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A Review of the Effects of Plate Configurations and Electrolyte Strength on Production of Brown Gas Using Dry Cell Oxyhydrogen Generator

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ABSTRACT

The production of brown gas (HHO gas) performance depends on the attribute of the oxyhydrogen generator. However, it is found that the main issue in the production of brown gas is the complexity of the oxyhydrogen generator system, electrolysis efficiency and safety. Therefore, this paper presents a review of the factors that affect the production of brown including the types of electrode materials, plate configurations, types of electrolytes, and the concentration of electrolytes. Furthermore, this study is also conducted to find out what are the suitable condition for each parameter stated in the research when using a dry cell oxyhydrogen generator in the production of brown gas. Therefore, it is found that by increasing the number of neutral plates and electrodes, the production of brown gas increases. Besides, the ideal plate orientation is the vertical position, and the suitable gap distance between each plate is 2 to 3 mm. Furthermore, the larger the cross-sectional area of plate, the higher the production of the brown gas. Not to mention, the ideal electrolyte that boosts the production of the brown gas is potassium hydroxide (KOH). In addition, dry cell oxyhydrogen generators are more preferred in the production of brown gas as it is much safer and offers more benefits than wet cell oxyhydrogen generators. This further demonstrates that the attribute of the oxyhydrogen generator does influence the production of brown gas.

1. Introduction

Energy has been one of the most essential necessities of humanity in their regular lifestyle for generations. When people consider that many activities cannot be accomplished without energy, it is indeed clear that energy is essential which is becoming more important as technology evolves. As fossil fuels are used to generate energy and are finite, appropriate precautions must be taken to avoid future difficulties for the governments and the planet [1]. However, an increasing number of governments around the world are focusing on renewable energy, revising policies and laws to limit ecological damage, and exploring alternative energy sources [2]. Therefore, hydrogen is regarded as

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a non-polluting energy carrier and as it is generated from renewable sources, it does not cause global warming [3]. Furthermore, hydrogen has been the only secondary power source in the industry that suits a broad array of applications [4]. Hydrogen, unlike some other fuels, natural gas, and coal, is sustainable and non-toxic. Hydrogen has a lot of promise as an environmentally sustainable source and for lowering energy imports [5].

Oxyhydrogen gas, also known as HHO gas, is a chemical combination usually in a 2:1 ratio of Hydrogen (H) and Oxygen ($\mathrm{O_2}$), which is like water. Yull Brown created and developed hydroxy gas in 1977. Brown gas is another name for Oxyhydrogen gas. Brown gas has improved ignition efficiency, is easily available, is environmentally acceptable, burns quickly, and has a higher flame velocity [6]. Brown gas may produce flames with temperatures ranging from 150°C to 9000°C and above depending on the electrical conductivity, thermal conductivity, density, and vapour point of the contact materials [7]. Brown gas is also a colourless and odourless gas.

Brown gas is created when hydrogen and oxygen molecules combine [8]. Brown gas is also produced by electrolysis of water, which involves an electrical generator and two separators containing hydrogen and electrolyte. When an electric current runs through water, the water molecule is disrupted and splits into oxygen and hydrogen by a reaction between the positive and negative electrodes. The electric current may destroy the bond because water acts as an electrolyte [9]. During the water decomposition, heat is discharged into the environment at higher voltages. Heat energy is generally more affordable than electricity and may be recycled back within the process. Thus, operating the electrolysis at lower voltages with increased heat is beneficial. In addition, when the operating temperature rises, the electrolysis efficiency also rises.

The oxyhydrogen generator is a system that uses the electrolysis principle, which converts water into hydrogen and oxygen gas [10]. Based on their architecture, oxyhydrogen generators are classified as either wet cell or dry cell [11]. The generator consists of electrodes that separate water into oxygen and hydrogen which results in the production of brown gas [12]. In the production of brown gas, there are several parameters that are critical which influence the performance efficiency of brown gas production. The following are amongst the most important physical characteristics for producing brown gas, where these would be the main objective of this review paper to bridge the gap in configuring the oxyhydrogen generator in the production of brown gas [13]. They are

i. Types of electrode material
ii. Arrangement of plates
iii. Number of electrodes and neutral plates
iv. Gap between the electrodes
v. Cross-sectional area of the electrodes
vi. Types of electrolytes
vii. Amount of electrolyte

2. Factors that Influence the Brown Gas Performance

2.1 Types of Electrode Material

In general, most conducting materials could be used as electrode. However, not all conducting materials can produce better efficiency in brown gas production. Therefore, after conducting research and reviews, it is found that stainless steel is the most suitable conducting material for an electrode as it has excellent corrosion resistance, does not form any precipitation during electrolysis, and is environmentally friendly. On the other hand, stainless steel is affordable and easy to fabricate compared to graphite even though graphite has better physical properties. Copper has high material conductivity but easily corrodes and only reacts with sulfuric acid, H_2SO_4 and forms copper sulphate precipitate, which can cause blockage of pipes. Iron is the most affordable conductivity material among them and can be easily fabricate to different shapes and sizes, but the nature of iron is not suitable to be used as an electrode for electrolysis as precipitation happens when ion oxidizes in water and rust will be produced, which can contaminate the electrolytic solution. The conducting materials selected for comparison are stainless steel, graphite, copper, and iron, which are shown in Table 1.

Table 1
Types and characteristics of materials [13-17]

No.	Types of Materials	Characteristics
1	Stainless Steel	Excellent corrosion resistance
		Affordable compared to graphite
		Does not form precipitation during electrolysis
		Environmentally friendly
2	Graphite	Excellent material conductor
		High cost
		Does not react more compared to stainless steel
3	Copper	High material conductivity
		Easily corrode
		Only react with sulfuric acid, H_2SO_4
		Forms copper sulphate precipitate which can cause blockage of pipes
4	Iron	Low cost
		Offers a variety of shapes and sizes
		Good material conductivity
		Rust will be produced during electrolysis which contaminates the electrolytic solution

2.2 Effect of Arrangement of Plates on the Brown Gas Production

Table 2 shows the generator configuration, the number of neutral plates and the volume of brown gas produced. As the number of neutral plates increases, the volume of brown gas produced also increases. This is because the contact of the surface area for the electrolysis process increases when the number of electrodes increases. In addition, by adding more neutral plates between anode and cathode, the system's potential will also decrease. As a result, the temperature of the system will increase which further increases the ionic mobility and the effective number of collisions which could result in a significant increase in the volume of the brown gas produced [18]. Table 3 also shows the effect of various plate configurations which influence the production of the brown gas. It is found that as the number of neutral plates between the anode and cathode electrode increases, the volume of the brown gas produced increases but the current decreases [19]. If the electrodes are arranged vertically, the efficiency of the electrolysis of water increases which increases the production of the brown gas [8]. In addition, the polarity of the electrode in the arrangement of plates affects the production of the brown gas. Since the positive electrode is an anode, and the negative electrode is a cathode, the positive ions, which are hydrogen ions will be attracted to the cathode while the negative ions, which are oxygen ions will be attracted to the anode [20]. Based on the previous studies conducted by Essuman *et al.,* [21], the decrease in the number of electrodes (anode and cathode) decreases the effective surface area for oxidation and reduction reactions in the oxyhydrogen generator, which subsequently decrease the production of the brown gas. Therefore, adding more electrodes could increase the efficiency of electrolysis.

Table 2
Variation in the number of neutral plates in the production of brown gas [18]

Generator Configuration	Number of Neutral Plates (N)	Volume of Brown Gas Produced (cm^3)
3C3A	12	152
3C3A	16	176
3C3A	20	258

Table 3
Electrodes configurations on the production of brown gas [19]

Connection	Electrolyte (g)	Current (A)	Flow rate (ml/min)
5C5A0N	2.5	20	270
5C5A0N	5	38	490
5C5A0N	10	60	703
5C5A9N	5	20	403
5C5A9N	10	30	507
5C5A9N	15	45	660
3C3A10N	5	7	238
3C3A10N	10	11	352
3C3A10N	15	20	634

2.3 Effect of the Gap Between Electrodes on the Production of Brown Gas

Table 4 shows that the spacing between both anode and cathode influences the performance of the oxyhydrogen generator. As the electrode gap narrows, the flow rate of brown gas increases. This is because resistance is proportional to the distance between both the electrodes. Thus, by minimizing the distance, the resistance can be decreased. As decreasing the distance between the electrodes lowers resistance, the shortest path must be maintained to prevent the gap from breaking [22]. The oxyhydrogen generator's operating current is also affected in a way that as the gap narrows, current increases. However, a gap which is too narrow is not suitable as it influences the temperature due to the increase in current. Furthermore, the increase of narrow gap also increases the resistance of air to flow. Therefore, the distance between the two plates should not be less than 2 mm, as the brown gas bubbles will not pass through [16,23]. However, since it is very difficult to change the electrode spacing, the best spacing is between 2 mm to 3 mm [19]. Table 5 shows that as the distance between plates becomes narrower, the time taken for the current to increase becomes shorter.

Table 4
Spacing of electrodes on production of brown gas [22]

Number of Plates	Gap (mm)	Size of Plate (mm^2)	Current (A)	Flow rate (ml/min)
11	4	120 × 160	6	320
13	4	140 × 100	11	513
13	2	120 × 120	9	470
14	2.5	180 × 120	15	650
14	5	180 × 120	12	440
25	2	120 × 120	18	550

Table 5
Distance between plates against current on production of brown gas [11]

Distance Between Plates (mm)	Current (A)	Flow rate (ml/min)	Time Taken (min)
5	1.8	1000	20
2.5	6	1000	4

2.4 Effect of the Cross-Sectional Area of Electrodes on the Brown Gas Production

Table 4 shows that by increasing the cross-sectional area of the electrodes, the rate of brown gas production increases. This is because the large surface area of the electrode lowers the resistance. The diameter of the electrode rises instead of the height, as the latter increases the risk of void fracture [22]. The current density, defined in amperes per square metre, is the amount of current transmitted per unit cross-sectional area [24]. More gas is produced as the current density rises. The ion movement and the effective number of collisions increase as the temperature increases. The anticipated field of the electrode can be adjusted by changing the size of the electrode surface. The production of brown gas is caused by ion mobility in the electrolyte solution. The form of the electrode will change the effective area or surface, resulting in increased gas production performance. In addition, effective surface area influences the production of hydrogen and oxygen bubbles. The larger the surface area of the electrodes, the higher the chance of water molecules to decompose and form hydrogen and oxygen gas [25].

2.5 Effect of Electrolyte on the Brown Gas Production

Table 6 shows the different types of electrolytes in the production of brown gas [18]. It has been proven that the greater the alkali content is, the more hydrogen is created. In addition, compared to the electrolyte in pure water, it increases the conductivity and reactivity rate of the water dissociation. Among the three electrolytes shown, potassium hydroxide (KOH) generates the highest volume of brown gas compared to sodium hydroxide (NaOH) and sodium bicarbonate ($NaHCO_3$). This could indicate that each catalytic mechanism base is slightly different, but this is supported by the fact that in the presence of KOH, the activation energy of every test is greater.

Table 7 shows the difference in molarity of the potassium hydroxide (KOH) in the production of the brown gas. As the electrolyte concentration increases, the production of brown gas also increases. This is because the effective ionic collision per unit time increases as the molarity of the electrolyte increases [18]. As the concentration of electrolytes increases, the conductivity of the solution also increases, which increases the current flow in the solution. This causes the solution to produce a larger current [10]. In addition, the concentration of the electrolytes also depends on the demand of the flow rate of brown gas. However, according to Sun and Hsiau [26], adding too much concentration of electrolyte does not increase production of brown gas. This is because the concentration of electrolytes influences the conductivity of the liquid. As the concentration of electrolyte is too high, the conductivity of liquid decreases, resulting in decreased electrolysis efficiency.

Table 6
Types of electrolytes on the production of brown gas [18]

Types of Electrolytes	Electrolyte Strength (M)	Volume of Brown Gas Produced (cm^3)
Potassium Hydroxide (KOH)	0.030	83.3
Sodium Hydroxide (NaOH)	0.030	74.0
Sodium Bicarbonate ($NaHCO_3$)	0.030	24.5

Table 7
Variation of electrolyte concentration on the production of brown gas [10]

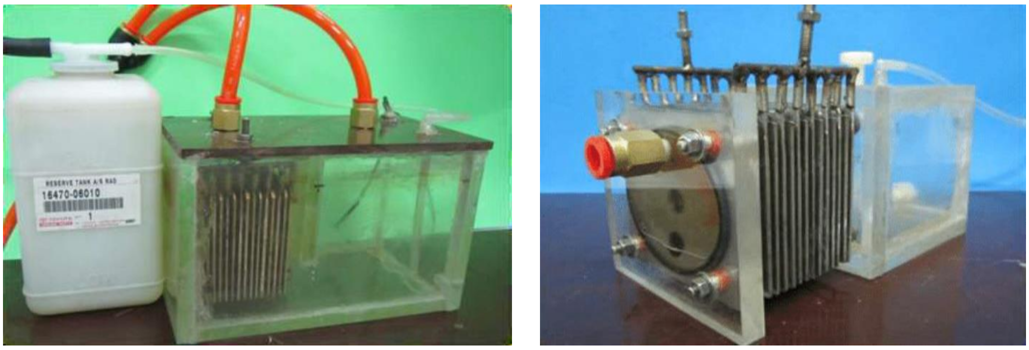
Electrolyte Concentration (M)	Current (A)	Flow rate (ml/min)
0.1	4.1	216.7
0.2	5.0	277.0
0.3	6.4	332.0
0.4	7.1	414.7

2.6 Wet Cell and Dry Cell

Table 8 shows the summary of the comparison between wet and dry cells oxyhydrogen generators based on past research [27,28]. In a wet cell, the electrodes are encased in water and immersed in the electrolyte. The numerous benefits of dry cells include increased gas output, more flexibility, simplicity in maintenance, and ease of manufacture. A wet cell, on the other hand, has limitations due to the fact that it uses more current, generates more heat, and permits corrosion via the positive electrode [28]. Therefore, the dry cell is introduced to address the issues with the wet cell. The reservoir's circulation of hot and cold water reduces the amount of heat produced. This is because less power is converted to heat and less electric current is used overall. The dry cell is a compact design that helps modern engines and lowers the frequency of maintenance [29]. Additionally, a dry cell does not need to be submerged in an electrolyte solution-filled reservoir. As the wires attached to dry cell electrodes are not in touch with the electrolyte, the system will not be harmed if a spark occurs at the connection between the wire and the electrodes. This makes dry cells considerably safer than wet cells. Only the gap between the electrodes is filled with electrolytes, and the reaction process only takes place inside the closed electrodes [30]. Figure 1(a) shows the wet cell oxyhydrogen generator while Figure 1(b) shows the dry cell oxyhydrogen generator.

Table 8
Comparison between wet and dry cells [27,28]

Wet Cell	Dry Cell
Requires more electrolytes	Require less electrolytes
The whole cell is immersed in the electrolyte	The electrolyte is filled in the cell
Shorter lifespan of plates	Longer lifespan of plates
More space consumption	Less space consumption
Not very safe to use as electrical connection is immersed in the electrolyte	Very safe to use as electrical connection is not immersed in the electrolyte



(a) (b)

Fig. 1. Comparison of wet cell and dry cell oxyhydrogen generator; (a) Wet cell oxyhydrogen generator, (b) Dry cell oxyhydrogen generator [27]

3. Conclusions

Brown gas (HHO) appears to be the best solution for alternative fuels and is produced through the electrolysis process. The production of brown gas is influenced by various parameters including the types of electrode materials, the plate configurations, types of electrolytes, and the concentration of electrolytes. In conclusion, stainless steel is the ideal material for an electrode used in electrolysis. Additionally, as the number of electrodes (anode and cathode) and neutral plates (between anode and cathode) increases, so does the production of brown gas. Besides, the vertical position is the ideal plate orientation. The best current and brown gas output are produced when there is a gap of between 2 to 3 mm between each plate. As the electrode's cross-sectional area increases, the resistance of the electrode reduces, increasing the current and, thus, brown gas is formed. Potassium hydroxide (KOH) is the ideal electrolyte for boosting the production of brown gas as it has an improved catalytic mechanism for the bases. Due to the solution's increased conductivity, the brown gas generation increases as electrolyte concentration rises. In addition, dry cell oxyhydrogen generators are preferable in producing brown gas since they are safer and offer more benefits than wet cell oxyhydrogen generators.

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