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Review on Development of Hydrogen CNG Blender Mechanism for Existing Gasoline Engine Vehicles

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ABSTRACT: *With increasing concern about energy shortage and environmental protection, research on reducing exhaust emissions, reducing fuel consumption, reducing engine noise and increasing specific outputs has become the major researching aspect in combustion and engine development. Alternative fuels such as CNG, HCNG, LPG, LNG, bio-diesel, biogas, hydrogen, ethanol, methanol, di-methyl ether, producer gas, p-series have been tried worldwide. Hydrogen and CNG blends (HCNG) may be considered as an automotive fuel without any major modification in the existing gasoline engine and infrastructure. It is observed in the experimental work that the HCNG blends are more superior to gasoline carburetted engines from fuel economy, power output and emission compliance point of view.There is a need to develop and install Hydrogen - CNG blenders in existing gasoline engines for improvement in efficiencies, for reduced fuel costs and for better reliability & operating flexibility of automobile.*

Keywords –*Electrolyses, Exhaust emissions, HCNG, Hydrogen Dispense, NOx reduction*

I. INTRODUCTION

The introduction of hydrogen technologies requires a huge effort for the development of the related technologies in the field of production, blending, storage and utilization of this fuel, as well as an enormous investment for the realization of the infrastructures. Furthermore, public awareness is very important for the introduction of blend of hydrogen with CNG as a fuel, in order to avoid unsustainable delays to this “Ultimate energy carrier”. A good opportunity in the short term can be represented by introducing Hydrogen blender mechanism to blend hydrogen with natural gas to prepare stoichiometric mixture of HCNG for existing gasoline Engine vehicles. 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 HCNG blend. Hydrogen is a ubiquitous element, found virtually everywhere, but always bound with other elements. Hydrogen is most prevalent in water, presenting the very real possibility of a virtually unlimited supply of energy from tap water. Hydrogen can either be burned in conventional internal combustion engines (ICEs). In either instance, the amount of pollution that results is dramatically less than that produced by contemporary vehicle technology. 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. As the required hydrogen infrastructure and refuelling stations are not meeting the demand, widespread introduction of hydrogen vehicles is not possible in the near future.

II. PREVIOUS WORK & INDIAN GOVERNMENT POLICY

India’s Standing Committee on Emission Regulation, part of the Ministry of Shipping, Road Transport and Highways, approved 20% hydrogen & 80% CNG blend for use in vehicles[1]. Bureau of Indian Standards (BIS). The project, involving Ashok Leyland, Bajaj Auto, Eicher Motors, Mahindra & Mahindra and Tata Motors, began as an attempt to control the emission of NOx from poorly-maintained CNG vehicles. At 20 percent, hydrogen mixes well with CNG and does not reduce the power output of engines significantly [2]. To demonstrate the viability of Hydrogen - CNG as an automotive fuel, this H-CNG transit bus development and demonstration program was initiated. SunLine Services Group was selected as a fleet partner, in part, because of their ten years of gaseous fuel experience in transit use including four years with gaseous hydrogen [3].

There are many unsolved issues associated with converting the existing infrastructure into hydrogen CNG - based system.

III. OBJECTIVES

The main objectives of the research are:

1. To demonstrate the generation of hydrogen and a blend of hydrogen and natural gas (HCNG).
2. To define the conditions under which hydrogen (part of a mixture with other gases) can be added to natural gas in the existing natural gas system (transmission, distribution, end use (engine),) with regard to: acceptable safety risks, improve performance of engine, study of impact on the integrity of the system;, consequences for gas quality management and for the end user, to develop technical options to blend/add hydrogen in natural gas mixtures, to assess the socio-economic aspects to illustrate the real value of HCNG fuel, to develop the a fuel flow control system that will determine/control the percentage of hydrogen that can be added to natural gas for all demands and identify the factors that limit the percentage.

It should be noted that although the objectives of the project concern hydrogen - natural gas mixtures, the outcomes are very relevant for defining the conditions under which the existing gasoline system can be used for other sustainable produced gases containing a certain amount of hydrogen.

IV. PRODUCTION OF HYDROGEN

Hydrogen can be produced from a various methods. These include fossil resources, such as natural gas and coal, as well as renewable resources, such as biomass and water with input from renewable energy sources. A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic and thermo-chemical. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges. Local availability of feedstock, the maturity of the technology, market applications and demand, policy issues, and costs will all influence the choice and timing of the various options for hydrogen production.

Table 1 Differences between the properties of Hydrogen and Natural gas

Property	Hydrogen	Natural gas
Caloric value [MJ/m^3]	13	38
Density [kg/m^3]	0.09	0.8
Air volume needed for the combustion of 1 m^3 [m^3]	2.5	8.5
Ignition energy gas/air mixture [mJ]	0.02	0.3
Ignition temperature [^{o}C]	585	540
Flammability limits gas/air mixture	4-75%	4.7-16.6 %
Viscosity [µPa.s] (1 bar, 20^{o}C)	8.8	110
Flame velocity [cm/s] (methane-air)	350	40
Diffusion coefficient in air [cm^2/s]	0.6	0.16
Diffusion coefficient in PE (20% H2/80%CH4	3,6 x 10^{o-6}	1,7 x 10^{-7}
Diffusion coefficient in steel [cm^2/s](100^{o}C)	2.5 x 10^{-7}	Nil

• Alkaline Electrolysis of Water To Produce Hydrogen:

Hydrogen produced by is electrolysis or splitting of water with an electric current. Electricity is lead through water and the water molecules split into oxygen at the anode and hydrogen at the cathode. One example of electrolysis from a chemical process but is not included further whereas the hydrogen is not as pure. Three types of industrial electrolytic units are used today. Two involve an aqueous solution of potassium hydroxide (KOH), which is used because of its high conductivity, and are referred to as alkaline electrolyzes. These units can be either unipolar or bipolar. The unipolar electrolyser resembles a tank and has electrodes connected in parallel. A membrane is placed between the cathode and anode, which separate the hydrogen and oxygen as the gasses are produced, but allows the transfer of ions. The bipolar design resembles a filter press. Electrolysis cells are connected in series, and hydrogen is produced on one side of the cell, oxygen on the other. Again, a membrane separates the electrodes. Electrolytic units are currently capable of producing the required amounts of hydrogen, and today are in the selected case for the needs such as automobile sector. The following reactions take place inside the alkaline electrolysis cell:

Electrolyte: 4H2O _ 4H+ + 4OH–
Cathode: 4 H+ + 4e– _ 2H2 (3.2)

Anode: $4OH^{-}$ _ $O_2 + 2H_2O + 4e^{-}$

Sum: $2H_2O$ _ $O_2 + 2H_2$

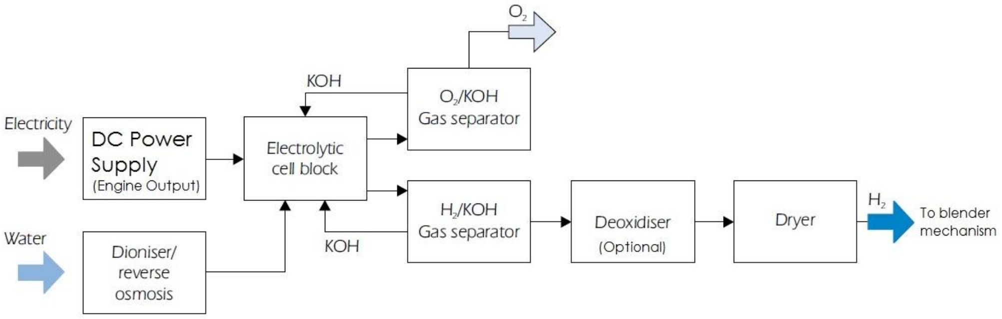

Fig. 1 Process Layout of Alkaline Electrolysis

V. HYDROGEN BLENDER MECHANISM

An online mixing system is used to blend desired amount of hydrogen (metered quantity) with natural gas just before entering the engine. The temporary storage tank can be used to improve the mixture uniformity. The flow rate of natural gas and hydrogen are measured using flow meter that uses the principle of Coriolis force for a direct measure of mass flow and flow control valve is used to adjust the flow rate of the hydrogen according to the flow rate of CNG and obtain the target hydrogen-natural gas blended charge fraction.

- **BLENDING MECHANISM MODEL LAYOUT**

Flow control valves on hydrogen and CNG lines can be operated by the control system assuring accurate blending of fuels. Hydrogen and natural gas can blend to a desirable ratio in terms of volume, mass, or energy equivalent basis. The layout of the system is shown in Fig.2. The fuel is delivered to the engine through a gas venturi, which is supplied with the fuel mixture at a slight overpressure. The richness is controlled using a control valve in the supply line. Both natural gas and HCNG mixture can be used with this system. The hydrogen is obtained from electrolytic unit; the natural gas is obtained from the CNG tank at pressure 80 bar to 120 bars. Measurement of the fuel flow rate is made using mass flow meters in both of the supply lines. From the measured natural gas flow the necessary hydrogen flow is computed and supplied as input signal to the mass flow controller.

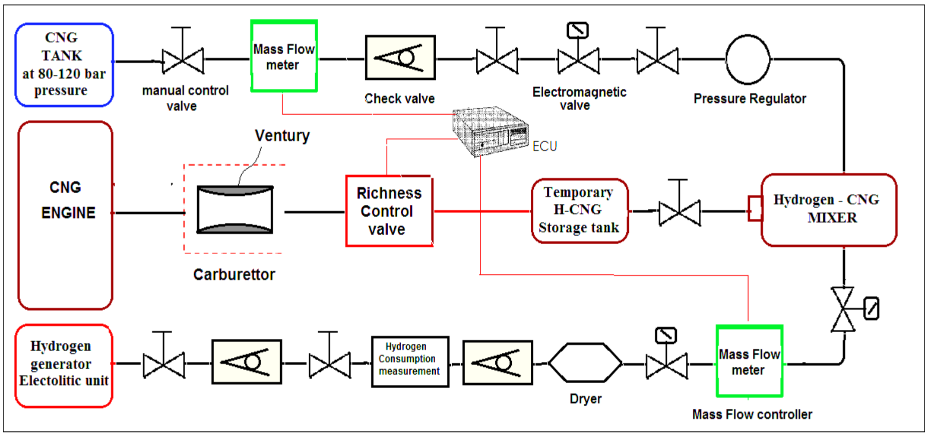

Fig. 2 Blender mechanism Model layout

This results in constant hydrogen content, independent of engine speed and load. The hydrogen concentration is given in volume % (the term mass flow meter/controller only means that the measurement is automatically compensated for temperature and pressure changes, the readings are in Nm3/h). Alternatively, hythane (or any other fuel) from a high pressure tank (180 bar) can be used for short runs (optional). By putting this tank on a scale fuel consumption (flow rate) can be measured. The system described as above is only able to provide mixtures with up to 30% hydrogen, due to limitations in the control unit and safety aspects regards.

VI. ENGINE MODIFICATION CONSTRAINS TO IMPLEMENT HYDROGEN BLENDER MECHANISM

The engines are designed for a certain specification set of gasoline/ CNG as characteristics. Since the combustion properties change when hydrogen is added to natural gas, this may also affect the performance that particular engine Without appropriate modifications to natural gas appliances, there is an increased probability that flames will be extinguished or will 'flash back'. System may be damaged, and there could be a risk of unintended gas releases and an increase in unsafe situations as a result of adding hydrogen.

- **Gas Quality Management**

It should be ensured that end users (engine carburetor) will remain supplied with Hydrogen blended CNG gas that meets the contractual specifications in order to guarantee their safety, performance of engine. Moreover, this is an issue if hydrogen is extracted from the mixture, and the remaining gas is supplied to engine. The carburettor will be configured to provide an accurate blend of hydrogen and CNG on single hose quantity of which are already metered with Coriolis type mass flow meters. The mechanism will configured to provide 5/95 % to 20/80 % by volume Hydrogen-CNG blend ratio. The accuracy of the H-CNG blend can be verified from gas composition analysis of the samples taken from the temporary storage tank which will be installing before carburettor. To assess the differential effects from varying levels of hydrogen in the H-CNG fuel blend, engine test will carried out. Data will be collected included emission rates of NO_x and THC as well as fuel consumption. To get a fair representation of the engine map, four distinct steady state engine-operating points (engine speed and load) will be choose.

- **Injection**

In order to avoid operating regimes with high NOx emissions, the vehicle should run on a lean-burn strategy with a constant relative air/fuel ratio. The calibration of the ECU should perform for a relative air/fuel ratio. Because of the changes in energy flow, adjustments in injection timing will be necessary. If only discrete blends with known compositions are being used, the injection settings can be changed manually according to the dependencies. If various blends or blends with unknown compositions are used to fuel the vehicle, the related provision should be implemented in the ECU and a means to identify the composition of the mixture should be developed.

- **Ignition**

Because of the lower combustion speed of methane compared with that of hydrogen, the spark timing has to be adjusted for optimum engine performance. With the current engine control strategy, the engine is being run with a constant air/fuel ratio. For blends with small amounts of hydrogen (<5% by volume), the engine can be operated without adjusting the spark timing, which will result in only a negligible loss in thermal efficiency. For blends with greater amounts of hydrogen, the spark timing should be adjusted to maintain efficiency and proper combustion.

- **Other ECU Functions**

Although the advanced spark timing that is required when blending hydrogen with methane could lead to knocking, this seem unlikely both, because of the good knocking properties of methane and because the lean burn strategy itself also inhibits knocking. Moreover, a knock sensor could be used to prevent engine knocking. Because of the changed composition of the feed fuel, the dependence of the air/fuel ratio on the exhaust oxygen feedback changes slightly.

VII. FEASIBILITY AND USEFULNESS OF EXISTING ENGINE INFRASTRUCTURE FOR DELIVERY OF HCNG BLEND

A Hydrogen blender mechanism provides a transitional delivery system which is suitable for the existing engine infrastructure, can be used for hydrogen delivery and further blending process. The accommodation of HCNG that contain a 5 to 30 % percentage of hydrogen (By Volume) it is important that the physical and chemical characteristics related to the composition of the gas fit sufficiently with the characteristics of natural gas, and do not initiate un-acceptable risks for instance the integrity of the application (engine fuel delivery system). The option of adding hydrogen to natural gas in the existing fuel delivery system, either by implementing appropriate modifications to the network, or through changes in the way it is operated. However, the results are also relevant for examining the potential of using the existing gasoline infrastructure for hydrogen.

Modifications will need to be made to operating conditions, condition monitoring and integrity management strategies in cases where a network, not designed for HCNG, is used to convey the same. The first step to overcome the above problem is that the pipelines are to be operating with hydrogen at significant lower pressures than their initial design pressures to avoid leakage and to maintain system safety.

VIII. ENGINE PERFORMANCE AFTER IMPLEMENTATION OF BLENDER MECHANISM

Performance plays an important role in the choice of a fuel. H-CNG has many advantages when it comes to performance because of the high octane number of hydrogen, the engine performance generally increases with the addition of hydrogen.

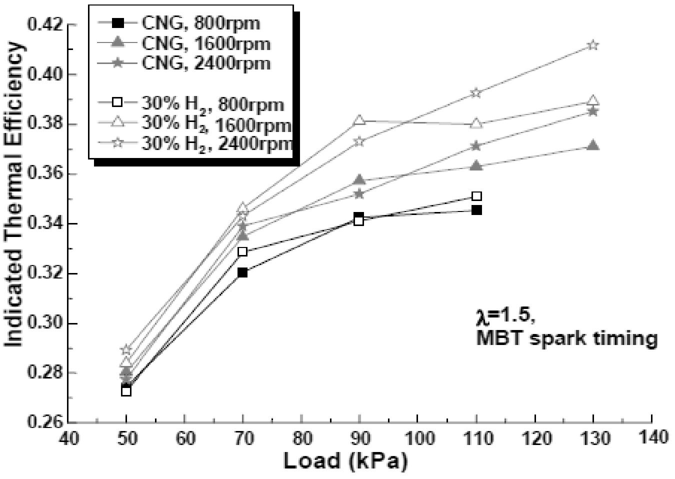

Fig.3 Thermal efficiency of H-CNG increases with increasing load (10)

The thermal efficiency of both natural gas and H-CNG 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.3. It is clearly seen in Fig.3 that in nearly every case, the H-CNG fuel has a higher thermal efficiency than pure natural gas. Engine performance is verified by comparing the torque curves for each fuel. The torque curve demonstrates the capability of the engine to maintain full load under H-CNG fuelling. As shown in Figure comparing full torque achieved under natural gas and H-CNG fuelling. As seen from the NREL H-CNG transits bus engine test results, the H-CNG torque is either equal to or slightly higher than the torque generated with natural gas. The engine achieves a peak torque of 697 Nm at 1600 rpm and a rated torque of 596 Nm at 2800 rpm. The engine achieves a rated power of 237 HP at 2800 rpm under H-CNG fuelling [1].

IX. BLENDER MECHANISM SAFETY ASPECTS

Safety will enable the risks presented by the Production, blending, transmission and use of a HCNG gas mixture. To ensure credibility amongst system operators, the major hazard scenarios previously studied for natural gas and hydrogen will be re-examined experimentally for HCNG gas mixtures. Tests will include investigation of combustion; build up of gas as per demand and calibration of engine performance parameters. The results (after iterations) will be used to modify existing risk assessment methodologies, developed originally for natural gas. The modified risk assessment methodologies will then be used to undertake risk assessments to compare with those completed for the existing natural gas system.

X. COST ELEMENT FOR DEVELOPMENT AND DESIGN OF BLENDER MECHANISM

As with anything, cost is a major consideration. Although these are just demonstration projects, the authors realize that resources are scarce. Thus, one criterion in the selection of demonstration projects was the potential cost of integrating hydrogen producing and blender mechanism capability on vehicle. This has been a difficult criterion to apply, however, since these costs are not well understood. There are few examples to point to where hydrogen has been integrated into an existing gasoline facility. Although the hardware prices are relatively well established, engineering and installation remain a big question mark. Thus, for this criterion, it is best to consider the complexity involved with modifying an existing facility to include hydrogen production and blender mechanism [1].

XI. CONCLUSION

Many aspects of the technology have still to be investigated, but its potential seems to be very promising. Probably different ICE models present different behaviors so it would be very interesting to carry out some laboratory tests for different vehicles, in different operating conditions and with different hydrogen contents in HCNG. In any case, for percentages of hydrogen less than 20% vol, above which important corrosion phenomena can occur, the modifications required to the engines are minimal. Furthermore, the existing fuel delivery system for NG can be adapted in order to supply HCNG simply by adding “hydrogen line” of limited capacity parallel to CNG line, since the mixing of the two gases is made by the blender mechanism during running condition of vehicle. The use of HCNG can allow a significative reduction of both global (GHG) and local pollution in the short term and with limited money investments. It should be noted that although the objectives of the work concern hydrogen - natural gas mixtures, the outcomes are very relevant for defining the conditions under which the existing gasoline fueling system can be used for biogas, hydrogen produced from other chemical processes, and other sustainable produced gases containing a certain amount of hydrogen. In the meantime, this technology could represent a “bridge” toward the introduction of pure hydrogen supply system for vehicles into the market.

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