Development of Hydrogen Generator for Hydrogen Enrichment of an Internal Combustion Engine

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***Abstract*— This paper presents design and development of an on-board hydrogen generator for hydrogen enrichment of a internal combustion engine as well utilization of hydrogen for any other purposes. The generation of hydrogen by electrolysis has been carried out through a wet cell type of process which is very inefficient. So to overcome the inefficiencies and to optimize the production rate a dry cell type of process is used in the designed generator. On board production of hydrogen is mainly done by partial oxidation reactor and electrolysis of water. The generator utilizes electrical energy from a battery to carry out the process of electrolysis and generates hydrogen. Hydrogen which has fast burning rate, when added to gasoline in an internal combustion engine, enhances its flame propagation rate. The emission of hydro carbons, carbon monoxide and few other parameters decreases with increasing percentage of hydrogen. The characteristics of the designed on board electrolyser is presented. The main purpose of this paper is to study and analyze the feasibility of the designed generator for use in internal combustion engine and other possible purposes.**

Keywords*— Hydrogen, Electrolysis, Gasoline, Enrichment.

I. INTRODUCTION

The reduction in emissions and increasing the efficiency of an internal combustion engine continues to be a challenging issue, particularly when the constraint of maintaining high engine efficiency is added. Increasing the efficiency of reciprocating engines has constantly been pursued since Otto-cycle engines were first used as vehicle power plants. The important effects of fuel consumption on factors such as vehicle range, operating cost, and vehicle structures have always been important design considerations. During the past decade, the impact of environmental factors and a national interest in energy conservation have accentuated the need to produce clean and efficient engines. Many concepts for improving efficiency and meeting emissions standards have been tested and reported. These ideas include using hydrogen as a supplement or use of hydrogen as a fuel for internal combustion engines has been discussed and researched for many years.

There are some kits which claim to run a vehicle using hydrogen generator hooked up to the alternator but actually, it is not possible to do that and has been proved by many researches. As the electrolyser draws more amount energy from the engine. The mechanical resistance created by the alternator and due to that more amount of current is being drawn by the electrolyser than to the amount of hydrogen produced. Also, it is not possible to convert one form of energy into another through 100% efficiency. There are also fraudulent kits available here in India which promises to increase mileage and people buy it due to lack of knowledge. These kits have electrolysers which generate hydrogen from wet cells which are most simple and inefficient way of generating hydrogen. This tends to decrease the mileage and there is no increase in efficiency.

One of the most effective solution to reduce some amount of emission is hydrogen assisted lean-mixture-ratio combustion in internal-combustion engines and has the potential of producing low emissions and higher thermal efficiency for several reasons. First, excess oxygen in the charge further oxidizes unburned hydrocarbons and carbon monoxide. Second, excess oxygen lowers the peak combustion temperatures, which inhibits the formation of oxides of nitrogen. Third, the lower combustion temperatures increase the mixture specific heat ratio by decreasing the net dissociation losses. Fourth, as the specific heat ratio increases, the cycle thermal efficiency also increases, which gives the potential for better fuel economy.

But, efficient lean-mixture-ratio operation, in terms of good vehicle performance, fuel economy, and low hydrocarbon emissions, is limited for several reasons. A reduction in indicated mean effective pressure (IMEP) occurs with lean mixtures, which produces sizable power fluctuations and causes engine surge and power train vibrations. In addition, as the mixture ratio is made leaner, the combustion process slows and occurs over larger crank-angle intervals, thereby causing hydrocarbon emission levels and fuel consumption to rise. Also, the thermal boundary layer, or quenching distance, increases with leaner mixture ratios, which also causes hydrocarbon emission levels to rise. Even though excess oxygen is available to oxidize these hydrocarbons, the quenching effect of the cylinder wall will still produce a net increase in hydrocarbon emissions. Lean-limit misfire is characterized by high hydrocarbon emissions, rough engine operation, and poor fuel economy.

The above-mentioned problems of lean mixture ratio operation can be solved by using hydrogen as a catalyst in the combustion process. Hydrogen supplied from the generator will increase the flame propagation rate and the problem of quenching will also be solved. The hydrogen generator developed will be used with lean mixture operation in an engine. To check for lean mixture operation several sensors

will be employed and these sensors will ensure hydrogen is only supplied when lean mixture burn takes place.

II. HYDROGEN GENERATION

Generation of hydrogen is carried by many processes and are used according to suitability and amount of hydrogen required. In this design hydrogen is produced by electrolysis of water. Electrolysis of water is the decomposition of water into oxygen and hydrogen gasses created by the passage of electric current. If the electricity used is produced from renewable resources like solar panels then it will definitely reduce the carbon footprints. Electrolysis of one mole of water produces one mole of hydrogen and half a mole of oxygen in their normal diatomic forms. Hydrogen will appear at the cathode and oxygen will appear at the anode.

Hydrogen is the simplest and most abundant element in the universe. It makes up about 75% of all matter in the universe. It is a basic element with tremendous potential. It is a non-metallic element with atomic number 1. Hydrogen gas or molecular hydrogen consists of two atoms of hydrogen held together by a covalent bond. Hydrogen produces clean energy. The energy content of hydrogen is much higher in comparison to other normal fuels like gasolene, coal and natural gas. The specific energy of hydrogen is 141 kilo Joules per gram which is roughly thrice that of gasoline. Specific energy is the energy content of the fuel per unit mass.

III. CURRENT SCENARIO

In the recent years, there has been a lot of interest in examining clean energy options. Even now, our energy comes mainly from fossil fuels like coal, oil and natural gas. So it is very important need to find a renewable source of energy which we can extract easily. And Hydrogen is one of the options available in abundance, but needed to be extracted from different sources. Since few decades many methods have been found which can extract hydrogen but are not completely efficient. Many laboratories and small-scale production of hydrogen gas have been attempted. Research at National renewable Energy Laboratory is experimenting several methods of producing hydrogen such as by fermentation, biological water splitting, photo electrochemical water splitting, conversion of biomass and wastes, solar thermal water splitting and renewable electrolysis. Another method being researched is Photo-electrochemical water splitting to produce hydrogen by using sunlight to directly split water into hydrogen and oxygen, this is believed to be the cleanest way to produce hydrogen but the feasibility of this method is in very less areas. Solar thermal water splitting is also being researched into in which highly concentrated sunlight is used to generate the high temperature needed to split methane into hydrogen and carbon.

IV. COMPONENTS

The main component of the experimental setup is the hydrogen generator and its power source which is used to carry out electrolysis. Also a microcontroller is used which uses different sensors and controllers to record data and also to ensure safety. Hydrogen is highly combustible gas and is very dangerous if not handled carefully. To prevent any explosion or implosion in the whole system devices like flashback arrestor and bubbler is used.

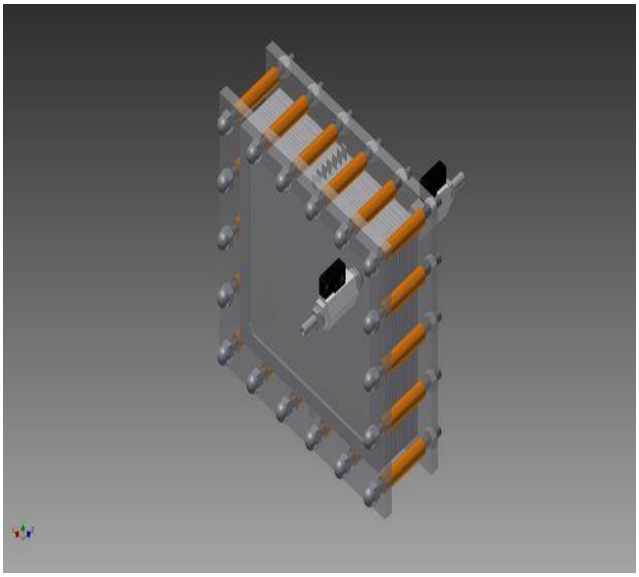

Fig.1: Designed hydrogen Generator

A. The Housing

The generator housing holds the electrolyte and the electrode plates. It is made from a low density polyethylene material with 2mm thickness. The housing holds all the electrode plates which are stacked over one another. All electrode plates are arranged accordingly with reference to polarity. There are two housings at each end which holds the entire electrodes between them. Housing has holes through which the bolts are tightened. Both the housings have connectors for input and output of the electrolyte and also for the output of hydrogen. These connectors are made of brass and have threads to fasten them on housings.

B. Electrodes

The generator has several plates stacked one over another and is separated by a rubber gasket. These plates are made of stainless steel of 20 gauge. Stainless steel is used to ensure no corrosion takes place on the surface of plates. Plates used are made of high quality stainless steel to prevent oxidation of chromium from the plates. Each plate is connected with their respective electrical connection i.e. the positive plate or anode, the negative plate or cathode and the neutral plate. Before the arrangement of electrode plates each plate is grinded down with a grinding belt machine to remove oxidized materials form the surface and also to attain maximum surface area.

C. Electrolyte

The electrolyte is formed from distilled water and sodium hydroxide mixed together. The solution is stirred properly and is filled into the reservoir tank. Maintaining the mixture ratio of distilled water and sodium hydroxide is very important. As proportion of sodium hydroxide increases more the resistance of the electrolyte solution increases. This tends to increase the power consumption and decrease the production rate. In this generator a ratio of 1:10 or 1:5 is maintained where one liter

distilled water contains ten or five grams of sodium hydroxide.

D. Reservoir

The reservoir contains the electrolyte solution and also has the connections for input and output of the electrolyte. The input of electrolyte solution from the generator also serves as the output of the produced gas. The pressure created by the gas facilitates the electrolyte in going back to the reservoir and hence completing a cycle. Reservoir tank is kept at a higher height than the generator to attain gravity feed of the electrolyte solution to the generator. The tank has to be pressure tight always to complete the cycle.

E. Electronic Circuit

Electronic circuit consists of an ACS 712 current sensor, a DS 18b20 temperature sensor and a micro controller which reads the analog input from the sensors and converts it to readable values and records them. Micro controller used is an arduino nano. The circuit also consists of a safety switch which cuts of the generator circuit as it reaches the threshold value of both current and temperature. The microcontroller is programmed using arduino integrated development environment. There is an abundance of memory in microcontroller for further optimizations in the system and also for programming required in lean mixture combustion system.

F. Safety Devices

As Hydrogen gas has a tendency to burn very quickly and also to backfire safety devices are used like flash back arrestors, bubblers and check valves. These all devices are used to prevent backfire and to ensure safety. A flash back arrestor consists of very small spools of steel wool inside tubings which prevent backfires. It actually works like a one-way valve.

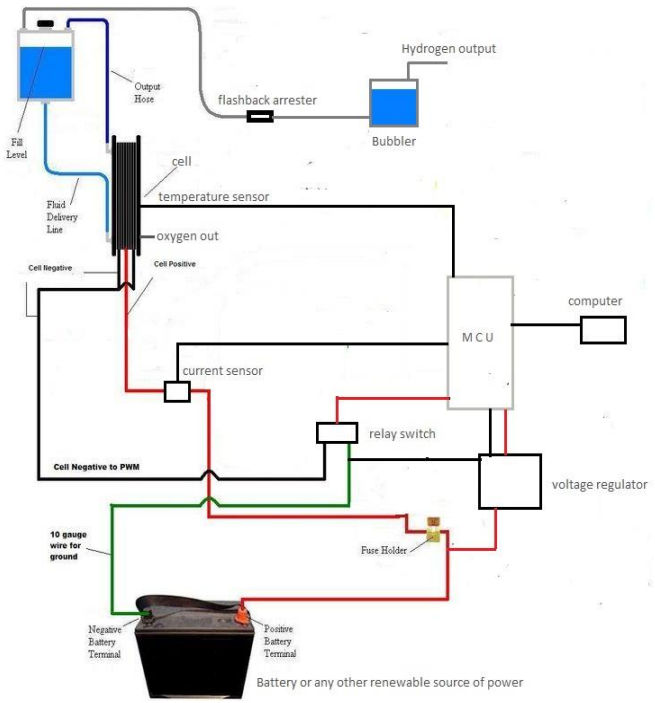

FIG.2: SCHEMATIC ARRANGEMENT

Where as a bubbler also serves to prevent backfire and it is a very simple device. It consist a tank filled with water and inlet connector for the gas. The produced gas enters the tank from beneath creating bubbles which also serves as an indicator.

V. OBSERVATIONS

The rate of gas produced during the electrolysis of water is dependent on the electrolyte, the spacing between the electrodes, the area and the preparation of the electrodes, the current flowing in the cell, and the concentration and the temperature of the electrolyte.

Gas Volume

The volume produced during the electrolysis of water is calculated by using Faraday's Law of Electrolysis In water, the weight of one mole is

$$H = 2 \times 1.008 \text{ g/mol} \quad (1)$$

$$O = 15.999 \text{ g/mol} \quad (2)$$

Thus, 1 mol of H_2O = 18.015 g/mol

The current supplied is 30 amps for 30 minutes (1800 seconds),

Redox Reactions:

At the cathode

$$2H^+ (aq) + 2e^- \rightarrow H_2 (g) \quad (3)$$

At the anode

$$OH^-(aq) + OH^-(aq) \rightarrow H_2O (l) + \tfrac{1}{2} O_2 (g) + 2e^- \quad (4)$$

Number of moles of electrons:

$$30 \text{ A} \times 1800\text{s} = 2x\ (1.08 \times 10^5) \text{ coulombs} \quad (5)$$

Taking faradays constant

1.08×10^5 C x 0.5F/96,485 C = 0.5596 moles of electrons.

In water electrolysis, 2 electrons are involved, 1 volume of oxygen gas is liberated whenever 2 volumes of hydrogen gas is produced.

Using the ideal gas law, the volume of hydrogen gas produced at standard temperature and pressure is:

$$pV = nRT \quad (6)$$

Where p = pressure = 1.013 x 105 Pa

V = volume = to be determined!

n = number of moles = 0.5596

R = gas constant = 8.3141

T = Temperature = 298 K

OR $V = nRT/p$

Putting all the above values

= 13.687 liters in 30 minutes at 30 amps of electric current

In one minute, hydrogen gas produced is 0.4562 liters.

It was noticed that results produced theoretically are quite lesser than in real.

Duration	Amp flow	Temperature	Gas production
10 mins	5	cold	0.5 lpm
½ hour	7.5	cold	0.7 lpm
1 hour	10	40 deg c	0.9 lpm
2 hours	12	50 deg c	1 lpm
3 hours	15	58 deg c	1.3 lpm
4 hours	20	65 deg c	1.7 lpm
5 hours	25	73 deg c	1.8 lpm
6 hours	30	74 deg c	1.8 lpm
7 hours	30	73 deg c	1.9 lpm

TABLE I. SHOWS THE CHARACTERISTICS OF THE GENERATOR

DISCUSSIONS

Results of testing hydrogen enrichment by several references have shown several effects:
(1) Reduction in exhaust emissions;
(2) improved engine power when the hydrogen is injected;
(3) Increased fuel economy under certain engine operating conditions, with 20% being a typical enhancement.

A detailed program of research is now under way to confirm and explain these initial observations by the designed hydrogen generator.

On the negative side, there are some disincentives:

- The electrolyte needs regular topping up.
- Proper standardized investigations have not been carried out.
- Some energy is lost in the electrolyser system because of ohmic heating etc.
- It has been proved by several references that the amount of hydrogen generated is less than the amount of mechanical resistance or the power drawn from the engine.
- The engine warranty may be invalidated by using these types of the generator in an engine.

These all problem can be solved using following methods

- Using solar energy to produce onboard hydrogen in the vehicle can significantly reduce the amount of effort on the engine. Thus, mechanical resistance to the engine through alternator will be reduced and definitely there will be an increase in the efficiency and mileage.
- Another method can be employed which is not to produce hydrogen onboard but to produce hydrogen at those places which have solar panels and uses renewable energy sources. The produced hydrogen will be compressed and stored in a tank and used by vehicles when necessary.
- Problems regarding ohmic heating can be solved by using and researching on materials which offer very less resistance and can be used as electrodes in this type of generators.

Further, it was observed during the testing that the production of hydrogen purely depends on the amount of current flowing through the cell and not depends on the voltage whether it is doubled. The next phase of this research will be to produce hydrogen using this generator by using renewable sources like solar panels. After that the produced clean hydrogen will be used in an internal combustion engine or as a supplement to lean mixture combustion operation.

CONCLUSIONS

- A hydrogen generator is being developed which is simultaneously optimized for improvement in production rate with the minimum amount of energy consumption.
- The hydrogen and oxygen gas produced during the generation can be used for hydrogen enrichment of engine or in residential, industrial and commercial purposes.
- Generation of hydrogen through this generator should only be done through renewable sources of power to reduce carbon footprint.
- As Hydrogen is referred as the fuel of future, there is a need for extensive research programs to study different methods of production of hydrogen and to choose the best of them.

REFERENCES

[1] Palmer, D. Hydrogen in the universe. 1997.
[2] National Renewable Energy Laboratory. Hydrogen and Fuel cell research. 2013.
[3] Maness, P., Thammannagowda, S., Magnusson, LFermentation and Pennington, G. Electrohydrogenic Approaches to Hydrogen Production. 2010 Annual Progress Report. Department of Energy, USA.
[4] Taylor, Charles F.: The Internal Combustion Engine in Theory and Practice. Vols. 1and 2, 2nd, Mass. Inst. Tech. Press, 1968.
[5] Hoehn, F. W.; and Dowdy, M. W. : Feasibility Demonstration of a Road Vehicle Fuelled with Hydrogen-Enriched Gasoline. Ninth Intersociety Energy Conversion Engineering Conference. Am. SOC.Mech. Eng., 1974, pp. 956-964.
[6] Internal combustion engine fundamentals: John B. Heywood.
[7] Bolt, J.; and Holkeboer, D. : Lean Fuel/Air Mixtures for High-Compression Spark-Ignited Engines. SAE Trans., vol. 70, 1962, pp. 195-202.
[8] Hoehn, F. W.; Baisley, R. L.; and Dowdy, M. W.: Advantages in Ultralean Combustion Technology Using Hydrogen-Enriched Gasoline. Tenth Intersociety Energy Conversion Engineering Conference. Inst. Electr.Electron.Eng.,1975,pp.1156-1164.
[9] Stebar, R. F.; and Parks, F. B. : Emission Control with Lean Operation Using Hydrogen-Supplemented Fuel. SAE Paper 740187, 1974.
[10] Erickson, P. A. Hydrogen Production for Fuel Cells via Reforming Coal-derived methanol. Quarterly Technical Progress Report April 2005. University of California, at Davies.
[11] Steve Perham; Hydrogen giving reduced carbon emissions from vehicles.