

Design and Development of an Oxyhydrogen Generator for Production of Brown's (HHO) Gas as a Renewable Source of Fuel for the Automobile Industry

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Abstract: This research work seeks to design and develop an oxyhydrogen generator for HHO gas production. Key parameters considered in this study include electrode area, electrodes spacing, electrodes surface conditioning, and electrode configuration as well as the efficiency of the generator. The constructed generator consisted of 26 plates made up of 3 anodes, 3 cathodes and 20 neutral plates with each having dimension of 10cm x 10 cm. The adjacent plates were spaced at a distance of 2 mm. The efficiency of the constructed generator was evaluated using 0.01 M-0.03 M strengths of KOH at a constant voltage of 13 V. The Results showed an optimum efficiency of 11.9 % when the HHO generator was run using 0.02 M KOH at 13 V for 1 hour.

Keywords: HHO gas, Rectifier, Stainless Steels (ST316), Electrolyte, Rubber gasket

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Highlights:

1. Designing an HHO generator
2. Development of an HHO generator
3. Determination of the efficiency of an HHO generator using KOH as a catalyst

I. Introduction

Electrolysis of water for hydrogen production has been employed industrially since the 19th century (Barton & Gammon 2010). In a typical electrolysis process, current is passed through water dosed with a calculated amount of catalyst in an electrolyser. The current supplied to the electrolyser dissociates water into hydrogen and oxygen gases which are collected together as a mixture called Brown's (HHO) gas (Afgan & Veziroghu, 2012). Industrial applications of HHO gas include; welding and cutting of metals, used as a supplementary fuel to conventional fuels to reduce the concentrations of pollutants emitted from the combustion chamber of diesel and petrol engines.

Currently, electrolysis of water is considered as a promising technique for producing a clean and sustainable source of energy as the process uses water as the main raw material to produce HHO gas without emission of pollutants into the environment (Le et al. 2010). In this regard, the production of oxyhydrogen without fossil fuel-based processes is one suitable alternative solution that can be used (Corbo et al. 2010). Electrolysis of water takes place in a reactor called oxyhydrogen generator or an electrolyser. The electrolyser basically consists of metal electrodes called anode and cathode which conduct electric current (Petrov Y. et al., 2011). These electrode plates are separated by a non-conducting material called gasket. The essence of gaskets found between the electrolyser plates ensures leakage free of electrolyte and HHO gas (Gramia et al., 2007). The entire electrolyser is housed in a transparent plexi-glass sheet. Other significant auxiliary parts include a reservoir tank and a bubbler. The reservoir tank contains the electrolyte solution which feeds the generator while the bubbler serves as a safety device. This type of electrolyser is called a dry cell oxyhydrogen generator. With a wet type generator, the stacked plates without the plexi-glass cover are inserted into a container containing the electrolyte solution for the electrolytic process.

Literature survey undertaken (2014-2017) shows limited research into the production of oxyhydrogen generators using metals such as platinum, gold, stainless steel plate, graphite, and lead. Other limited areas reviewed include parameters such as temperature, pressure, electrolyte type, electrode configuration and spacing, the electrical resistance of the electrolyte, electrode material, and properties, and bubble phenomena that affect the operation of an HHO generator. However, the design of oxyhydrogen generators has not been studied.

A.L. Yuvaraj, and D. Santhanaraj, 2014 did a systematic study on the electrolytic production of hydrogen gas by using graphite as an electrode. In their experiment, they connected two cylindrical rods of Stainless Steel 316 L with uniform dimensions of diameter 20 mm and length 80 mm. The electrodes were separated by 2mm and were subsequently connected to a bridge rectifier to convert AC to DC for the generator operations. In addition, Nikhil Narayan 2014 studied the performance and emission characteristics of oxyhydrogen gas on a three-cylinder four stroke petrol engine. The HHO gas electrodes were made up of SS 316 L of thickness 15 gauge wire which was spiraled and glued around a core of acrylic. The HHO generator was subsequently equipped with air bubbler adjuster and electric terminals for electricity supply as well as outlet valves. The study also used high-density polyethylene as external plate cover due to its high strength to density and non-corrosive nature. Similarly, an onboard production of hydrogen gas for power generation was studied by Nikhil. Joshi and Deepak Naik, 2015. In their study, the HHO generator was constructed using SS 316 L plate of thickness 1 mm. The electrodes were cut into dimensions of 6" by 2.5 ". The plates were then tightened together with screws and capped with PVC. The end PVC caps served as electrode terminal and passage for HHO gas outflow. Ahmad H. Sakhrieh et al., 2017 investigated the optimization of oxyhydrogen gas flow rate as a supplementary fuel in compression ignition combustion engines. In their experiment, they built the HHO generator using 316L Stainless Steel plates made up of 43 plates separated by 16 silicon gaskets. The outer ends of the arranged electrodes were covered with CPVC transparent plates. The generator was designed to achieve a voltage of 2.3 V between two successive plates by placing 5 neutral plates between every negative and positive plate. The entire set-up was completed by the addition of a reservoir tank that supplied electrolyte solution to the generator and a bubbler which condenses the water vapor that comes alongside with the HHO gas. The comparative analysis of performance characteristics of CI Engine with and without HHO Gas (Brown Gas) was evaluated by Ghulam Abbas Gohar and Hassan Raza, 2017. In this, the HHO generator was developed using 29 Stainless Steel (SS) plates. The plates were further separated with a Jain sheet with the entire reactor fitted with SS bolts and nuts.

This study, therefore, seeks to establish the main design principle of an HHO generator. The development, as well as other factors such as the efficiency of the generator, studied in other works would also be considered in this present work.

II. Methodology

2.1 Materials

Metal marker, metal ruler, brass metal bolts and nuts, 2mm EPDM rubber gasket, 12mm transparent acrylic sheet, two insulated copper cables, HPTE reservoir tank, PVC bubbler bottle, braided pipe hose, 90° Anderson Brass Metal Fittings, epoxy glue, carpenter glue, sandpaper of grit 40, KOH pallets, 2000 cm³ volumetric flask, and Spatula

2.2 Equipment

Metal cutting machine, drilling machine, Analytical balance and rectifier

Table 1. Specification of used metal cutting machine

| Parameter | Description |
|----------------------|---|
| Plasma model | HPR-130XD, HPR-260XD, HPR-400XD/cutting thickness up to 40 mm |
| Plasma height sensor | Hypertherm ArcGlide |
| Flame cutting system | Auto ignition/capacitive height sensor/cutting thickness 60mm |
| Nesting software | SIGMA NEST X1 |

Table 2. Specification of rectifier

| | |
|----------------------------|--------------|
| Length | 20cm |
| Width, Height | 10 cm, 14 cm |
| Rated voltage | 0 V-16 V |
| Rated current | 0 A-13 A |
| Incorporated safety device | Breaker |

Table 3. Specification of the used drilling machine

| Parameter | Description |
|----------------------------|---|
| Spindle servo motor | Servo motor 30 HP |
| Spindle tapper | BT 50 |
| Spindle rpm | 200-2000 rpm |
| Drilling diameter capacity | 6-50 |
| Tapping capacity | M8-M30 |
| Tool length | 170-300 mm |
| Cooling system | Internal coolant mist & External coolant mist |

| | |
|-------------------------------|----------------|
| ATC magazine | Stationary ATC |
| Chip cleaning mechanism | Standard |
| Chip collecting tank | Standard |
| Cutting dross collecting tank | Standard |

2.3 Preparation of Electrolyte strength

1.12 g of KOH were placed in a clean 2 L volumetric flask containing 500 cm³ distilled water. The flask was corked and placed in a sonicator for 10 minutes. The contents in the flask was topped up with distilled water to the 2 L meniscus mark to obtain 0.01 M KOH. The flask was labeled V₁ and was sonicated for additional 5 minutes to ensure homogeneity. The procedure was repeated to prepare 0.015M, 0.02M, 0.025M, and 0.03M KOH as indicated in Table 4.

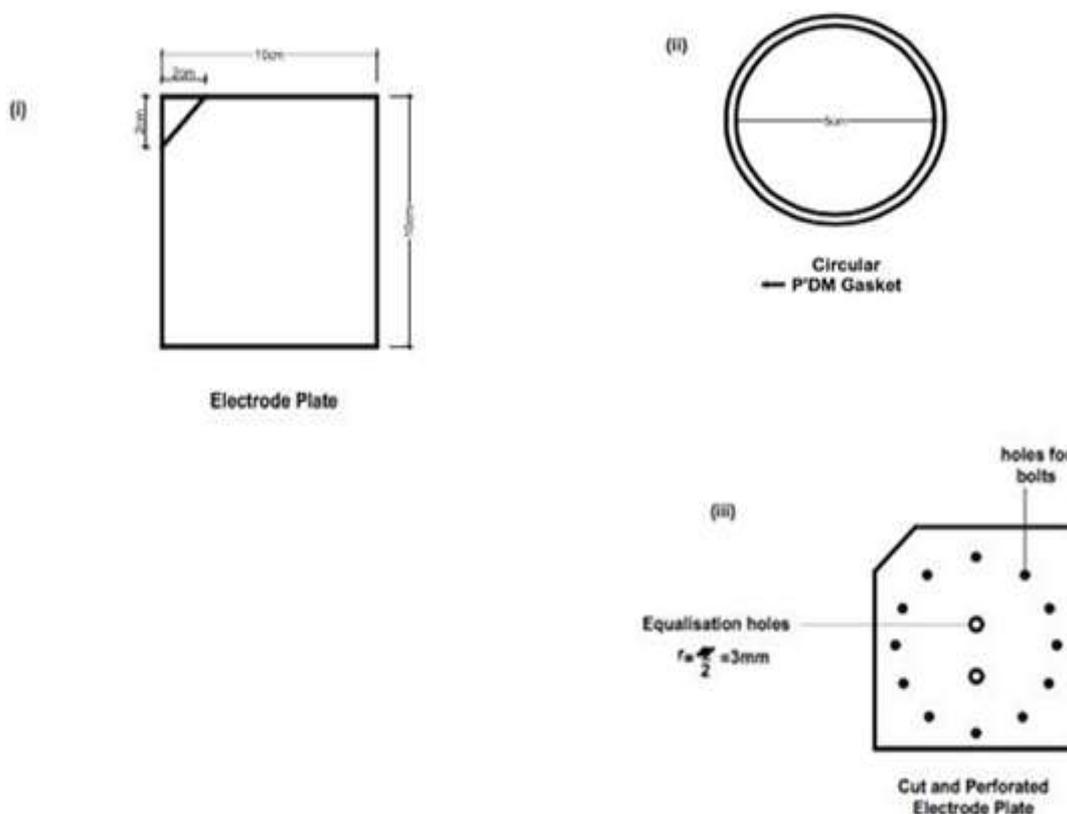
Table 4.KOH strengths

| Mass of KOH weighed (g) | Strength of KOH (M) |
|-------------------------|---------------------|
| 1.12 | 0.010 |
| 2.24 | 0.015 |
| 3.36 | 0.020 |
| 4.48 | 0.025 |
| 5.60 | 0.030 |

2.4 Designing the oxyhydrogen generator

2.4.1 Cutting of metal electrodes

Stainless steel plate (SS) 316 L of thickness 20 gauge was selected for this experiment among platinum and nickel based on economic analysis. 26 square plates consisted of 6 electrodes and 20 neutral plates of dimensions 10 cm x 10 cm were cut out of a SS 316 L plate. Two liquid level equalization holes each of radius 3 mm were drilled in each of the 26 plates for passage of electrolyte and HHO gas. The electrode surfaces was conditioned by rubbing it with a coarse sandpaper of grit 40. Circular gaskets (20 No.) of diameter 5 cm was cut out of an Ethylene Propylene Diene Monomer (EPDM) rubber of thickness 1.6 mm. Two 12 cm x 12 cm x 1.2 cm high transparency acrylic sheets were cut and each was fitted with one 90° Anderson Metal Brass Hose Fitting (0.5 in Barb x 0.5 in Male Pipe) as shown in Figure 1.



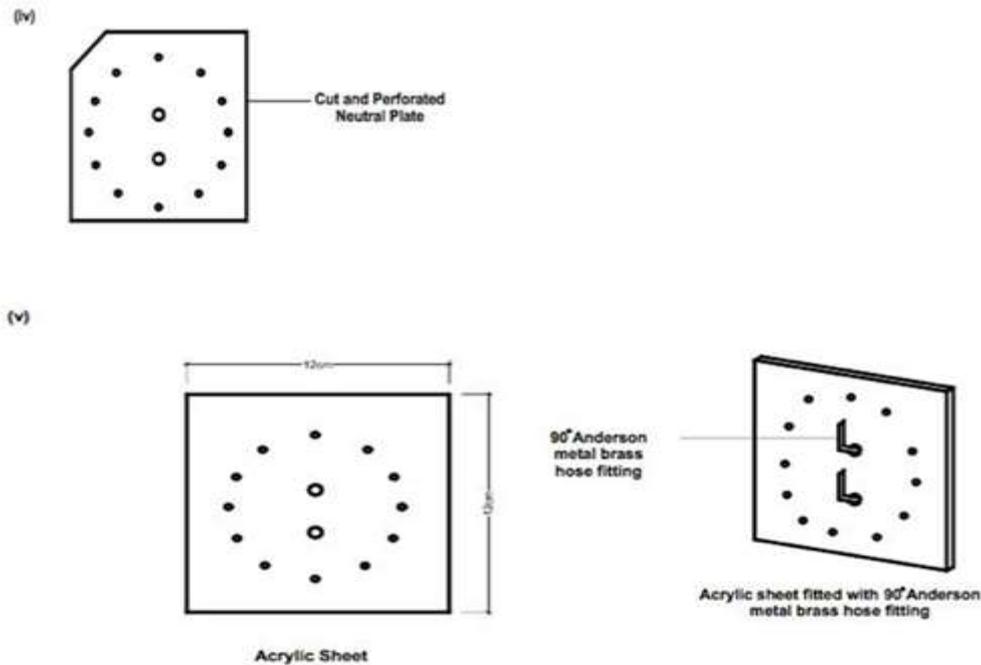


Figure 1. Cuts components of HHO generator

2.4.2 Calculating the required voltage across two successive electrode

To work within the optimal voltage range of 1.25 V to 2.7 V, four neutrals were chosen. For this experiment, a potential difference of 13 V was used. This was selected using an adjustable rectifier. The voltage between two successive plates in the constructed oxyhydrogen generator was calculated using the formula below;

$$V_n = \frac{V_0 n}{[n^2 + [(2n - q - 1)d]}$$

Where V_0 is the applied voltage supplied, n is the number of neutral plates proposed for use, d is the common difference derived from the number of plate's series and q is the correction factor given by $(n-d)$. The values of n , d , and q were derived from table 5 below.

Table 5: Deduced experimental values for calculating expected cell potential

| | | | | |
|---------|---|---|---|-------|
| n-value | 1 | 2 | 3 | n_z |
| d-value | 1 | 1 | 1 | d_z |
| q-value | 0 | 1 | 2 | q_z |

The required voltage was therefore calculated as;

$$V_4 = \frac{13.4}{[4^2 + [(2 \times 4 - 3 - 1)1]} = 52 / 20 = 2.6 \text{ V}$$

Where, the values of n , d , and q used were 4, 1 and 3 respectively.

2.4.3 Building the oxyhydrogen generator

Figure 2 shows the step-wise arrangement used in the construction of the HHO generator. Each plate was fitted with one circular rubber gasket of diameter 5 cm using carpenters glue. To achieve the calculated 2.6 V described in section 2.4.2, the electrodes was arranged such that four neutral plates were placed between two successive electrodes to achieve a configuration of 3 anodes and 3 cathodes respectively. Each of the 12 cm x 12 cm x 1.2 cm high transparency acrylic sheets fitted with one 90° Anderson Metal Brass Hose Fitting (shown in Figure 1) was placed behind the externals of the electrodes and was tightened together using brass bolts, nuts, and washers. An auxiliary bubbler (fitted with 2 Anderson Metal Fittings) and a reservoir tank (fitted with 3 Anderson Metal Fittings) were positioned at a height above the constructed HHO generator. Finally, the fitted Anderson Elbows on the acrylic sheets and the reservoir tank were connected using braided PVC hose having inside and outside diameter of 0.25 in and 0.5 in respectively.

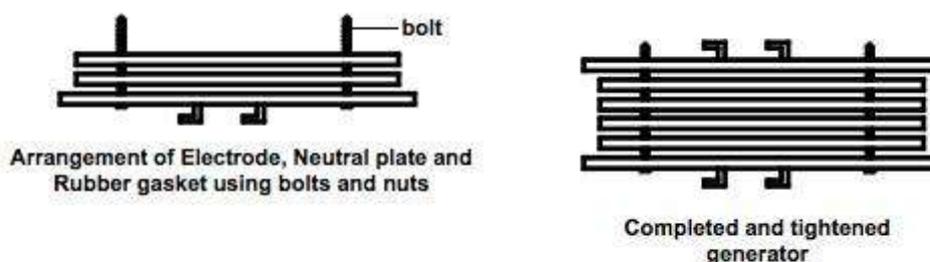


Figure 2. The step-wisearrangement of the oxyhydrogen generator electrode plates

The completed oxyhydrogen generator is shown in figure 3.



Figure 3. Front view of the oxyhydrogen generator

III. Results And Discussion

3.1 Result

Results of the investigations conducted in the present work are presented and discussed in this session.

Table 6. The efficiency of the built oxyhydrogen generator using 0.01-0.03 M KOH run at 13V at 32 °C

| Description | | | | |
|--------------------------|---------------------|------------------------|-----------------------------|----------------|
| Concentration of KOH (M) | Ammeter reading (A) | Actual Flow rate (LPH) | Theoretical Flow rate (LPH) | Efficiency (%) |
| 0.030 | 9.68 | 16.416 | 151.88 | 10.8 |
| 0.025 | 8.71 | 15.120 | 136.55 | 11.1 |
| 0.020 | 6.71 | 12.528 | 105.19 | 11.9 |
| 0.015 | 4.84 | 8.352 | 75.88 | 11.0 |
| 0.010 | 3.74 | 6.048 | 58.63 | 10.3 |

3.2 Discussion

3.2.1 Calculating the efficiency of the constructed oxyhydrogen generator

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 the purpose of this experiment, this law can be expressed mathematically to deduce the theoretical volume of HHO gas produced during the electrolytic process as follow;

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

This implies $m = ZQ$ (1)

Where, Z is called the electrochemical equivalent (ECE) and $Q = It$.

But the ECE ($Z = M/Fv$), (2)

where '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 $m = (MQ)/(Fv)$ (3)

Therefore, the mole of H₂ or O₂ deposited can be expressed as $(n) = m/M = (Q)/(Fv)$ (4)

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

$$V = \frac{R.T.It}{F.P.Z} \quad (5)$$

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 (s), F = Faraday's constant = 96,485 Coulomb/mol, P = ambient pressure (atm), and z = number of excess electrons (2 for H₂ and 4 for O₂).

Therefore, at Standard Temperature and Pressure (STP), running theoxyhydrogen generator at a current of 1 A for one hour, where T = 0°C = 273 K, P = 1 atm and t = 3600 s, implies that the respective volumes of hydrogen gas and oxygen gas that can be produced during the electrolytic process are as follow;

$$\begin{aligned} \text{Volume of hydrogen gas produced} &= [(0.0820577.1.273.3600)/(96485.1.2)] \\ &= 0.4179211/\text{hour}/\text{Ampere} \end{aligned}$$

$$\begin{aligned} \text{Volume of oxygen gas produced} &= [(0.0820577.1.273.3600)/(96485.1.4)] \\ &= 0.208961 \text{ l}/\text{hour}/\text{Ampere} \end{aligned}$$

But the total volume of HHO gas produced = volume of hydrogen gas produced + volume of oxygen gasproduced

$$\begin{aligned} &= 0.417921 + 0.208961 \\ &= 0.6268821/\text{hour}/\text{Ampere} \end{aligned}$$

However, in the experiment, the volume of HHO gas produced and the current observed when the oxyhydrogen generator was run using 0.03 M solution of KOH for 50 seconds was 228cm³ and 9.68A respectively.

$$\begin{aligned} \text{Hence the experimental flow rate for the HHO gasproduced} &= (\text{Volume of HHO gas produced})/\text{time utilised} \\ &= (228/50) \times 3.6 = 16.416\text{LPH} \end{aligned}$$

Subsequently, the theoretical volume of HHO gas that can be produced using25 cells at a current and operating temperature of 9.68A and 32°C respectively can be expressed as;

$$V_{\text{theoretical}} = 0.6271 \times 9.68 \times 25 \times 0.895082 \times 1.1172 = 151.88\text{liters per hour}$$

Therefore, the efficiency of the constructed HHO gas generatorwas calculated using the formula;

$$\begin{aligned} \eta_{\text{(HHO gas generator)}} &= (\text{Actual HHO gas produced})/ (\text{Theoretical volume of HHO gas produced}) \\ &= (16.416)/(151.88) \\ &= 10.8 \% \end{aligned}$$

In a similar work, MuntherIssaKandahstudied the enhancement of water electrolyser efficiency in 2014. In his study, the HHO gas generator was constructed using 22 SS 316 L plates made of 4 cathodes, 4 anodes and 14 neutrals each of dimension 17 cm x 15 cm. The efficiency of the built generator was found to be 62.92 %. The difference in valuesbetween the observed efficiency of 10.8% and 62.92%could be attributed to the differences in electrode surface area and the number of anodes and cathodes used in the present study. This is because, operating with smallerelectrode surface area increased the electrical resistance and the rate of heat dissipation of the electrolytic system resulting in the observed decreasein efficiency of the HHO gas generator constructed. In addition, the decreasein number of electrodes (anodes and cathodes)used in the present experiment also decreased the effective surfacearea for oxidation and reduction reactionswhich subsequentlydecreased the volume of HHO produced and thereby contributed to the lower efficiency of the HHO generator constructed.

IV. Conclusion

The design and development of an oxyhydrogen generator for the production of HHO gas was studied. The generator was constructed using Stainless Steel plate 316 L made of 3 anodes, 3 cathodes, and 20 neutral plates. The experimental results obtained showed an optimal efficiency of 11.9 % when the oxyhydrogen generator was run using 0.02 M solution of KOH at a constant potential of 13 V for 1 hour.

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