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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, electrode 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 was spaced at a distance of 2 mm. The efficiency of the constructed generator was evaluated using0.01 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 dissociate water into hydrogen and oxygen gases which are collected together as a mixture called Brown's (HH0) 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 (Granıa 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 whiles 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) show 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 was 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 was 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 was then tightened together with screws and caped 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 was 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 their experiment, the HHO generator was developed using 29 Stainless Steel (SS) plates. The plates was 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 cm^3 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 cm^3 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 V_1 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.

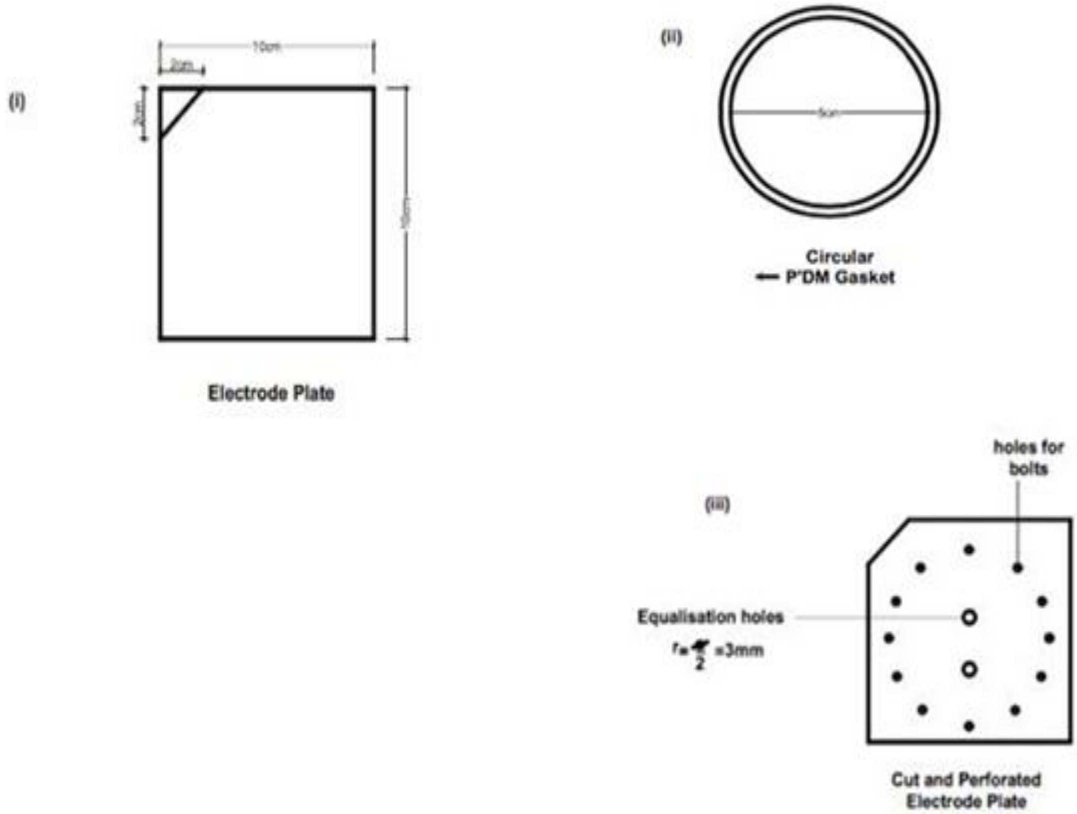
Table 4. KOH strengths

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 coarses and paper 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.



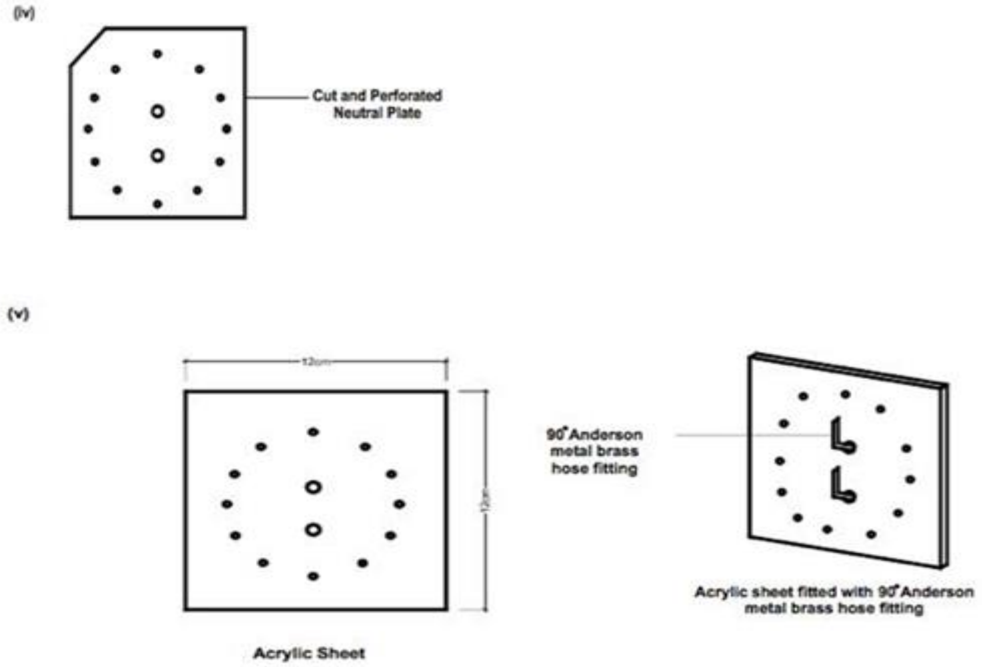


Figure 1. Cuts components of HHO generator

2.4.2Calculating 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;

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

WhereV_o 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_∞
d-value	1	1	1	d_∞
q-value	0	1	2	q_∞

The required voltage was therefore calculated as;

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

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.

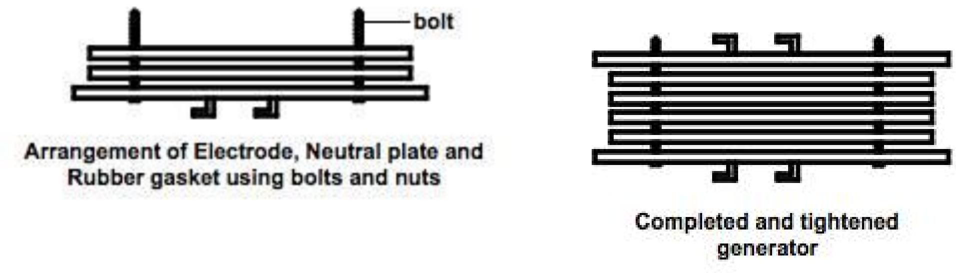


Figure 2. The step-wise arrangement of the oxyhydrogen generator electrode plates

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 = Z Q (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 H_2 or O_2 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.

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

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 H_2 and 4 for O_2).

Therefore, at Standard Temperature and Pressure (STP), running the oxyhydrogen 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;

Volume of hydrogen gas produced = [(0.0820577.1.273.3600)/ (96485.1.2)]
= 0.417921 *l*/hour/Ampere
Volume of oxygen gas produced = [(0.0820577.1.273.3600)/ (96485.1.4)]
= 0.208961 *l*/hour/Ampere
But the total volume of HHO gas produced = volume of hydrogen gas produced + volume of oxygen gas produced

= 0.417921 + 0.208961
= 0.626882 *l*/hour/ Ampere

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 228 cm^3 and 9.68 A respectively.

Hence the experimental flow rate for the HHO gas produced = (Volume of HHO gas produced)/time utilised
= (228/50) x 3.6 = 16.416 LPH

Subsequently, the theoretical volume of HHO gas that can be produced using 25 cells at a current and operating temperature of 9.68A and 32°C respectively can be expressed as;

$V_{theoretical}$ = 0.6271 x 9.68 x 25 x 0.895082 x 1.1172= 151.88 *l*iters per hour

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

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

In a similar work, Munther Issa Kandah studied 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 values between 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 smaller electrode surface area increased the electrical resistance and the rate of heat dissipation of the electrolytic system resulting in the observed decrease in efficiency of the HHO gas generator constructed. In addition, the decrease in number of electrodes (anodes and cathodes) used in the present experiment also decreased the effective surface area for oxidation and reduction reactions which subsequently decreased 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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