)	25.2	0.472	53.4	33.7
	6.6 wt% H2 (48 vol %)	24.6	0.523	47.0	28.4

* kg CNG equivalent on energy basis

Table-4 Acceleration and Torque Performance of the Three Wheeler at Different Fuel Compositions (with payload of 150 kg)

Fuel		Average time taken to cover 1 km stretch in best possible manner, s	Max. speed achieved, km/h
CNG	0% H2	80	60
H-CNG	1.1% H2 (12 vol %)	79.3	58
	1.1% H2 (12 vol %)	74.5	59
	3.7 wt% H2 (33.5 vol%)	72	60

	6.6 wt% H2 (48 vol %)	74	58

FIGURES

Fig. 1 Hydrogen-CNG blend filling

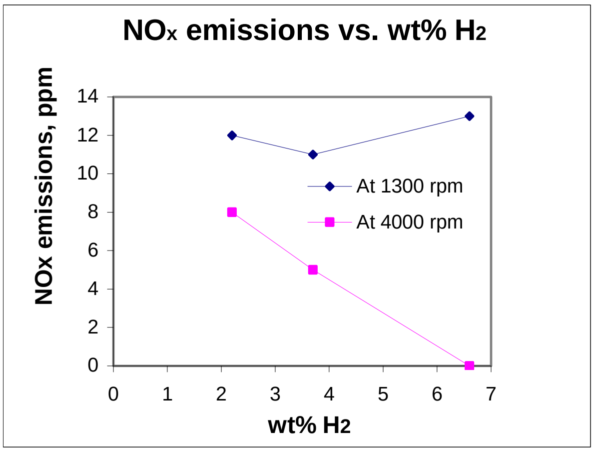

Fig. 2 Effect of hydrogen concentration in CNG on NOx emissions

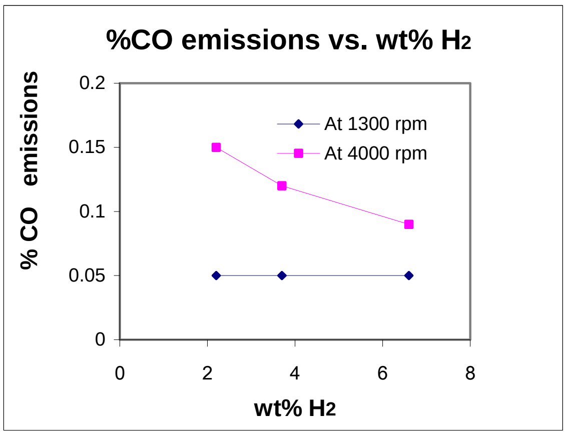

Fig. 3 Effect of hydrogen concentration in CNG on CO emissions

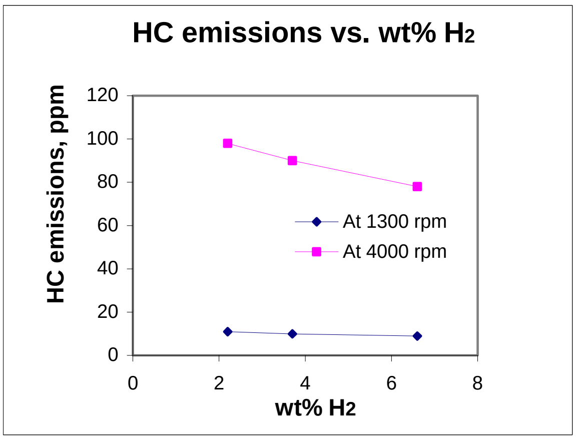

Fig. 4 Effect of hydrogen concentration in CNG on HC emissions