Generation of Brown Gas as an Alternative Fuel for Combustion Engines

Parthib Majumdar [a], Sachin. S. Deshmukh [b], Manav Pande [c], Amir Hussain [d]
[a] *Student, Shri Ramdeobaba College of Engineering and Management, Nagpur*
[b] *Associate Professor, Shri Ramdeobaba College of Engineering and Management, Nagpur*
[c] *Student, Shri Ramdeobaba College of Engineering and Management, Nagpur*
[d] *Student, Shri Ramdeobaba College of Engineering and Management, Nagpur*
[a-d] *Department of Mechanical Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur*

Abstract: -The overuse of fossil fuels and the resulting drastic increase in pollution levels has made us realize the requirement for a new sustainable fuel that does not cause pollution. This search has ended up with an innovative idea of using HHO/Brown gas as a fuel enhancer in internal combustion engines which uses fossil fuels as a primary source for combustion. Many developments have been made in this area with several experiments on both gasoline and diesel internal combustion engines till now using HHO gas or brown gas as a fuel performance enhancer. This work involves reviewing various developments that have taken place in this field. With the addition of HHO gas, there was a net increase in brake power range and an increase in brake thermal efficiency ranges. A decrease in specific fuel consumption will be obtained with a decrease in CO and HC emissions. The HHO/Brown gas generation is done through water electrolysis, producing oxy-hydrogen gas that has two-thirds of hydrogen and one-third of oxygen. The experiment maintained constant speed but varied the engine load, adjusting the amount of HHO gas injected at three different amperages (1, 2, and 3 amps) with a 12-volt DC supply.

Keywords: HHO, Brown Gas.

Research Roadmap: -

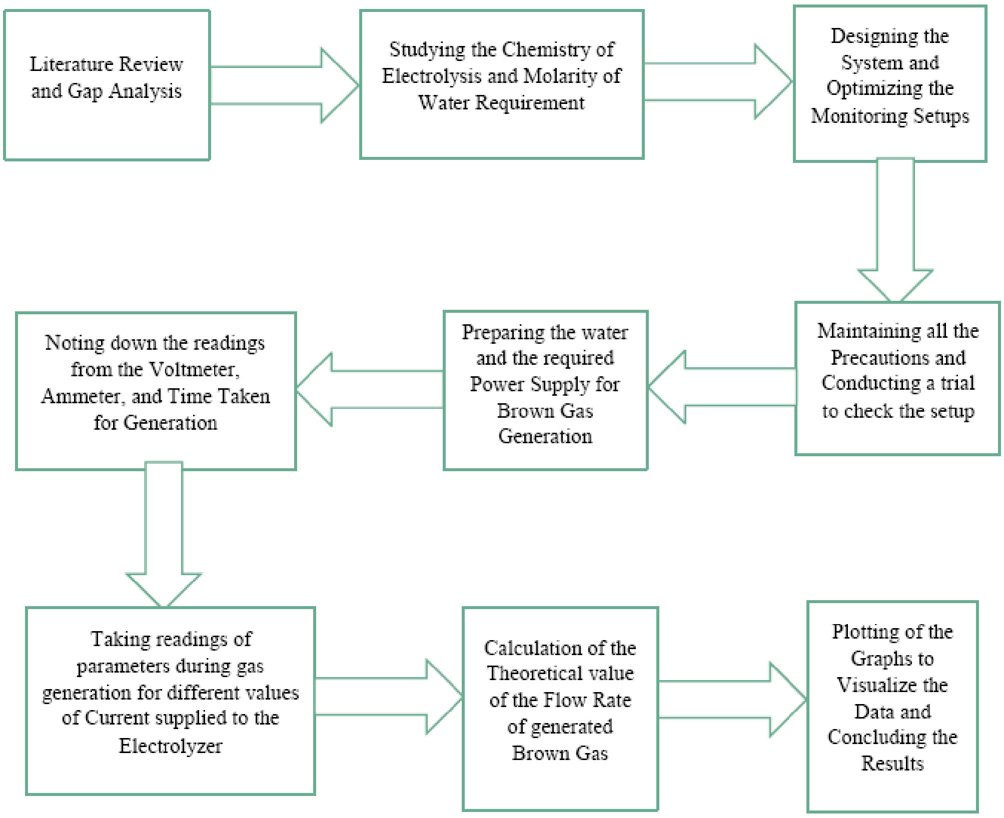


Fig 1 - Research Roadmap of Brown Gas Generation

1. INTRODUCTION

The decline in petroleum fuel demand due to limited non-renewable resources has significantly led to a rise in crude oil prices. This rise in costs has not only directly affected consumers, who've seen increased expenses at fuel pumps, prompting a shift towards more fuel-efficient vehicles, but also the giant conglomerates who are in the crude oil refinery business, who are shifting to the generation of energy through renewable sources. Researchers are also exploring alternative fuels, with pressurized hydrogen gas in internal combustion engines showing promising benefits like increased engine power and reduced exhaust emissions to a great extent. Efforts are being made to develop fuel supply systems capable of creating a gasoline and hydrogen gas blend, optimizing engine performance.

Despite technological advancements, gasoline-powered internal combustion engines remain the best choice for both consumers and automakers. Unless there's a substantial increase in gasoline prices or a proper network of availability of a sustainable fuel resource, it's unlikely that newer technologies will overtake gasoline-fuelled engines by certain timelines like 2020 or 2030. Market forces, like a significant rise in gasoline prices, might prompt the adoption of alternative fuels like diesel or ethanol, potentially coupled with hybrid-electric technology. However, the pursuit of new technologies and fuels is primarily driven by regulatory mandates rather than consumer demands. Such a gap between societal goals and individual preferences justifies government regulations, especially in emissions control, alternative fuel usage, and fuel economy standards. Regulators are enforcing stricter emission standards and encouraging the adoption of alternative fuels to reduce dependence on imported petroleum and lower emissions. While regulators can influence automakers and fuel suppliers through penalties and restrictions, convincing consumers to embrace these changes remains challenging. Consumer acceptance of new propulsion systems or fuels would require superior performance, efficiency, or a significant drawback in current fuels, such as high greenhouse gas emissions.

2. LITERATURE REVIEW

Brown gas, often referred to as "oxyhydrogen" or "HHO," is a mixture of hydrogen and oxygen gases produced via water electrolysis. Unlike standard hydrogen production, Brown gas contains a stoichiometric mixture of two parts hydrogen (H_2) and one part oxygen (O_2). This gas has garnered attention in various fields due to its potential applications in combustion, energy generation, and even as a fuel supplement. The interest in Brown gas is primarily driven by its clean combustion properties, producing water vapor as the only byproduct. Rusdiansari, Yohandri Bow, and Tresna Dewi [5], conducted research solely focusing on the variation of electrolyte concentrations used and how much electric current was applied to Brown Gas (HHO) generation. Variations of electrolyte concentrations and applied electric current were conducted to see the relation between those parameters and the HHO gas produced, and finally, the best setup was achieved to get the highest volume of HHO gas by electrolysis.

Munther Issa Kandah [3], factors affecting the efficiency of water electrolysis such as the electrolyte type, electrode spacing, electrode surface morphology (smooth or rough), electrode effective area (or a number of electrodes), and electrode connection configuration were investigated. The efficiency was calculated as the ratio between the HHO flow rate measured experimentally to that measured theoretically from Faraday's law. It is found that the best efficient electrolyzer consists of 22 plates (4 anodes, 4 cathodes, and 14 neutrals) where each plate area was 17x15 sq. cm.

TS De Silva, L Senevirathne, and TD Warnasooriya [10], research mainly focused on finding an efficient configuration of an ordinary HHO generator that is efficient than an ordinary system. Here the generator was tested under several conditions in order to determine a convenient design for an efficient HHO generator. An efficient/optimal system is supposed to produce a large volume of Hydroxy gas using very little power. They found out that HHO generator is an efficient approach that is used to increase the fuel efficiency in an Internal Combustion Engine by increasing the energy produced per mole of fuel during the ignition process. As a result, unburnt fuel in combustion engines is reduced.

B. Sivakumar, S.Navakrishnan, M.R. Cibi, and R. Senthil [11], contributed to constructing a dry hydroxy cell generator that generates Brown Gas, which is usually known as hydroxy gas. The primary catalyst used is lye (NaOH) and caustic potash (KOH), which is to be incorporated with stainless steel and followed by supplying a unidirectional current. The reaction is accelerated since the catalyst offers a proxy pathway to expedite the response. The law of electrolysis of Faraday governs this process. To lower the consumption of fossil fuels, which is the primary root cause of pollution. This dissertation provides detailed scrutiny of brown gas generators and their best harvest, which is known to be the highest production volume of HHO gas.

3. HHO GAS AS A CLEANER FUEL SOURCE

Oxy-Hydrogen, over wide temperature, and pressure ranges, has very high flame propagation rates within the engine cylinder in comparison to other fuels. Unlike other fuels, brown gas can be generated on-demand and on-site, reducing the need for storage and transport. Although it is possible to run an engine solely on brown gas, this is less common due to its low energy density compared to traditional fuels and the high energy cost associated with its production. However, the lean operating limit of a spark ignition engine using oxyhydrogen/Brown gas is much lower than other common fuels, which ensures stable operation and lean mixture control of oxyhydrogen-fueled engines. Lean burn operation provides high production efficiency due to the rapid rate of combustion energy release near the top dead center, which is caused by the very rapid combustion of the brown gas/air mixture. Of course, such lean operation also results in a loss of power, regardless of engine size.

Furthermore, when operating lean, NO levels are generally significantly lower than with other fuels. The rapid burning characteristics of oxyhydrogen fuels result in more satisfactory engine performance at high revs. This reduces the penalty for running lean and increases power output, and because hydrogen has a very low boiling point, there are fewer issues when operating in cold climates.

Sr. No.	Property	Hydrogen	Petrol (Gasoline)
1.	Calorific Value	120000kJ/Kg	44400kJ/Kg
2.	State	Gaseous	Liquid
3.	Residue	No Residue	Residue Present
4.	Self-ignitiontemperature	570℃	280℃ - 300℃

Table 1 - Properties of Brown Gas compared to Petrol (Gasoline)

It is a mixture of 2/3 of hydrogen and 1/3 of oxygen bonded together molecularly. It is generally produced by electrolysis of water. When electric current passes through water it divides into hydrogen and oxygen. The hydrogen and oxygen rise from the liquid water as gas. This gas is called HHO gas or Brown's gas.

Oxy-hydrogen (HHO) gas is produced in a common-ducted electrolyzer and then sent to the intake manifold to be introduced into the combustion chamber of the engine. Oxy-hydrogen gases will combust in the combustion chamber when brought to their auto-ignition or self-ignition temperature. For a Stoichiometry mixture at normal atmospheric pressure, auto-ignition of oxy-hydrogen gas occurs at about 570°C (1058°F). The minimum energy required to ignite such a mixture with a spark is about 20 microjoules. At normal temperature and pressure, 'oxy-hydrogen gas' can burn when it is between about 4 and 94% hydrogen by volume. When ignited, the gas mixture turns into water vapor and releases energy. The amount of heat generated does not depend on the combustion method, but the temperature of the flame changes. The maximum temperature is around 2800 ° C reached with a pure stoichiometry mixture, about 700°C hotter than a hydrogen flame in air. Oxy-hydrogen gas has very high diffusivity. This ability to disperse in air is considerably greater than gasoline and it is advantageous for mainly two reasons. First, it facilitates the formation of a homogeneous air-fuel mixture and secondly, if any leak occurs it can disperse at a rapid rate. Oxyhydrogen gas is very low in density. This results in a storage problem when used in an internal combustion engine.

4. METHODS OF GAS GENERATION

There are two general methods that are used in this research work for the generation of oxy-hydrogen gas. The first method makes use of the basic principle of Faraday's law. The power source is connected to two electrodes or two plates, usually made of an inert metal such as platinum or stainless steel, that are placed in water. In a properly designed cell, hydrogen appears at the cathode (the negatively charged electrode where electrons enter the water) and oxygen appears at the anode (the positively charged electrode). Assuming ideal faradaic efficiency, the amount of hydrogen generated is twice the number of moles of oxygen and both are directly proportional to the total electrical charge conducted by the solution. Following are the reactions that normally take place at the cathode and anode:

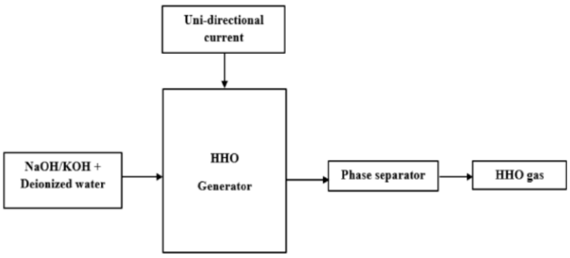


Fig 2 - Schematic Diagram of HHO Gas Generation

Cathode (reduction): 2 H, + 2c- → H, + 2 OH
Anode (oxidation): 4 OH- → 02 + 2 H,0 + 4 e-
Overall reaction: 2 H20 → 2 H2 (g) + 02 (g)

The second method uses a direct current pulse (usually a square wave output) to create a resonance within the water molecules between the electrodes. This change in the natural vibration frequency of the water creates an enormous electrical force that breaks the hydrogen-oxygen bonds, releasing them as magnetically bound gas molecules. Needless to say, in both methods, we have used an electrolyzer for the generation of the oxy-hydrogen gas.

5. EXPERIMENTAL SETUP AND PROCEDURE

Figure 3.1 shows the schematic diagram of the experimental system. The experiment was on an HHO production system where gas was generated by a dry cell using a 12-volt external DC supply. The generated HHO is then passed through a fire trap container before it is introduced to the engine via the air inlet manifold. The current controller and PM are employed to control the current fed to the electrolytic cell. A flask was used to measure the amount of distilled water to be mixed with electrolyte and put inside the bubbler. A Rheostat (Rh) was also there to monitor the current flow into the electrolyzer used to electrolyze the water for gas generation.

Fig 3 - HHO Gas Generation Setup

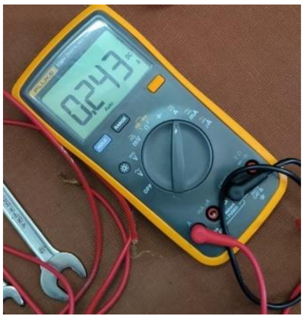
Fig 4 - Power Supply Control Setup

The setup that has been used in the experimentation for Brown/HHO Gas generation is a very simple setup made up of a bubbler, an electrolytic cell, an AC-DC converter with a pulse width modulator, some pneumatic wires, and pneumatic connectors.

Electrolytic Cell Maker	Hydroxy
Rated Voltage	12 V
Current	1-25 A DC
DC Power Supply Maker	Tridev Rain Proof 12V, 25 A, 300 W DC Switching
Pneumatic Pipes and L Shaped Threaded Connectors	10 mm in diameter
Rheostat	30-ohm, 2 A

Table 2 - Generation Setup Specifications

Image of the Devices	Name of the object in the image	Description
	Electrolytic Cell	The electrolytic cell represents the most important component of the system. It works on the principle of electrolysis of water to dissociate it into hydrogen and oxygen.

	DC Power Supply	A 12V DC supply was provided across two end plates providing a voltage of 2V per electrolytic compartment (a threshold value of 1.48V was always met). KOH was used as the electrolyte to increase the conductivity of water.
	Pneumatic Connector	Connectors or fittings are used to join pipes, hoses, or tubes in a pneumatic system, ensuring the proper and leak-free transfer of air. The connectors used over here are threaded L-shaped pneumatic connectors (also called elbow fittings) are essential for changing the direction of airflow in pneumatic systems while maintaining a secure, leak-proof connection.
	Pneumatic Pipes	Pneumatic pipes transport compressed air from one part of the system to another. These pipes are usually made from materials that are lightweight, durable, and resistant to corrosion. Common materials include - Polyurethane (PU), Polyethylene (PE), Nylon (PA), Poly polyvinyl chloride (PVC), and metals.
	Rheostat	A rheostat is a type of variable resistor used to control the flow of electric current by adjusting resistance. It typically consists of a coil of resistive wire with a slider or knob that moves along the coil, allowing for changes in resistance.
	Ammeter	An ammeter is a device used to measure the electric current in a circuit. Current, measured in amperes (A), flows through the ammeter, which is connected in series with the circuit components. To avoid altering the current flow, an ammeter is designed with a very low resistance.

	Voltmeter	A voltmeter is an instrument used to measure the electric potential difference (voltage) between two points in a circuit. Voltage, measured in volts (V), is an essential parameter in understanding the energy per unit charge available in an electrical circuit.

Table 3 - Detailed Description of Every Device Used in the Research

HHO production system broadly comprises four components namely the electrolytic cell, bubbler, pneumatic pipes L-shaped pneumatic threaded connectors, and DC Power Supply. The system produced HHO gas which was supplemented along with the gasoline to the engine. A brief description of each component of the HHO production system is given below. An HHO production system generates a mixture of hydrogen (H_2) and oxygen (O_2) gases through the process of electrolysis of water (H_2O). This system is often referred to as a "hydrogen-on-demand" system because it produces hydrogen and oxygen gases only when needed, without storing large amounts of either gas. The mixture of H_2 and O_2 is sometimes called "Brown's gas" or HHO.

Prepare an electrolyte solution by adding KOH into distilled water solution and make ready it for the production of HHO/Brown gas. Ensure that the jar in which the mix will be prepared is completely dry. Also, check that the electrolyte taken from the box must be put immediately into the water since it is highly reactive and being in contact with air might lead to exothermic reactions. The solution which has been prepared to be put inside the bubbler is made by keeping a constant molarity.

Then with no change in experimental condition, 1 ampere & 12 volts DC supply was introduced to the electrolytic cell. This is leading to the generation of HHO gas. The gas is not generated directly, but by the constant flow of water mixed into the electrolytic cell, ultimately leading to gas formation within about 30 to 40 seconds then the gas generation is checked by the bubbles emerging from the pipe outlet which has been kept in a water-filled jar (till the bottom), whose other end has been fixed at the top of bubbler to allow the gas to escape. After 1 ampere, it is charged with 1.5 amperes and then 2 amperes at 12 volts DC supply. The current variation has been done with the help of a Rheostat, keeping the voltage constant. Accounting, a total of five readings were taken for every current value, by increasing both the water and electrolyte amount, keeping in mind to have a constant molarity, i.e. both are mixed in a proportional amount.

6. OBSERVATIONS AND CALCULATIONS

Sr. No.	Amount of water used for preparing the mixture in ml	Amount of Potassium Hydroxide mixed with water in g	Concentration of the Solution in M	Time taken for the gas to be generated in sec	The flow rate of gas that has been coming out in LPH
1.	200	5	0.445	74	14.395 x 10^{-3}
2.	300	7.5	0.445	105	20.418 x 10^{-3}
3.	400	10	0.445	125	25.370 x 10^{-3}
4.	500	12.5	0.445	169	32.850 x 10^{-3}

Table 4 - Observation table for gas generation at 1 ampere current supply

Sr. No.	Amount of water used for preparing the mixture in ml	Amount of Potassium Hydroxide mixed with	Concentration of the Solution in M	Time taken for the gas to be generated in sec	The flow rate of gas that has been coming out in LPH

		water in g			
1.	200	5	0.445	60	16.598 x 10^{-3}
2.	300	7.5	0.445	82	23.234 x 10^{-3}
3.	400	10	0.445	98	28.510 x 10^{-3}
4.	500	12.5	0.445	125	33.290 x 10^{-3}

Table 5 - Observation table for gas generation at 1.5 amperes current supply

Sr. No.	Amount of water used for preparing the mixture in ml	Amount of Potassium Hydroxide mixed with water in g	Concentration of the Solution in M	Time taken for the gas to be generated in sec	The flow rate of gas that has been coming out in LPH
1.	200	5	0.445	50	19.015 x 10^{-3}
2.	300	7.5	0.445	68	26.051 x 10^{-3}
3.	400	10	0.445	85	31.920 x 10^{-3}
4.	500	12.5	0.445	96	36.173 x 10^{-3}

Table 6 - Observation table gas generation at 2 amperes current supply

According to Faraday's first law of electrolysis, the mass of a substance deposited on an electrode surface is directly proportional to the amount of current that flows through the system at Standard Temperature and Pressure (STP).

For this experiment, this formula can be represented mathematically to derive the theoretical volume of HHO gas created during the electrolytic process as follows:

The mass of substance deposited (m) α to the quantity of current (Q)

$$m = Z\,Q \qquad (1)$$

Where Z is called the electrochemical equivalent (ECE) and Q= I * t.

But the ECE,

$$Z = \frac{M}{F * V} \qquad (2)$$

Here 'M' is the atomic weight of the element, v is the valency of the element in its ionic form, and F is Faraday's constant given as 96,485 C/mol.

Putting (2) into (1) gives

$$m = \frac{M * Q}{F * V} \qquad (3)$$

Therefore, the mole of H2 or O2 deposited can be expressed as:

$$n = \frac{m}{M} = \frac{Q}{F * v} \qquad (4)$$

Finally, putting (4) into the Universal Gas Equation; PV = nRT, gives equation (5) below.

$$V = \frac{R * T * I * t}{F * P * z} \qquad (5)$$

Where:
V = volume of the gas produced in liters
R = the ideal gas molar constant = 0.0820577 l*atm/(mol*K)
I = current (A), T = temperature (K)
t = time (sec)
F = Faraday’s constant = 96,485 Coulomb/mol
P = ambient pressure (atm)
z = number of excess electrons (2 for H2 and 4 for O2).

Assumptions: -

P = 1atm
z = 2 for Hydrogen and 4 for Oxygen
T = 32ºC = 305 K
R = 0.0820577 l*atm/ (mol*K)

$$\text{Volume of hydrogen gas produced} = \frac{0820577 * 305 * 1 * 74}{96{,}485 * 1 * 2} = 9.597 \times 10^{-3}\ LPH$$

$$\text{Volume of oxygen gas produced} = \frac{0820577 * 305 * 1 * 74}{96{,}485 * 1 * 4} = 4.798 \times 10^{-3}\ LPH$$

the total volume of HHO gas produced = volume of hydrogen gas produced + volume of oxygen gas produced will be:

$= 9.597 \times 10^{-3}\ LPH + 4.798 \times 10^{-3}\ LPH$

$= 14.395 \times 10^{-3}\ LPH$

7. RESULTS AND CONCLUSION

In this investigation, the generation capacity of the Electrolytic Cell has been studied to determine how much HHO gas can be generated with variation in solution and current supplied. Hence, the flow rate of the HHO mixture was varied to obtain the optimum amount of gas that can be produced with different amounts of solution of water + KOH (the fuel source for Brown Gas generation) and with different currents of l ampere, 1.5 ampere, and 2 amperes. In this experiment, the HHO mixture was generated using a 12-volt external power DC supply.

Figure 5.1 shows how the concentration of KOH varies with the generating rate. The concentration of potassium hydroxide (KOH) plays a significant role in the generation rate of Brown Gas, a mixture of hydrogen (H_2) and oxygen (O_2) produced through the electrolysis of water. In an electrolytic cell, KOH is often used as the electrolyte to increase the water's conductivity, facilitating the electrolysis process. Here's how varying KOH concentrations can affect Brown Gas production. With increased conductivity, the rate at which water molecules are split into H_2 and O_2 rises, leading to a higher Brown Gas production rate.

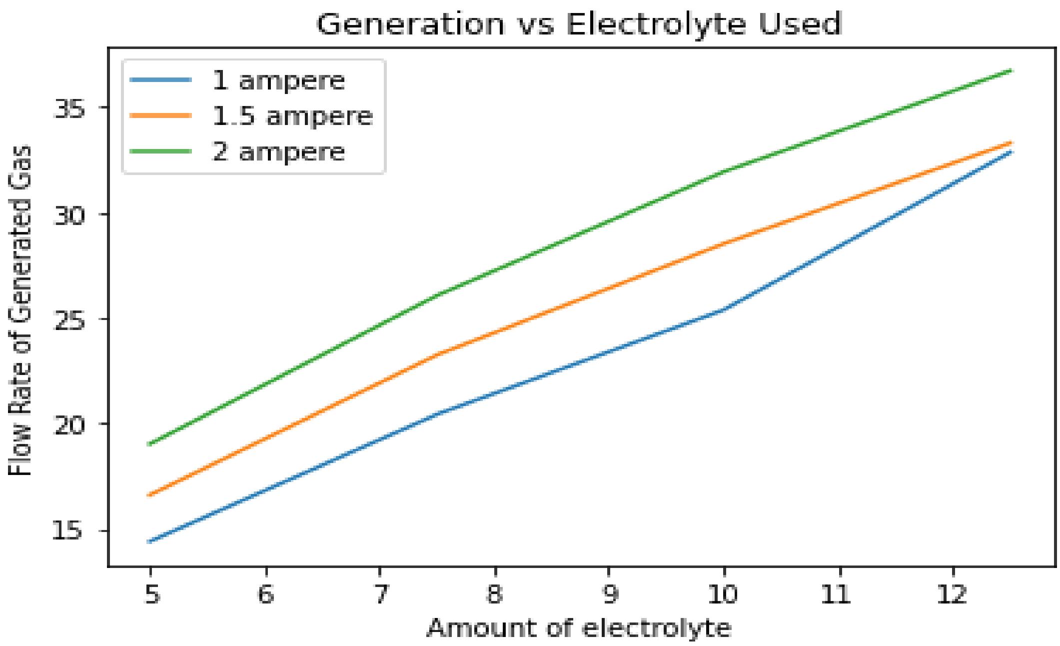


Fig 5 - Variation of flow rate vs amount of electrolyte used at different current supply

Time is extremely important in this method because it is completely focused on providing hydrogen gas into the engine instantly, without the need to store the gas in temperature-controlled tanks. The rate of Brown Gas (hydrogen and oxygen gas) production during electrolysis changes over time due to different parameters within the electrolytic cell, such as electrolyte temperature, electrode wear, and ion concentration. Current has a substantial effect on the time required to produce a specific amount of HHO gas (Brown Gas) through electrolysis, as it directly influences the production rate. Higher current increases the rate at which HHO gas is generated, meaning it takes less time to produce a specified volume of gas. This relationship follows Faraday's laws of electrolysis, which state that the quantity of substance produced at an electrode is proportional to the electric charge (current × time) passing through the electrolyte. If the current is doubled, the time to produce the same volume of HHO gas is approximately halved, assuming all other factors (e.g., electrolyte concentration, temperature, electrode surface area) remain constant.

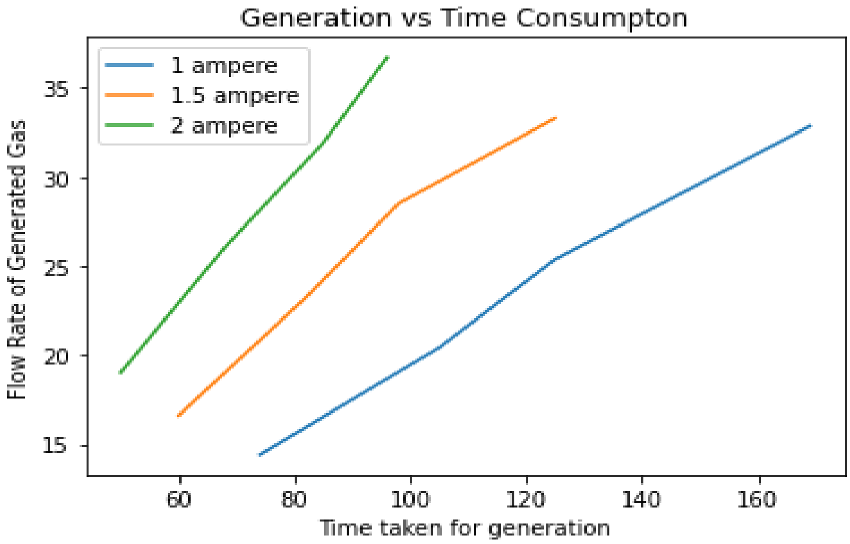


Fig 6 - Variation of time and flow rate at different current supplies with the same concentration of impure water

The amount of water in an electrolytic cell has several impacts on the generation of HHO gas (Brown Gas), as it is the primary source of hydrogen and oxygen atoms in the electrolysis reaction. Here's how water volume and availability affect gas production. The electrolysis of water splits water molecules (H_2O) into hydrogen and oxygen gases. A sufficient amount of water is required to maintain a constant supply of these molecules for HHO gas production; hence water has a direct function in HHO gas formation. As electrolysis continues, water molecules are consumed, progressively diminishing the water volume in the cell. If the water level becomes too low, gas production will slow down or stop entirely. The amount of water in an HHO generator directly influences the gas production rate by impacting electrolyte concentration, temperature stability, and electrode immersion. Maintaining optimal water levels ensures continuous, efficient gas generation and minimizes downtime due to water depletion or concentration imbalances.

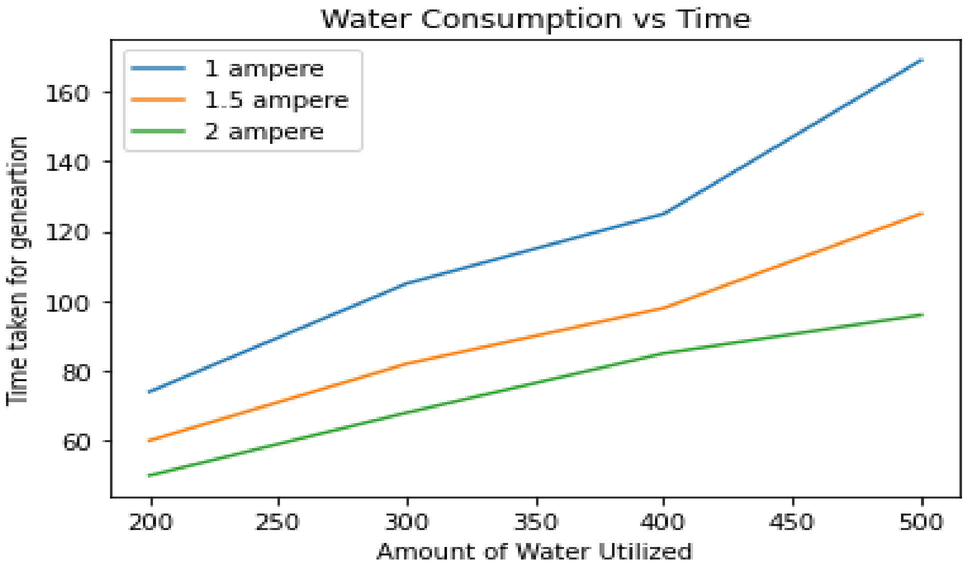


Fig 7 - Variation of time concerning water consumption at different current supply

The following are the conclusions from the results obtained after experimentations while running an HHO gas generation setup at different concentrations of water and electrolyte mix, keeping the molarity constant and also at different amperes of current, keeping the voltage constant. The optimum results were obtained at 2 ampere 12V DC supply -

1. At 2 amperes 12-volt DC, the flow rate of generated HHO gas increased about 20% - 30% in

comparison to 1 ampere current generation and 10% - 15% in comparison to 1.5 amperes supply. The generation variation between the corresponding readings, means readings correspondingly at 1, 1.5, and 2 amperes have a variation of 10% - 15%. At 1 ampere 12-volt DC, the generation rate is the lowest in comparison to the other two and highest at 2 amperes 12-volt DC as we can observe in Fig. 5.1 and 5.2, showing that the higher the power supply more will be the generation rate, eventually more brown gas will be released from the generation system.

2. The time variation showcases here that the faster the generation rate, the lower the time needed by the electrolyzer. As we observe in Fig. 5.2, the more the power supply, the greater the flow rate of gas generated and the lesser the time needed to generate HHO gas. In Fig. 5.3, the more the power supply, the less time is required for gas generation. The time decreases by 21% - 25% for corresponding current supply records, which means for 1 and 1.5 amperes 12-volt DC supply, simultaneously for 1.5 and 2 amperes 12-volt DC supply as well. For the highest and lowest values of power supply, the time decreases by 30% - 35%, leading to a 30 % increase in the flow rate of HHO gas, keeping the electrolyte concentration the same for all generation runs.

Therefore, it is concluded that if higher is the amount of power supplied to the electrolyzers, more will be the disintegration rate of water molecules into hydrogen and oxygen atoms (basically ions over here) and the process of HHO gas generation will increase by about 25% - 30%.

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List of Figures