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HYDROGEN AS A FUEL SUPPLEMENT IN A CNG OPERATED VEHICLE USING A SIMPLE ONBOARD HYDROGEN GENERATION SYSTEM

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ABSTRACT

Natural gas operated gasoline engines achieve superior fuel economy on the expense of reduced engine power and increased emissions. One method of offsetting these disadvantages is by the addition of hydrogen gas up to 20% by volume to compressed natural gas (CNG) using the existing natural gas conversion systems. This offers major benefits in fuel economy, light load performance and lower emissions.

The effect of supplementing CNG with hydrogen is studied along with the design of a simple hydrogen generation system for a 1.3 L bi-fuel engine. The Suzuki 1.3 L G13BA (SOHC) gasoline engine fitted with the Landi Renzo CNG pressure regulator, Type TN1 (Standard) has been used for experimentation. The system uses a small current for electrolysis of ordinary tap water for production of hydrogen. The light load performance is significantly enhanced and carbon monoxide and unburnt hydrocarbon emissions are reduced. Constraints on system design have been duly accounted for and the complete system is placed under the hood of the vehicle.

INTRODUCTION

The ongoing efforts for developing alternate fuels all over the world are a direct consequence of rapidly depleting crude oil reserves, increasing petroleum prices, exhaust emissions resulting in global warming and a need to have better fuel economy. Environmental issues, most notably air pollution, are among the principal driving forces behind this movement. Over the past two decades, compressed natural gas commonly known as CNG has emerged as a viable option for meeting the needs of the transportation sector as a cost effective fuel. The major drawback of using natural gas as a vehicular fuel is reduced engine power and increased emissions of carbon monoxide (CO) and unburnt hydrocarbons (HC).

One method of improving performance of natural gas operated engines is the use of hydrogen as a fuel supplement. The technology of using hydrogen as a combustion enhancement method in internal combustion engines has been investigated and verified for many years [1,2]. The results show that a small amount of hydrogen added to the incoming fuel-air mixture would enhance the flame velocity and permit the engine to operate with leaner mixtures. Consequently, hydrogen having a catalytic effect causes a more complete burn of the existing fuel and yields significant reduction in exhaust emissions with more power and better mileage.

Using a blend of 20% Hydrogen by volume to natural gas, referred to as Hythane (a registered trademark of Hydrogen Consultants, Inc.), the effects of hydrogen on the combustion of natural gas have been demonstrated [3,4]. However, problems related to onboard storage of hydrogen, safety concerns and refueling limitations have hindered the practical application of this proven concept.

This paper describes the design of a hydrogen generation system for a CNG fueled vehicle. The device presented in this study produces hydrogen and oxygen onboard, using electrolysis of water. Both the hydrogen and oxygen produced are fed directly into the intake manifold of the engine. This system is suitable for vehicles fitted with standard CNG conversion kits. No major modifications in the vehicle are required and the complete system is placed under the hood of the vehicle. The system is primarily based on the electrolysis of water in closed cell electrodes. Due to the simultaneous production and consumption of hydrogen, no storage is necessary, which incorporates inherent safety into the system. Tests with the system installed in Suzuki Swift Sedan with the 1.3 L G13BA Engine show a 5~8% reduction in fuel consumption. Moreover, exhaust emissions, especially carbon monoxide emissions, at idle running conditions are reduced drastically.

ENGINE DESCRIPTION

The hydrogen generation system has been tested with the Suzuki 1.3 L G13BA (SOHC) gasoline engine. It is a naturally aspirated engine with four cylinders in line. The engine has a carburetor based fuel system. The engine specifications are given in Table 1.

Table 1: Specifications – Suzuki G13BA Engine

Type	G13BA (SOHC), 4 Cylinder
Bore	74.0 mm
Stroke	75.5 mm
Displacement	1298 cm^3
Compression Ratio	9.0 : 1
Ignition Timing	6 Degrees B.T.D.C.
Maximum Power	50KW @ 6000 RPM
Maximum Torque	99 Nm @ 3500 RPM

The natural gas system installed in the vehicle uses the Landi Renzo Pressure Regulator Type TN1 (Standard) with a 3000 psi storage cylinder. The regulator is heated by the engine coolant to prevent natural gas freeze up and to reduce variations in fuel density caused by changing pressure drops. Natural gas is admitted into the engine through a gas mixer placed between the air cleaner and the intake manifold. The regulator specifications are given in Table 2.

Table 2: Specifications – Landi Renzo TN1 Regulator

Model	TN1 (standard): up to 175 KW
Type	Three Stage with electronic starting device and vacuum controlled idling
Inlet pressure	3230 psi
1st Stage Adjustment Pressure	60 psi
2nd Stage Adjustment Pressure	22 psi

PRACTICAL CONSIDERATIONS

Theoretically, any hydrogen production system fitted inside a vehicle should be able to produce sufficient quantities of hydrogen so that a fixed percentage of hydrogen by volume to natural gas can be maintained. An alternate way to achieve this fixed proportion between hydrogen and natural gas would be by storing hydrogen gas under pressure in a suitable container at low engine speeds and light loads so that the deficiency in hydrogen production at high engine speeds can be made up through the stored hydrogen. This would ensure steady operation at all engine speeds and load conditions and optimize the benefits of hydrogen addition on the combustion of compressed natural gas. However, several aspects render these options unfeasible for an onboard hydrogen system.

Constraints on the size of the electrolyser are dictated by the space available under the vehicle hood. In an effort to save space and increase cabin volume, modern day cars have little empty space under the hood and as such impose severe restrictions on the size of the electrolyser and related components. Moreover, the maximum current drawn by the electrolysis process is not only dependent on the alternator and battery size but is also limited by the quantity of heat produced during the production of hydrogen and the ability of the cooling system to efficiently remove this heat energy from the electrolyser.

Safety concerns are the primary reason for deciding against the storage of hydrogen under pressure in a container on the vehicle. Hydrogen due to its light weight and extremely high flammability is a difficult gas to handle and requires special sealing materials and techniques. Such sealing is prone to leakage and needs constant renewal and care. Furthermore, the electrolysis of water produces both hydrogen and oxygen gases in the ratio of 2:1. Separation of these gases within the electrolyser is practically difficult and will make the design quite complex. On the other hand, a mixture of hydrogen and oxygen under pressure is extremely inflammable and storing it onboard the vehicle is simply out of the question.

Addition of hydrogen to natural gas has a more pronounced effect on engine power and exhaust emissions at low engine speeds [2]. Hence, this team decided to design a hydrogen generation system which produces sufficient hydrogen gas to primarily address the problems associated with light load performance of natural gas engines.

DESIGN PARAMETERS

The onboard hydrogen system has been designed on the following set of parameters. These parameters have been selected keeping in view the various constraints and practical considerations.

1. The system must be small enough to be placed under the vehicle hood.
2. Hydrogen production rate should be sufficient to meet the fuel requirements at low engine speeds.
3. System current should not exceed 20 Amperes.
4. Ordinary tap water must be used as electrolyte.
5. Replenishment of electrolyte must be automatic with adequate storage system.
6. Fail safe operation shall be ensured.
7. Ease of maintenance.

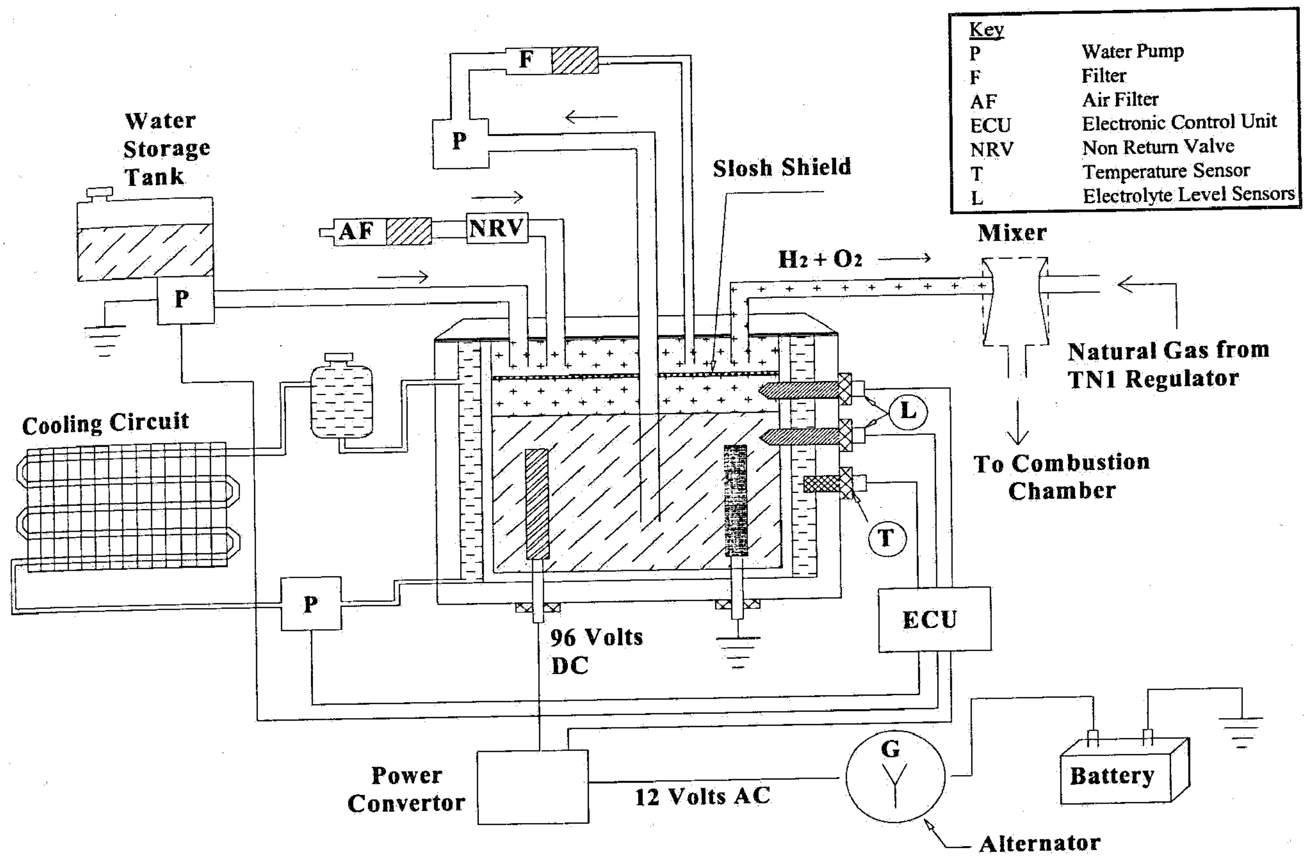

Figure 1: Schematic of the Hydrogen Generation System

HYDROGEN GENERATION SYSTEM

The hydrogen generation system shown in Fig. 1 produces hydrogen and oxygen onboard by electrolysis of water in closed cell electrodes. Initially, this team experimented with several catalysts and additives such as acids and salts for electrolysis of ordinary tap water. Electrolysis was carried out at 12V DC using a current value of 12~20 amps. Due to the high current requirements, high temperatures involved and the corrosive nature of such chemicals, there was always a chance of evaporation of these additives and their entrance into the combustion chamber with potentially damaging effects. To make the system practically feasible and to avoid the use of additives, it was finally decided to use only ordinary tap water as the electrolyte.

With normal tap water, a large potential is needed to initiate electrolysis. For this purpose, the alternator voltage has been stepped up to 96 volts using a power converter device. The alternating current is converted to direct current and is fed to the anode electrode of the electrolysis cell. Carbon graphite rods as the cathode constitute one pole of the electrolyser. The use of carbon electrode results in increased electrolysis efficiency and heating of the electrode is reduced. The anode electrode is made of Steel 316. The electrolysis cell is cooled by means of water circulating around it. A pump circulates the electrolyte continuously. This prevents sticking of gas bubbles to the electrodes which otherwise would inhibit the production rate of hydrogen gas. A slosh shield has also been added to prevent the electrolyte from entering any of the outlets. System installation onboard the vehicle requires minimum of modifications. The complete system is electronically controlled through the Electronic Control Unit (ECU). The ECU performs the following tasks:

1. Maintains the electrolyte (water) level in the cell between pre-defined intervals.

2. Switches on a warning light in case of low water level or excessive electrolyte temperature.

3. Automatic system shutdown in case of abnormal temperature rise.

4. Automatic system shutdown in case the engine stops for any reason.

A master switch available to the driver allows the system to be switched off in an emergency.

OPERATION

The system operation is very straightforward. The system produces nearly 17 liters of hydrogen per hour. Hydrogen and oxygen produced are fed directly to the engine through the gas mixer. Hydrogen is not stored in the system and is produced only when the engine is running, which results in safe operation.

The water replenishing system adds water after approximately every 450~500 km of operation. The electrolyte level is maintained between two pre-defined intervals. The technical specifications of the system are given in Table 3.

Table 3: Specifications: Hydrogen Generation System

Maximum Hydrogen Production	17 liters/hour
Electrolyte	Ordinary Tap Water
Cathode	Carbon Graphite
Anode	Steel 316
Electrolysis Voltage	96 V
System Current	15.5 Amps
Maximum Power Consumption	185 Watts
Water Storage Capacity	1.5 Liters
Water Consumption	32 ml / 100 Km
Electrolyte Temperature Range	50 ~ 55 °C
Dimensions	145 x 140 x 140 mm
Weight	2.1 Kg

ANALYSIS AND RESULTS

To check the performance of the onboard hydrogen generation system, a series of test were carried out to study the effects of hydrogen addition on fuel economy, engine power, efficiency and exhaust emissions. No engine adjustments were carried out and the engine static ignition timing of 6 degrees was used during all the tests.

Fuel Economy

To assess the fuel consumption reduction potential of the system, tests were carried on the vehicle (Suzuki Swift Model 1994 with G13BA Engine) with and without the system under urban and highway-driving conditions using direct fuel measurement technique. A reduction of 5~8% in fuel consumption during urban driving conditions was recorded. However, at high speeds, no significant fuel savings were not observed. This is due to insufficient amount of hydrogen produced to meet the fuel requirements at high speed.

Moreover, laboratory fuel consumption tests based on carbon dioxide emission data did not show any fuel savings. This could be attributed to the possibility of narrow efficient operating range of the system as Shrestha and Karim [9] state that when the work energy required for the production of hydrogen by electrolysis is taken into account, the range of viable operation of an engine is very narrow. Therefore, it is difficult to declare an accurate or exact saving figure obtained by employing this system.

Power Output

The power output of the engine on gasoline, natural gas and natural gas + hydrogen combination is shown in Fig. 2. The power curve on natural gas operation shows a 7~13% loss of power compared to the power curve on gasoline operation. This reduction in power is mainly due to exhaust of unburnt natural gas at the end of power stroke. With the addition of hydrogen to natural gas, power loss at low speeds is nearly eliminated but at high speeds, an improvement in power output (4~6%) compared to natural gas operation is observed. The difference in power improvement at low and high engine speeds is primarily due to the inability of the hydrogen generation system to produce enough hydrogen to meet the fuel requirements at high engine speeds.

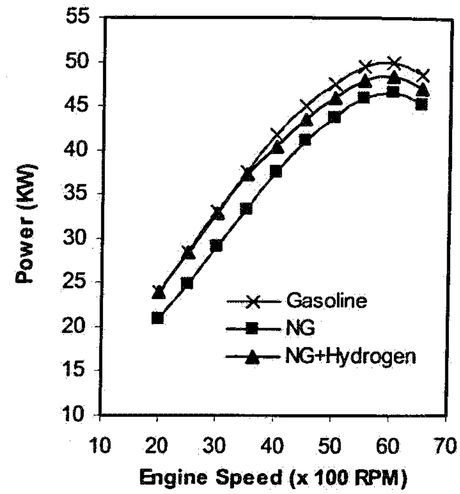

Figure 2: Power vs Engine Speed

Efficiency

Efficiency is that percentage of the available thermal energy, which is converted into useful power output by the engine. At full load, CNG fueled engine showed efficiency comparable to gasoline operation at full load but at part-load, the efficiency dropped considerably as shown in Figure 3. This decrease in efficiency is due to the slow burning rate of natural gas, which results in loss of unburnt natural gas at the end of power stroke.

By supplementing natural gas with hydrogen, while no substantial improvement in efficiency at full load was observed, the decrease in efficiency at part-load with natural gas only operation was offset to a considerable degree, particularly at low engine speeds.

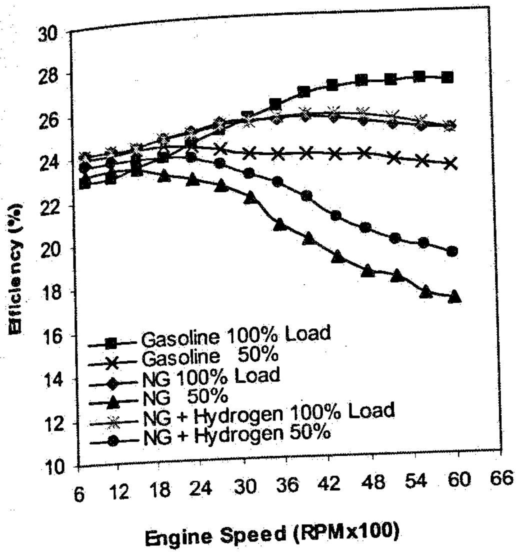

Fig. 3. Efficiency vs. Engine Speed

Exhaust Emissions

Engines running on natural gas suffer from relatively higher emissions of carbon monoxide and unburnt hydrocarbons. These two components have been measured for both natural gas only and natural gas + hydrogen operation at idle running speed and at a fixed engine speed of 3500 rpm.

Idle Exhaust Emissions. The exhaust emissions were measured at the engine idle running speed of 750 rpm. With the addition of hydrogen, carbon monoxide emissions are drastically reduced at idle running conditions, approaching zero levels while hydrocarbon emissions are reduced significantly by more than 70 %. There is no change in the carbon dioxide emission levels. The results are shown in Table 4.

Table 4: Idle Emissions

	Natural Gas	Natural Gas + Hydrogen
CO (%)	0.07	0.00~0.01
CO_2 (%)	15.30	15.33
HC (ppm)	37	8

Exhaust Emissions at 3500 RPM. The exhaust emissions at 3500 rpm for both natural gas only and natural gas + hydrogen operation are given in Table 5. It is evident that although, there is still a reduction in carbon monoxide emission levels, it is far less than that at the idle running conditions. This is because the quantity of hydrogen produced in relation to the fuel-air mixture volume at that speed, is not enough to meet the engine requirements. This is also obvious from the hydrocarbon emission levels which do not show a substantial decrease. These unburnt hydrocarbon emissions do not represent a cause for concern, since the bulk of HC emissions are methane, which is not believed to contribute to smog formation.

Table 5: Exhaust Emissions at 3500 RPM

	Natural Gas	Natural Gas + Hydrogen
CO (ppm)	7	4
CO_2 (%)	2.2	2.2
HC (ppm)	9.1	8.4

CONCLUSION

An effort has been made to develop an onboard hydrogen generation system, which is not only practical but also cost effective. By eliminating the need for onboard hydrogen storage and the use of normal tap water, safety has been built into the system. The system requires the least of maintenance, making non-corrosive and wear free operation possible for extended durations.

The results show that the system does not adversely affect the performance of the engine. In fact, addition of hydrogen to natural gas results in the restoration of engine power performance and displays slight enhancement in fuel economy. Engineers worldwide are faced with the challenge to meet new stringent standards for vehicular emissions. Natural gas operated engines suffer from relatively higher emissions of carbon monoxide and unburnt hydrocarbons. Exhaust emissions at idle are an important part of the engine operation and a major contributor to emission levels. The use of this system effectively reduces both emission types, especially at idle running conditions.

There is a lot of improvement potential in both the design and operation of this system. From the point of view of fuel economy, since the production of hydrogen is insufficient at high engine speeds, the system could be turned off at engine speeds other than idle. Moreover, by incorporating systems for variable hydrogen production rate and current control, the effects on fuel saving can be enhanced. The system is a proof-of-concept project and is not mature yet. The efficiency of this system can be improved further by modifying various design parameters including the electrolyser design, electrode selection etc.

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