An investigation on the production of Brown gas (HHO) as an alternative automotive fuel by water electrolysis

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Abstract

The ever increasing cost of conventional fossil fuels and the associated environmental impacts of their uses have become the major concerns worldwide. Exhaust pollutants from internal combustion (IC) engines are one of the major sources that contribute to the total environmental pollutions globally. Consequently, researchers worldwide are working overtime to improve the fuel economy and emission characteristics of such engines. At the same time, they are forced to focus on the study of alternative fuels that can be used in engines without the need for a dramatic change in the vehicle design. Among different alternative fuels, brown gas (HHO, also known as hydrox gas) can be considered as a renewable, recyclable and non-polluting fuel as it contains no carbon in its molecule. The aim of this work is to design and fabricate a compact unit for generating HHO gas by water electrolysis. This HHO cell can be attached to the air intake manifold of an IC engine, so that a fuel mixture of gasoline and HHO gas is introduced inside the cylinder. Plates of stainless steel were used as both the anode and cathode in the HHO cell throughout the whole process. The electrolyte of the cell was a mixture of distilled water and potassium hydroxide (KOH). Effects of inter electrode gap, number of electrodes, solution concentration and current density on the production of HHO were investigated. Results revealed that single anode and cathode provided unsatisfactory production of HHO gas. Optimum yield of HHO was found using multi-electrode system i.e. single anode and two cathodes from a solution containing 1% KOH and 100ml of water producing 2150 cc of HHO gas when electrolysis was carried out for 15 minutes.

Keywords: Alternative fuel, Brown gas, Water electrolysis, internal combustion engines, pollution.

1. Introduction

In modern days the growing energy demands are still met mainy from fossil fuels such as coal, petroleum oils and natural gas. Fossil fuels provide energy in a cheap and concentrated form, and as a result they dominate the energy supply. However, the burning of the fossil fuels emits harmful pollutants which have negative impacts both on the environment and lives. Global warming is considered as one of the major problems the scientific community is facing today. Many theories refer to the increase of exhaust gases concentration in the atmosphere as one of the major causes of the global warming [1]. Industrial plants and automobiles are the major source of the exhaust gases. Fossil fuel uses in the transportation sector, in particular, is of great concern for the age as the world energy consumption in the transportation sector increases by an average of 1.1 percent per year [2]. Transportation activity is expected to grow significantly worldwide of the next years, with most of the increase occurring in non-OECD countries. The fast-paced growth in non-OECD transportation energy demand is a result of strong economic growth that leads to rising standards of living and corresponding increases in demand for personal and commercial travels.

The combination of issues - the increasing prices of petroleum fuels, the rise in awareness of environmental issues, concerns over energy security, stricter regulations on engine/vehicle emissions, and high growth rate of their consumptions, spurred interest in moving the world away from petroleum fuels for engine (especially vehicles) applications and toward alternative fuels and advanced vehicle technologies. This encourages researchers to seek for alternative solutions to be used in engines without the need for a dramatic change in the vehicle design. Among those using hydrogen (H_2) as an alternative fuel which enhances the engine efficiency and runs with almost zero pollution effect has been researched well in the last decade. The combination of the molecular composition of H_2 and some of its interesting properties (such as high laminar flame speed, wide flammability range, etc.) reveals hydrogen as an attractive fuel for internal combustion engines [3]. Besides, compared with traditional fossil fuels, H_2 is a carbonless fuel whose combustion does not generate emissions such as HC, CO and CO_2. However, there are concerns regarding the viable solutions both for the generation and storage of H_2 from the commercial point of views. Other researchers have used biogas [4-5], syngas [6], producer gas [7murari] either solely or with H_2 blends successfully in gasoline engines. The use of HHO gas in gasoline engines is comparatively new. HHO gas is the mixture of H_2 and O_2 in a ratio 2:1 by volume – products of water electrolysis, which is invented since March, 1978 by Yull Brown [8]. Hence, electrolytic gas often called as "Brown's gas" or Hydrogen Rich Gas (HRG). In recent years, there are some investigations on the effects of HHO gas addition on performance of spark ignition (SI) [9] and compression ignition (CI) engine [10]. Studies indicated that the addition of HHO gas seemed to affect engine performance in the same way as if the hydrogen had been used on its now: fuel consumption reduced [11], the torque and indicate mean effective pressure (IMEP) surged, the combustion duration and cycle-to-cycle variation also declined. However, the NO_x emissions were found to be increased [12].

Water electrolysis is a technique that utilizes a direct current (dc) to split water into protons, electrons, and gaseous oxygen at the anode (positive electrode) and hydrogen at the cathode (negative electrode) in the electrolyzer. HHO gas can easily be obtained from water using a HHO fuel cell. As fresh water is available, it is possible to generate HHO gas cheaply. When dc electricity is supplied through water it separates hydrogen and oxygen molecules. Usually two metallic electrodes (as anode and cathode) are immersed in aqueous solution of catalyst. The positive current positively charges the anode which yields the electrolysis reaction of the electrolytic solution and eventually releases gaseous unseparated oxygen and hydrogen. In industrial plants the alkaline electrolysis is preferred, because corrosion is more easily controlled and cheaper construction materials can be used compared to acidic electrolysis technology. An alkaline electrolyzer immerses the two electrodes, the cathode and the anode, into an aqueous alkaline electrolyte, typically a solution of sodium or potassium hydroxide, and a voltage is applied across the electrodes. The resulting migration of ions in solution results in the production of hydrogen at the cathode and oxygen at the anode according to [13]:

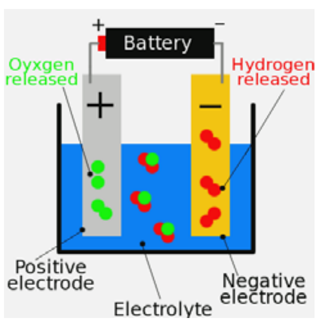

Fig. 1. Alkaline Electrolysis [14]

$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$ Anode reaction

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ Cathode reaction

$2H_2 + O_2 \rightarrow 2H_2O$ + electric energy + heat Overall reaction

The catalysts can be NaOH, KOH or NaCl for more HHO production and an optimum molality of the catalyst is important to keep electrical resistance-conductivity balance in the cell. Hydrogen and oxygen do not form into O_2 and H_2 molecules. Rather they may remain in their monoatomic state (a single atom per molecule) and thus there are no atomic bond needed to be broken (i.e. the bonds of the H_2 and O_2 respectively) before turning back into water. Hence, HHO gas can have more energy because these bonds are never made. In this state, which is an unstable state of H_2O vapor, more energy can be achieved compared to H_2 burning with O_2 [10].This hydrogen molecule acts as a fuel and oxygen molecule helps to burn the fuel. The heating value of hydrogen is high and for the presence of oxygen the proper combustion can be assured.

The main objective of the present work is to design and fabricate of a compact unit of HHO fuel cell for HHO gas production in laboratory scale. The electrolyzer used for this project is easy to construct by using locally available materials and they are cheap. Electrodes are chosen bearing into mind that they should withstand high temperatures as well as high current flows. The used electrolyte is relatively cheaper which is not harmful for human being. Total construction procedure is simple and also it consumes less time for maintenance. The produced gas is monitored, measured, collected and sampled for elemental analysis. Finally, a theoretical analysis is done in order to assess the potentiality of using the gas as an alternative fuel for gasoline engines.

2. Experimental details

The experimental setup includes mainly the fabrication of an electrolyzer in which the electrolysis reactions would occur. The other important tasks includes material selection for electrodes, electrolyte selection, gas collection method development etc. Transparent plexiglass (having 4mm thickness) is used to make the reactor container or the eletrolyzer. The dimension of the designed electrolyzer is about 18cm×15cm×15cm (Fig.2) with a capacity of 3 liters solution. Plexiglass has some special properties other than visibility such as noncorrosive, nonconductive, nonreactive with electrolyte and it can withstand high pressure and temperature. Stainless steel is selected as electrode material as it is high corrosion resistant, non reactive with the electrolyte, good

trolyzer

conductor, and capable to withstand high temperature and voltage. Also the use of stainless sttel as electrodes can assure better HHO production rate at low cost [9-11]. The size of the electrodes used in this study is about 15cm×10cm. In this study, both the cathode and anode are made from the same stainless steel plates (Fig.2) for the cell. Since the target HHO gas is collected from cathode, the number of cathode plates are kept more than the anode. In this study, we have used two cathode and one anode plates arranging in cathode-anode-cathode order. Food grade Potassium Hydroxide (KOH) is used as electrolyte to speed up HHO production. Researchers have demonstrated that HHO gas flowrate increases in relation to mass fraction of catalyst in water. An electrolyte with increased amount of catalyst can dramatically increase current supplied from battery due to the higher reduction of total electrical resistance in the solution. Two types of electrolyte: 1 % and 0.5% KOH solution are used to perform the electrolysis process. The plate electrode and KOH(aq) are found satisfactory in relation to the electrical power consumed in the experiment. A DC battery (similar to that is used in automobiles) is used as the main power source of this experiment. The terminal voltage of the battery is 12 V and current rating is 30Amp/hr. Typically 15-18 amps current is supplied through the electrolyzer.

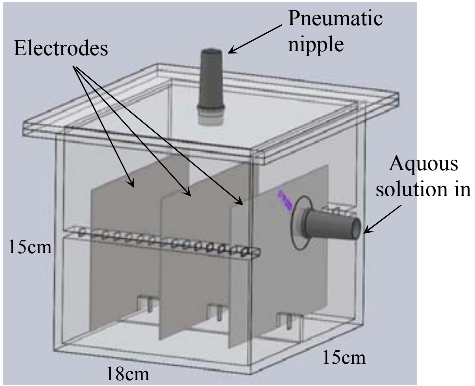

Fig. 2. Designed plexiglass electrolyzer

The generated HHO gas is collected by the water displacement method. The gas collection container initially filled with water and is placed as inverted cylinder in a reservoir of water. As the gas is created, it will displace water from the container. The volume of gas can be determined by the amount of water displaced by the gas. Electric currents are measured by an ammeter (0 to 30 amps AC/DC ammeter) and voltages are measured by a digital multimeter. The total experimental setup is presented in Fig.3.

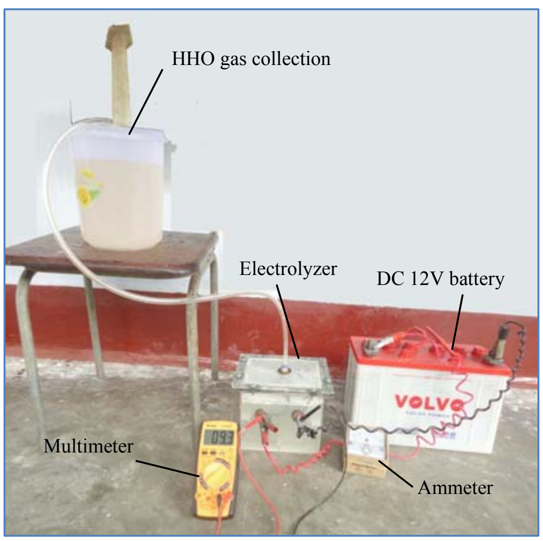

Fig.3. Total experimental setup

According to Natalia Chraplewska, Kamil Duda and Milosz Meus [15], the optimal voltage on the electrode is 1.48V, while the amount of the produced gas depends on the current strength. The volume of the produced gas for a single pair of plates - a cell can be estimated from the following equation [15],

$$V = \frac{R.I.T.t}{F.P.z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where,

V: volume of gas [m^3],

R: gas constant (≈ 8.314472$[\frac{J}{mol.K}]$),

I: current [A],

T: temperature [K],

T: time [s],

F: Faraday constant (≈ 96485.34$[\frac{C}{mol}]$),

P: ambient pressure [Pa],

z: number of excess electrons (2 for H_2, 4 for O_2).

According to (1), when connected to 14V voltage and 20A current strength in standard temperature and pressure conditions, a generator comprising 8 cells will produce 110 dm^3 of gas per hour [15]..

3. Results and discussion

As mentioned earlier, HHO gas production depends on the number of elcctrodes, strength of the electrolyte solution, inter-electrode gaps, amout of supplied current etc. During the experiment it has been observed that the regulation of the current flow into the cell is very important. It has also been experienced that this current regulation is not so easy and it requires to use another control circuit. However, this sort of current regulation control circuit has not been used in this study. Rather it has been tried to control by varying other parameters such as number of elctrodes, solution strength and inter-electrode gaps. The current flow is recorded between 7-10 amps for 2-electrodes cell and 15-18 amps for the 3-electrodes cell respectively indicating that as the number of electrodes increases, the current flow through the cell is also increased proportionately. However, the number of electrodes are kept to three intentionally, in order to avoid the overheating of the connecting wires. Current flow rate also increases with solution concentration as it enhances the conductivity of the solution in the cell. The experiment is started with two electrodes and eventually three electrodes are used for HHO gas generation. Figure 4(a) and 4(b) presents compare the gas production as a function of time and current flow for 2-electrodes and 3-3lectrodes for 0.5% KOH solution. It can be observed that the gas production increases sharply with time, but increases slowly with current flow rate and decreases for further increase in current flow rate. As shown, the cell with 3-electrodes produce HHO gas at a faster rate than the other cell. However, the current flow rate does not show significant effect on the gas production rate when compared between the two cells. The voltage is found to vary between 8-10V during the total experiment.

The current flow is increased upto 18 amps as the solution strength increases to 1.0% KOH. Figure 5 presents the same results but for the 1.0% KOH solution. The trend for both the curves in Fig.5(a) and 5(b) is found to be similar to those obtained in Fig.4(a) and 4(b). However, HHO gas production becomes even more faster for the 1% KOH solution cell than the 0.5% KOH solution cell indicating that the solution strength has a greater impact on the gas production. According to Fig.5(a), it takes almost one-third of the time period to produce the same volume of gas for the stronger solution as compared to the weaker solution cell. According to Fig.5(b), as the current flow increases, gas production rate first increases slowly and raises to a peak at around 17 amps and then evetually starts to fall for further increased currents. It also shows that as the number of electrodes increases from two to three, the gas flow rate increases by almost three times. It can generally be observed in these figures that the 3-electrode-cell dominates the HHO gas production rate when compared with the 2-electrode-cell. For the single annode and double cathodes cell with 1% KOH electrolyte solution about 2150 ml of HHO gas has been collected in 15 minutes of time period in this etudy.

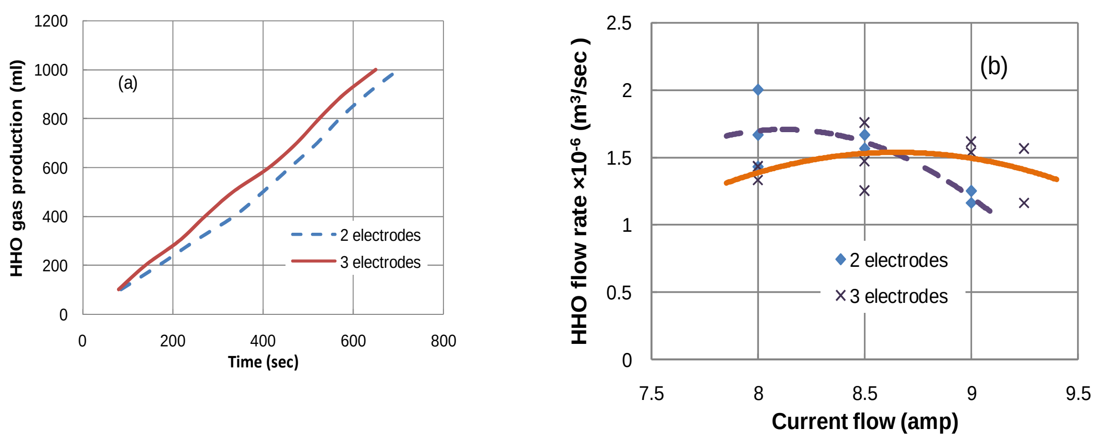

Fig.4. (a) HHO gas production (in ml) as a function of time and (b) HHO gas production rate (in m^3/s) as a function of current flow for 0.5% KOH solution.

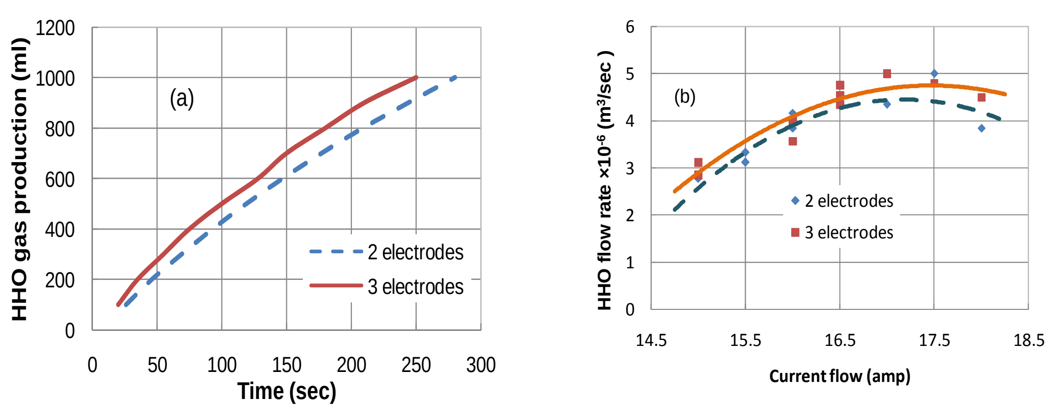

Fig.5. (a) HHO gas production (in ml) as a function of time and (b) HHO gas production rate (in m^3/s) as a function of current flow for 1.0% KOH solution.

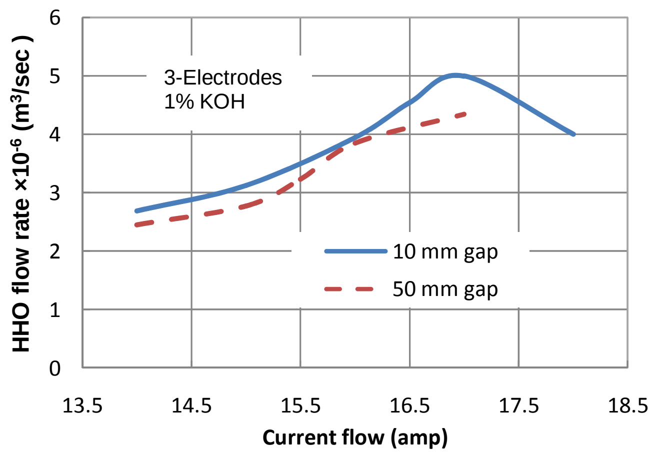

Fig.6 represents the effect of inter-electrode gaps on the gas collection rate or production rate for the 3-electrode cell with 1% KOH electrolyte solution. It can be observed from the figure that as the inter-electrode gap decreases from 50 mm to 10 mm, the current flow increases for the cell. As the current flow increases in the cell, the HHO gas production rate is also high for lower inter-electrode gap arrangements. One thing is to be noticed that at higher current flow (such as at 18 amp), the gas production rate falls as there develops a layer of unknown solid materials on the electrolyte solution (perhaps from the impurities existed in electrode materials) creating a barrier to gas flow.

Although it is planned before to do the elementary analysis, heating value, pour point and flash point determination of HHO gas, eventually they are not performed due to the unavailability of necessary laboratory facilities. However, the combustibility of the produced gas has been tested manually. The gas is fired using a torch and a substantial explosion has been experienced indicating the sudden oxidatiob reaction of the HHO gas. HHO gas is found to explode with a heavy sound (BOOM!) during the firing which proves the explosiveness property of HHO and hence it needs an extra care for handling.

4. Conclusions and Recommendations

The main aim of the project is to conduct an experimental investigation of alkaline water electrolysis for the purpose of HHO gas production. The total investigation has covered the effects of solution concentration, number of electrodes, current flow and space between the pair of electrodes on the production of HHO by alkaline water electrolysis. An electrolyzer for HHO gas generation has been successfully designed and constructed. The study has been carried out under atmospheric pressure using stainless steel electrodes and KOH as electrolyte. The current flow is measured between 7-10 amps for 2-electrodes cell and 15-18 amps for the 3-electrodes cell respectively indicating that as the number of electrodes increases, the current flow through the cell is also increased proportionately. The experimental results have showed that the performance of alkaline water electrolysis unit is dominated by operational parameters like the current flow, alkaline solution strength and the gap between the electrodes. Generally 3-electrode-cell has produced more gas than the 2-electrode- cell which indicates that the HHO gas production is directly proportion to the number of electrodes. However, it is limited to the control of the current flow through the cell for safer operation. The production rate of HHO gas has been observed to increase with increasing solution strength and current flow. It takes almost one-third of the time period requires to produce the same volume of gas for the stronger solution as compared to the weaker solution cell. Smaller gaps between the pair of electrodes increase the current flow which results in an enhanced production rates of HHO. For single anode and two cathodes, 1% KOH solution concentration provides 2150 ml of HHO gas from 15 minutes from 100ml of water. The followings can be recommended for further development:

- Problems have been experienced to maintain a uniform DC current flow through electrolyzer. So, a current flow controlling device is highly recommended in order to maintain the desired current flow. It would also provide opportunities then to increase the number of electrodes more than three (say 8-10).

- Electrolyzer container should be highly leakproof.

- A device can be recomanded that can act as a stirrer for the electrolyte solution in order to provide a uniform concentration throughout the cell.

- There should be a temperature controlling device attached with the system in order to avoid any internal damage caused by the elevated temperatures.

- A gas reservoir can be attached to the system for storing HHO gas which would be convenient to supply for any useful purpose such as engine applications.

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