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Review on Opportunities and Difficulties with HCNG as a Future Fuel for Internal Combustion Engine

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Abstract

Air pollution is fast becoming a serious global problem with increasing population and its subsequent demands. This has resulted in increased usage of hydrogen as fuel for internal combustion engines. Hydrogen blended with natural gas (HCNG) is a viable alternative to pure fossil fuels because of the effective reduction in total pollutant emissions and the increased engine efficiency. This research note is an assessment of hydrogen enriched compressed natural gas usage in case of internal combustion engines. Several examples and their salient features have been discussed. Finally, overall effects of hydrogen addition on an engine fueled with hydrogen enriched com-pressed natural gas under various conditions are illustrated. In addition, the difficulties to deploy HCNG are clearly described.

Keywords: CNG; HCNG; Hydrogen; Emissions.

1. Introduction

In today's modern world, where new technologies are being introduced, use of transportation energy is increasing rapidly. Fossil fuel, particularly petroleum fuel, isthe major contributor to energy production. Fossil fuel consumption is continuously rising as aresult of population growth in addition to improvements in the standard of living. Increased energy demand requires increased fuel production, thus draining current fossil fuel reserve levels at a faster rate. This has resulted in fluctuating oil prices and supply disruptions. Rapidly depleting reserves of petroleum and decreasing air quality raise questions about the future [1][2][7]. Alternative fuels such as CNG, HCNG, LPG, LNG, bio-diesel, biogas, hydrogen, ethanol, methanol and di-methyl ether have been tried worldwide. The useof hydrogen as a future fuel for internal combustion (IC) engines is also being considered [2].

Main drivers for introducing Hydrogen Enriched Compressed Natural Gas Blended Fuel for automobiles are to increase IC engine performance and reduction of both local pollutants and emission gases from environments. Air pollution is fast becoming a serious global problem with increasing population and its subsequent demands. This has resulted in increased usage of hydrogen as fuel for internal combustion engines. Hydrogen resources are vast and it is considered as one of the most promising fuel for automotive sector. However, several obstacles have to be overcome before the commercialization of hydrogen as an IC engine fuel for the automotive sector [3].

1.1 Fuel characteristics of HCNG

In an internal combustion engine, the addition of small amount of hydrogen to natural gas which can vary 5-30% by volume, leads to many advantages, because of some particular physical and chemical properties [5]. Xu *et al.* developed a new HCNG premixed system which was used to blend desired amount of hydrogen into CNG. According to Dalton's partial pressure law, hydrogen fraction was decided by the partial pressure of these two fuels in HCNG tank [6]. The influence of gas composition on engine behavior can be adequately characterized by Wobbe index. If the Wobbe index remains constant, change in the gas composition will not lead to a noticeable change in the air-fuel ratio and combustion rate [4]. The overall comparison of properties of Hydrogen, CNG, 5% HCNG blend is given in table 1 shows the characteristic values of the HCNG fuels with different hydrogen fractions. Also, these confirm that the properties of HCNG lie in between those of hydrogen and CNG. There are a number of unique features associated with HCNG that make it remarkably well suited in principle to engine applications. Some of the most notable features are:

Table 1: Comparison of properties of hydrogen, CNG, and HCNG 5 with gasoline [4]

Properties	H2	HCNG 5	CH4	Gasoline
Limits of flammability in air, [vol.%]	4-75	5-35	5-15	1.0-7.6
Stoichiometric composition in air, [vol.%]	34.3:1	22.8	17.2:1	1.76
Minimum energy for ignition in air, [mJ]	0.02	0.21	0.29	0.24
Auto ignition temperature, [K]	858	825	813	501-744
Flame temperature in air, [K]	2318	2210	2148	2470
Burning velocity in NTP* air, [cms–1]	325	110	45	37-43
Quenching gap in NTP* air, [cm]	0.064	0.152	0.203	0.2
Normalized flame emissivity	1.0	1.5	1.7	1.7
Equivalence ratio flammability limit in NTP* air	0.1-7.1	0.5-5.4	0.7-4	0.7-3.8
Research Octane number	130	-	120	91-100
Methane number	0	76	80	-

Composition of CNG: CH_4 – 90.2%, C_2H_6 – 8.5%, C_3H_8 – 0.6%, N_2 – 0.6%, butane – 0.1%

*NTP denotes normal temperature (293.15 K) and pressure (1atm)

Table 1 shows that, addition of hydrogen increases the H/C ratio of the fuel. A higher H/C ratio results in less CO_2 per unit of energy produced and thereby reduces greenhouse gas emissions.

Natural gas has low flame speed while hydrogen has the flame speed about eight times higher therefore, when excess air ratio is much higher than the stoichiometric condition, the combustion of natural gas is not as stable as HCNG [11]. The problem encountered using natural gas is that the engine will experience incomplete combustion (misfire) before sufficient NO*x* reductions are achieved. Adding hydrogen to the fuel extends the amount of charge dilution that can be achieved while still maintaining efficient combustion [7]. Hydrogen also has a very low energy density per unit volume and as a result, volumetric heating value of the HCNG mixture decreases as the proportion of hydrogen is increased in the mixture.Blends of HCNG ranging from 15-30% extend the lean operating limit ensuring complete combustion which reduces HC and CO emissions [4][7].

1.2 Engine Performance of HCNG

Number of experiments had been performed and all had shown that the HCNG which is a blend of hydrogen and natural gas increases the efficiency and reduces the emissions of gasoline (SI) engine. HCNG has many advantages when it comes to performance because of the higher octane rating of hydrogen, the engine performance generally increases with the addition of hydrogen. Many researchers shown that the thermal efficiency of both natural gas and HCNG increases with increasing load, which makes it an ideal fuel for high load applications and heavy-duty vehicles, this relationship can be seen in Fig.2 and it is clear that in every case, the HCNG fuel has a higher thermal efficiency than pure natural gas[3][6][8].

Raman *et al.* [11] analysed the usage of HCNG in lean burn SI engines, using different volumes of hydrogen on a GM 5.71, V8 engine. With 15 and 30% volume of H_2, abruptly reductions in NO_X with some HC penalty were observed as a result of very lean combustion.

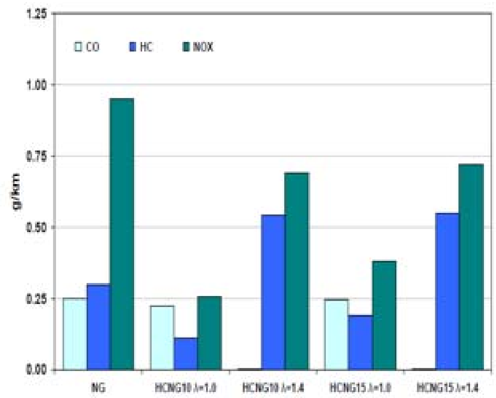

Fig. 1: Local Emissions for different contents of hydrogen in HCNG

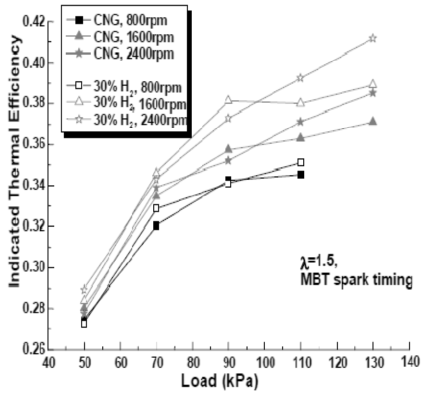

Fig. 2: Thermal Efficiency of HCNG increases with increasing load [8]

Munshi *et al.* [12] performed experiments on a turbocharged lean burn natural gas engine with a mixture of hydrogen and natural gas. Tests were carried out to get the most suitable H_2-CNG blend for H_2 fractions between 20 and 30% by volume. 20% volume of H2 was found to provide the desirable effects when the engine and vehicle performance attributes are taken in consideration. Bysveen [13] investigated that the brake thermal efficiency for HCNG is greater than CNG for the same excess air ratio (λ) and the difference in brake thermal efficiency between HCNG and CNG increases with increasing excess air ratio. Results also shows that by increasing the excess air ratio and fraction of hydrogen to the CNG emissions of NO_X are reducing significantly. This leaning out may easily be achieved without any substantial HC penalty. Ma *et al.* [5] carried out an experiment on Combustion and emission characteristics of port injection turbocharged (SI) engine fuelled with many H_2-CNG blend ratios varying between 0-50% under various ignition timings. Results show that with increased percentage of hydrogen, the maximum brake torque (MBT) timing decreases and the indicated thermal efficiency increases. MBT gets close to top dead centre and the indicated thermal efficiency increases with decreased load. The duration of combustion is reduced by higher fraction of hydrogen in HCNG. All the NO_X, CO, and HC emissions tend to come down with the increase of spark advance angle with the increase of load. Effects of adding hydrogen to the CNG is also same for heavy–duty vehicles. Park *et al.* [14] analysed the influences of hydrogen on the performance and emission characteristics of a heavy duty natural gas engine. He explained that NO_X reduction of over 80% is possible by employing retarded spark timing with the addition of 30 vol.% hydrogen with natural gas under the condition of best thermal efficiency.

Morrone [14] developed a numerical model and used this to investigate the time evaluation of the mass burned fraction of a passenger car engine in order to calculate the variation of brake thermal efficiency for hydrogen-natural gas blends. Satisfactory results were found between the numerical and experimental results for a CNG fuelled engine.

2. Challenges for Implementation of HCNG

One of the biggest challenges using HCNG as a fuel for engines is determining the most optimized hydrogen/natural gas ratio. When the hydrogen fraction increases above certain limit, abnormal combustion such as pre-ignition, knock and backfire, will occur unless the spark timing and air-fuel ratio are adequately adjusted [10]. As the percentage of hydrogen increased, the lean operation limit extends and the maximum brake torque (MBT) decreases, which means that there are relation among hydrogen fraction, ignition timing and excess air ratio[7][6]. Therefore finding the optimal combination of hydrogen fraction, ignition timing and excess air ratio along with the other parameters is certainly a large hurdle [9].

The emissions levels of fuels are probably the most important factor in determining whether the fuel is suitable as an alternative fuel or not. Although the NO_X emissions for CNG are already extremely low compared to traditional fuels, the addition of hydrogen causes increased NO_X emissions [10]. As shown in fig. 1, the addition of hydrogen has the opposite effect on the hydrocarbon emissions, so it is necessary to compromise at a hydrogen ratio for which the NO_X and hydrocarbon emissions are equally low. Probably most evident challenge for wide-spread use of the new fuel is the current lack of infrastructure. Similar to other gaseous fuels, natural gas and hydrogen are both lighter than air, therefore if there is a leak it will quickly disperse into air with adequate ventilation. Lastly, the currently cost of hydrogen is higher than the cost of natural gas resulting in HCNG being more expensive than CNG [2][6][9].

3. Conclusion

HCNG has many advantages when it comes to performance.Research has shown that the brake effective thermal efficiency increases with an increasedpercentage of hydrogen. Another effect of the addition of hydrogen is that the brake specific fuel consumption is reduced, the cycle by cycle variations are also reduced, and the thermal efficiency is increased. Foremost advantage, HCNG is safer than hydrogen due to its lower energy content from hydrogen.

It is evident from literature that emissions can also be improved with the addition of hydrogen. Compared to naturalgas, HCNG reduces the HC emissions, which is in part due to the increased combustionstability that comes with the addition of hydrogen. Increased in NO_X emissions are observed due to the increased combustion duration and temperature which is accompanied by addition of hydrogen. The biggest challenge with the commercialization of the fuel comes with developing an infrastructure to support this promising alternative fuel. Although there is currently a large amount of research taking place regarding the HCNG fuel, there are requirement of many steps to take before wide-spread implementation can occur.

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