



Research article

HHO Gas Production Rate at Different Electrode Plate Configurations and NaOH and KOH Electrolyte Concentrations

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ABSTRACT

This study assessed the efficacy of the HHO gas generator concerning the quantity of electrode plates and varying electrolyte concentrations, specifically NaOH and KOH. The HHO gas production rate during electrolysis exhibited variations with electrolyte concentrations of 2%, 4%, 6%, 8%, and 10%. The configurations of the electrode plates utilized comprised two, four, and six stainless-steel plates. The experimental findings indicated that the KOH electrolyte continuously surpassed NaOH, particularly at elevated concentrations, where increased electrolyte levels significantly enhanced the HHO gas production rate. Optimal conditions were achieved by employing six electrode plates with a 10% potassium hydroxide solution, equivalent to 66.67 grams per 600 milliliters of distilled water, yielding a maximum gas generation rate of 6.9 ml/s. Moreover, hydrostatic pressure study indicated that elevated electrolyte concentration and an increased number of electrode plates directly correlated with enhanced gas production and pressure.

1. INTRODUCTION

The increasing worldwide climate disaster calls for a change to alternative fuels that significantly reduce emissions, such natural gas, hydrogen, and biofuels derived from many different renewable sources [1], [2], [3]. Because of its abundant availability, high energy density, and environmentally benign combustion producing only water vapor as a product, hydrogen is a strong candidate for alternative fuel [4]. Electrolysis has become one of the most environmentally friendly and sustainable methods of hydrogen production, as it effectively dissociates water molecules into hydrogen and oxygen through the use of

electrical current [5], [6].

Through the addition of electrolytes such as NaOH and KOH, the performance of electrolysis can be enhanced. These electrolytes increase the electrical mobility of the solution as well as the rate at which hydrogen is generated [7], [8]. Ofori et al. [9] investigated how well KOH, NaOH, and NaHCO₃ as electrolytes in the production of HHO gas. The most gas was made by KOH, which was 245.7 mL (0.250 M). NaOH came in second with 180.6 mL, and NaHCO₃ was the least efficient, making only 20.0 mL. Varying KOH's equipment, such shown by Ridhwan et al. [10] allows to improve hydrogen generation using KOH by changing electrode plate surface textures, hence improving the performance of an HHO generator. The work looked at how changing KOH concentrations together with variable electrode surface textures affected a hybrid wet-dry cell HHO generator. Results showed that output current, gas generation rates, and operating timeframes were much better with increased KOH concentrations and altered plate textures. In particular, the lowest operating time (112.25 s) and greatest gas production rate of 267.26 L/min were obtained with the linear surface texture. Using stainless-steel electrodes and a KOH electrolyte solution, Mutlag et al. [11] built a hydrogen gas wet cell, hence generating hydrogen brown gas using the electrolysis concept. At 16 amps, 18 seconds, with a KOH content of 2.5 g/l, their best performance attained an efficiency of 11.72 ml/min/W. One can also improve the use of KOH by changing its configuration setting, as shown by Mousa et al. [12] which assessed the effect of applied voltage (10.5–13.0 V) and electrolyte concentration (0.05–0.20 M KOH) on the performance of an HHO gas generator. At 12.0 V and 0.10 M KOH, optimal conditions were found to produce the most output (343.9 cm³/min), minimum specific energy (3.43 kWh/m³), and best efficiency (53.79%).

Previous studies have demonstrated that HHO gas production rates are greatly increased by raising electrolyte content and improving electrode designs. Still, even with current studies, complete practical application situations still under-researched, especially for components like electrode plate designs and hydrostatic pressures seen in actual operations. This study aims to address the under-researched interplay between electrode plate configuration and electrolyte concentration, NaOH and KOH, under realistic hydrostatic conditions. By doing so, it contributes valuable experimental insights toward the development of more scalable and energy-efficient hydrogen generation systems.

However, while numerous studies have reported the benefits of varying electrolyte concentration or modifying electrode surfaces individually, there remains a lack of integrated investigation that systematically analyzes the combined effects of electrode plate configurations and electrolyte concentration on HHO gas production, especially under realistic hydrostatic pressure conditions simulating practical applications. Most existing literature has yet to comprehensively evaluate the interplay of these two parameters using common electrolytes such as NaOH and KOH. Therefore, this study aims to fill this research gap by experimentally investigating how different electrode plate numbers and a range of NaOH and KOH concentrations affect the HHO gas production rate and hydrostatic pressure. The outcomes are expected to provide essential data for optimizing future HHO generator designs with improved efficiency and scalability.

2. METHOD

This study investigates the use of NaOH and KOH as electrolytes, evaluating their performance under varying concentrations and electrode plate configurations. This study used identical techniques, configuration, electrolyte concentration, and electrode plate count as prior NaOH investigations [13]. Each concentration was varied employing two, four, as well as six stainless steel plates as electrodes. The rate of HHO gas production per second is quantified using a 25 ml measuring cylinder in the data collection technique with an input of 3V DC electricity for the HHO generator's operation. Figure 1 illustrates the experimental setup, including the placement of the electrodes, electrolyte container, inverted cylinder, and power supply.

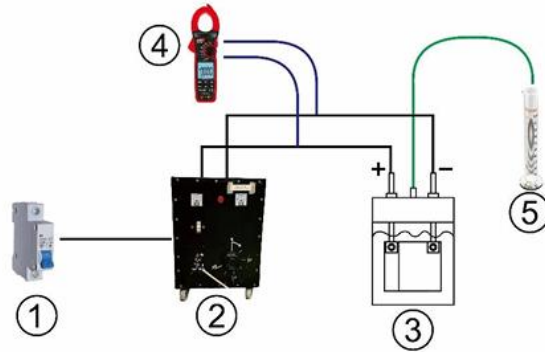


Figure 1. Research Setup [13].

Gas is passed through an upside down measuring cylinder drowned in water to measure HHO gas production. To calculate gas production rate, the volume of water transferred is collected at 10-second periods at three separate times to assure the data consistency. Hydrostatic pressure is used in this investigation because HHO gas needs to surpass water pressure to move inside the column. Equation 1 is employed to ascertain the hydrostatic measurement.

$$P_h = \rho g h \quad (1)$$

The symbols ρ (water density at 1000 kg/m^3), g (gravity acceleration at 9.81 m/s^2), and h (gas flow rate in ml/s) show the removal of water during HHO gas production. The graduated cylinder's column of water pressure keeps HHO gas from escaping, so the gas production rate in this arrangement is based on real-world pressure.

To ensure the replicability of the results, each experimental condition was repeated three times under identical setups, and the average values were reported. All instruments, including the measuring cylinder and DC power supply, were calibrated prior to the experiments to maintain measurement accuracy. Moreover, data consistency was checked by calculating standard deviations of the measured gas production rates, which remained within $\pm 5\%$ across all replications, confirming the validity and repeatability of the data collection process.

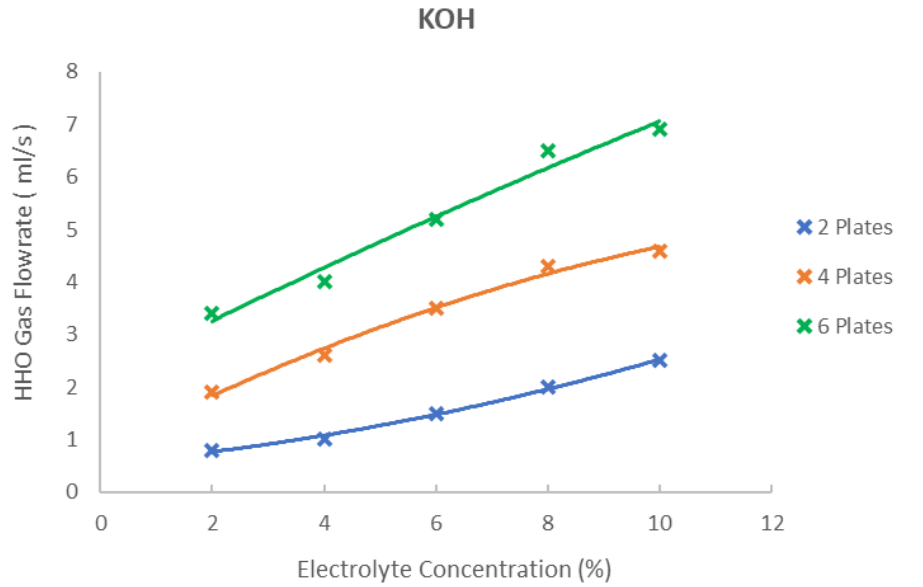
3. RESULT AND DISCUSSION

a. Electrolyte Concentration Analysis

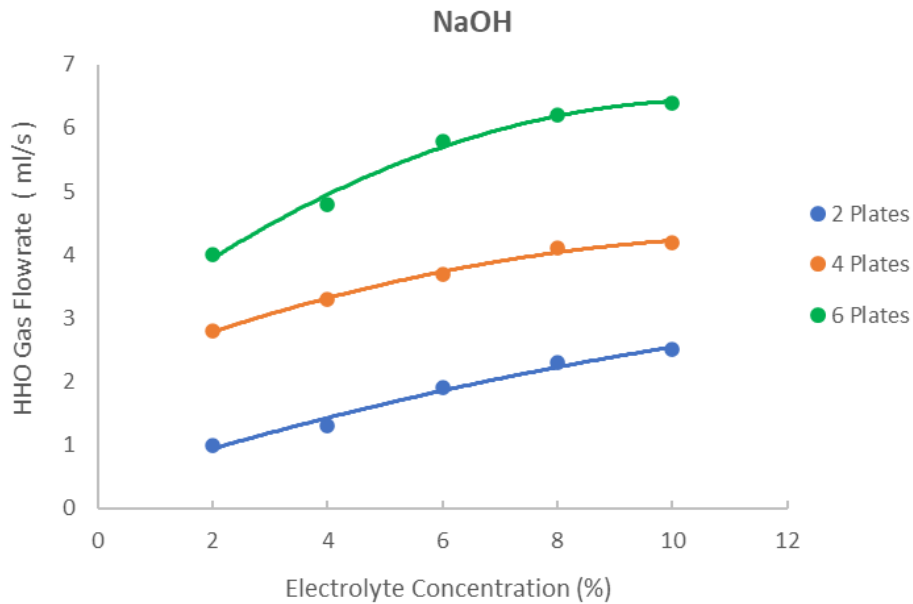
Electrolyte concentrations, electrolyte types of NaOH and KOH, and the number of electrode plates are all clearly correlated with HHO gas generation rates, as indicated by the experimental results shown in Figure 2. NaOH electrolyte generated HHO gas at 1 mL/s , 2.8 mL/s , and 4 mL/s for electrode configurations of 2, 4, and 6 plates at 2% electrolyte concentration, equivalent to 12.24 g in 600 mL of purified water. By comparison, KOH at the same concentration showed marginally lower HHO generation rates of 0.8 mL/s (2 plates), 1.9 mL/s (4 plates), and 3.4 mL/s (6 plates), implying NaOH's first better performance at lower electrolyte concentrations.

Both electrolytes showed a significant increase in HHO generation rate as electrolyte concentration rose. These observations indicate increased conductive ability of ions and lower resistance to electrical current in electrolyte solutions. At a concentration of 10%, or 66.67 grams per 600 milliliters of pure water, both electrolytes showed the highest possible HHO generation. NaOH gas generation rates at this concentration were 2.5 , 4.2 , and 6.4 mL/s with 2, 4 and 6 electrode plates configurations, respectively. Especially, KOH at 10% concentration showed better results, producing HHO gas generation rates of 2.5 mL/s (2 plates),

4.6 mL/s (4 plates), and 6.9 mL/s (6 plates).



(a)



(b)

Figure 2. HHO Gas Flowrate using (a) KOH (b) NaOH electrolytes

b. Calculation of Hydrostatic Pressure

There are clear correlations between the electrolyte concentrations, electrolyte types, electrode plate numbers, and the hydrostatic pressure that is associated with the formation of HHO gas, as demonstrated by the experimental data. All of the information pertaining to each variation is shown in Table 1. The NaOH electrolyte had hydrostatic pressures of 9.81 Pa, 27.468 Pa, and

39.24 Pa for electrode configurations of 2, 4, and 6 plates at 2% electrolyte. Due to its lower gas generation rates at low concentrations, KOH electrolyte produced slightly lower pressures, 7.848 Pa (2 plates), 18.639 Pa (4 plates), and 33.354 Pa (6 plates).

Hydrostatic pressure increased significantly with electrolyte content. Pressures climbed steadily for NaOH, peaking at 24.525 Pa (2 plates), 41.202 Pa (4 plates), and 62.784 Pa (6 plates) at 10% concentration. KOH demonstrated even greater pressure rises at higher concentrations, topping NaOH at 24.525 Pa (2 plates), 45.126 Pa (4 plates), and 67.689 Pa (6 plates) at 10% concentration.

Hydrostatic pressure in the measuring setup rises with HHO gas generation; hence, these pressure readings directly correlate with gas production. Pressure adjustments induce KOH to produce more gas during electrolysis, with the maximum pressures at 10% concentration with a six-plate electrode arrangement.

Table 1. Hydrostatic Pressure Calculation using KOH and NaOH Electrolyte

Electrolyte Concentration (%)	2 Plates		4 Plates		6 Plates	
	Flowrate (mL/s)	Pressure (Pa)	Flowrate (mL/s)	Pressure (Pa)	Flowrate (mL/s)	Pressure (Pa)
NaOH						
2	1	9.81	2.8	27.468	4	39.24
4	1.3	12.753	3.3	32.373	4.8	47.088
6	1.9	18.639	3.7	36.297	5.8	56.898
8	2.3	22.563	4.1	40.221	6.2	60.822
10	2.5	24.525	4.2	41.202	6.4	62.784
KOH						
2	0.8	7.848	1.9	18.639	3.4	33.354
4	1	9.81	2.6	25.506	4	39.24
6	1.5	14.715	3.5	34.335	5.2	51.012
8	2	19.62	4.3	42.183	6.5	63.765
10	2.5	24.525	4.6	45.126	6.9	67.689

c. HHO Gas Production Rate Analysis in Different Electrode Plate Numbers

The combined data shows that more electrode plates improve HHO gas production for both electrolytes. At the lowest concentration of 2%, NaOH increased from 1 mL/s (2 plates) to 2.8 mL/s (4 plates). KOH improved from 0.8 mL/s (2 plates) to 1.9 mL/s (4 plates). At 10% concentrations, NaOH increased from 2.5 mL/s to 4.2 mL/s and KOH from 2.5 mL/s to 4.6 mL/s. The switch from four to six plates increased gas output, although at a slower rate. At 2% concentration, NaOH increased from 2.8 mL/s to 4 mL/s and KOH from 1.9 mL/s to 3.4 mL/s. NaOH increased from 4.2 mL/s to 6.4 mL/s and KOH from 4.6 mL/s to 6.9 mL/s, again significantly improving production rate from four to six plates at the highest concentration of 10%. The comparison of both HHO production using NaOH and KOH electrolytes is shown in Figure 3.

Due to the increased electrochemical reaction surface area given by extra electrode plates, electrical current conduction in the electrolyte solution during electrolysis increases HHO gas production. Despite maintaining 3 V across all test configurations, each electrode plate addition increased current usage. The measured currents climbed from 4 amperes in two plates setup, to 9 amperes in four plates setup, to 17.5 amperes in six plates setup. The increased current from reduced electrical resistance from more electrode plates shows that increasing electrode plates enhances ion mobility and active surface area, which could be pivotal for scaling up HHO generator systems in real-world applications.

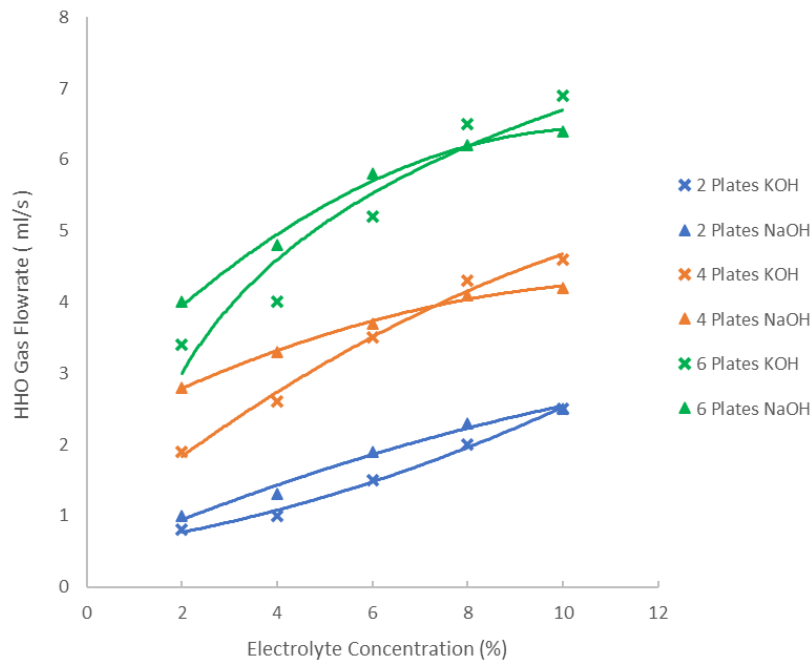


Figure 3. HHO Gas Flowrate Comparison Using KOH and NaOH Electrolytes

These findings are consistent with the theoretical principles of water electrolysis, where an increase in electrolyte concentration enhances ionic conductivity, thereby reducing the resistance of the electrolyte solution and facilitating greater current flow [8]. According to Santos et al. [8], higher alkaline concentrations in electrolytic solutions improve hydrogen production rates by providing more hydroxide ions that participate in the dissociation of water molecules. Furthermore, the use of additional electrode plates effectively expands the electroactive surface area, which in turn increases the number of active sites for the electrochemical reactions to occur, corroborating the findings reported by Ridhwan et al. [10] regarding enhanced HHO production through electrode surface modification. The rise in hydrostatic pressure observed during the experiments also supports the Bernoulli principle in fluid statics, where increased volumetric gas flow directly correlates with elevated pressure in a closed water column. Therefore, the experimental results not only demonstrate empirical improvements but also reinforce well-established electrochemical and fluid dynamics theories, confirming the validity and scientific basis of the observed HHO gas production trends.

4. CONCLUSION

The performance of different electrolyte concentrations and electrode plate amounts shows that more electrode plates increase HHO gas production, regardless the type of electrolytes. Lower electrolyte concentrations of 2% generated the least HHO gas, 0.8 mL/s for two plates with KOH electrolyte, and 1 mL/s for two plates with NaOH electrolyte. Gas production increased correspondingly with electrolyte concentrations from 2% to 4%, 6%, 8%, and 10%. Gas generation rates were 6.9 mL/s for six electrode plates with KOH and 6.4 mL/s for six electrode plates with NaOH at 10%. This shows that larger electrolyte concentrations boost gas generation. These findings support the idea that more electrode plates and electrolyte concentration boost hydrogen and oxygen gas generation. Electrolysis efficiency increases due to greater solution conductivity, quicker electrode reactions, and lower resistance.

This process requires a lot of electrical energy, usually from fossil fuels, which might cause greenhouse gas emissions and pollution. Future study should assess its energy efficiency using power-to-gas conversion measures and investigate renewable electrolysis energy sources. Waste generated during electrode manufacture should also be studied for environmental consequences. Practical and efficient hydrogen generation requires an energy balance, environmental sustainability, and long-term feasibility review.

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