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Effect of KOH Concentration on the Performance of HHO Generator at Varying Plate Surface Textures

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ABSTRACT

In an effort to improve the performance of the HHO generator, the surface texture of the electrode plate has been introduced through this study. Optimization of the HHO generator's performance has been developed continuously in many parts of the world. Therefore, the effect of KOH concentration on the performance of the HHO generator at different plate surface textures was investigated in this study. The HHO generator used in this study combines wet and dry cells. Generally, the results showed an increase in output current, HHO production rate, and output temperature, and conversely, a decrease in operating time due to the effect of increasing KOH concentration and different surface textures. The output current exhibits a significant increase of over 200% for all types of plate surfaces. For the output temperature, the smallest increase of about 9.7% is achieved by the linear plate surface. Meanwhile, the best HHO gas production rate is 267.26 L/min with an operating time of only 112.25 s, which occurred on the surface of the linear plate. Briefly, increasing the KOH concentration followed by modification of the plate surface has yielded better results compared to the plain surface. As for the surface texture, it causes a change in the plate surface area, which has a positive impact on the performance of the HHO generator.

1. Introduction

The limited stock of fossil fuels and the high production of hazardous pollutants demands the finding of a renewable alternative fuel. Recently, the Oxy-Hydrogen (HHO) generator has been introduced as one of the economical and widely available alternative energies using water as the main resource [1]. It is well-known that hydrogen or hydroxy (HHO) gas is the cleanest energy resource among all alternative fuels. Hydroxy Gas (HHO) is actually generated by dissociating the atoms in the water molecules using an electrolysis concept. It is understood that water electrolysis is the process of H_2 (hydrogen) and O_2 (oxygen) gases production by streaming electrical energy to the cathode and anode acting as negative and positive poles, respectively, which are soaked in water

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[2,3]. The characteristics of HHO gas are colorless, flammable, extremely light and easy to react with other chemicals. However, the optimization of HHO generators is highly required to enhance their performance, which can be improved by taking into consideration the effective surface of electrodes and also the concentration of electrolyte solution on the gas release from water electrolysis [4].

Recently, surface texturing has been introduced as a promising method to produce the desired pattern, offering many advantages for engineering applications. Basically, it has been widely used to enhance materials' performance and properties. Moreover, its ability to manage exterior properties in specific applications, such as in surface medicine self-cleaning, anti-biofouling, etc., has attracted the interest of many scientists in the world [5,6]. Nevertheless, surface texturing offers many advantages which can lower friction and wear, intensify load-carrying capacity and escalate fluid film stiffness. In this regard, previous studies have indicated that textured electrode surfaces may influence the electrolysis process, which ultimately impacts the effectiveness of hydrogen gas production [7,8]. Several methods have been utilized to prepare the surface texturing such as laser surface texturing, chemical etching, atomic layer deposition, ultrasonic-assisted grinding, electrical discharge machining (EDM) and micro-milling [9-12]. According to the statements above, the surface texturing on the electrode plate could be considered to increase HHO gas production.

In terms of electrolytes used in the HHO generator, Essuman *et al.,* [13] examined the influence of electrolyte strength, voltage, and time on the rate of HHO gas production in the HHO generator. In their study, the optimal HHO gas rate was 2.27 cm^3/s when the generator was supplied with a voltage of 13 V in a 0.025 M KOH solution. In fact, according to several studies, the rate of HHO gas production is strongly influenced by the electrolyte used, including sodium hydroxide (NaOH) and potassium hydroxide (KOH) [14-17]. Both are types of electrolytes that are strong and able to mobilize ions to accelerate the electrolysis of water. In line with that, Yilmaz *et al.,* [18] conducted research on the production rate of HHO gas by using different types of electrolytes such as NaOH, KOH and NaOH connected to a control unit to control the rate of HHO production. Then the results stated that an increase in the HHO gas flow rate was associated with an increase in electrolyte concentration, and even a 1% increase in the molality of NaOH in water can increase the current consumed. Meanwhile, De Silva *et al.,* [1] claimed that NaOH and KOH were selected as the catalyst in the HHO gas production due to their stability in water electrolysis. The increase of generator temperature was attributed to the increase of consumed current and the increase of cell temperature resulted in the increase of HHO gas production.

Furthermore, there are two types of HHO generators: wet-cell and dry-cell generators. A wet cell is basically a condition where all electrodes are submerged in an electrolyte solution in a vessel. Then the electrode plates are supplied with direct current (DC), where the anode acts as the positive pole and the cathode as the negative pole. There are several advantages to this wet cell, namely: (i) the operation is stable and able to produce more gas; (ii) the design is relatively easy and simple; and (iii) the maintenance is relatively easy. The disadvantage of this wet cell is the occurrence of excessive heat from the electrolysis process that cannot be removed from the system. In contrast to wet cell, the electrodes in a dry cell are partially submerged, but the gaps between the electrodes are filled with electrolyte solution. The advantages of this dry cell are that (i) the amount of water electrolyzed is less, (ii) the required electric current is low, and (iii) relatively little heat is generated due to the small amount of power lost from heat dissipation. The weakness of the dry cell is the current leakage due to the formation of small holes in the electrode plates [19].

More interestingly, HHO gas production is also influenced by other factors such as the type of electrode material, plate arrangement, distance between electrodes, and electrode cross-sectional area [20]. So far, the engineering of the electrode surface texture has not been widely studied, making it very promising to be further developed for the improvement of HHO generator performance. Based on these reasons, the concentration of electrolyte solution combined with various plate surface textures on the HHO generator is the focus of this research, which is interesting to explore. Therefore, the main objective of this study is to determine the effect of KOH concentration on the performance of HHO generators at different plate surface textures.

2. Methodology

2.1 Materials

A commercial 316 stainless steel with chemical composition of 16 Cr, 10 Ni, 2 Mo, 0.03 C, 2 Mn, 0.045 P, 0.03 S, 0.75 Si, 0.1 N, and balance Fe (in weight percent) was selected as a plate with a surface area dimension of 100 mm by 100 mm and a thickness of 1 mm. Three different plate shapes (the plain, linear, and cross surfaces) as shown in Figure 1 were used in this study. This HHO generator consists of five plates made of 316L steel with a distance of 2 mm between the electrodes.

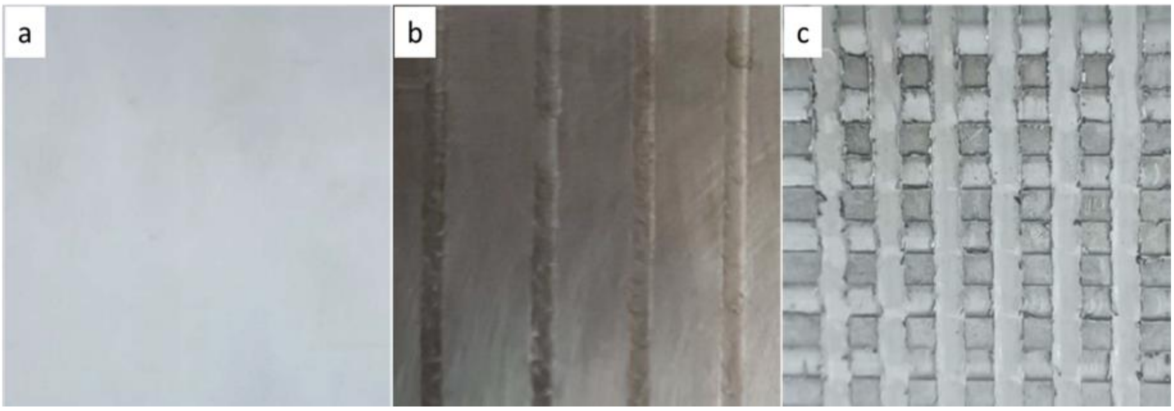


Fig. 1. Plate shapes used in HHO generators (a) Plain (b) Linear (c) Cross surfaces

2.2 Fabrication of Electrode Surface Textures

In terms of the electrode surface textures, the pattern of each plate was initially drawn using CAD software, namely CATIA V5 R20, to obtain results with good accuracy and precision, as shown in Figure 2 and Figure 3. From this software, the patterns then run the machining process to conduct simulation before generating the program codes. After that, the program codes were transferred to the CNC machine for the next process.

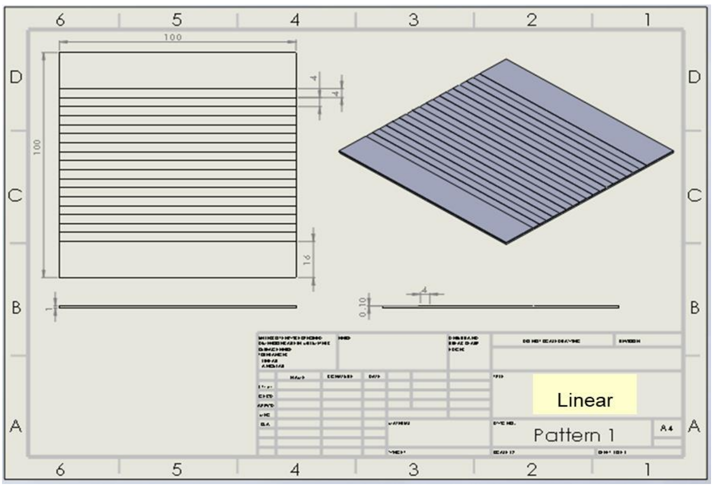


Fig. 2. The design of a linear surface plate

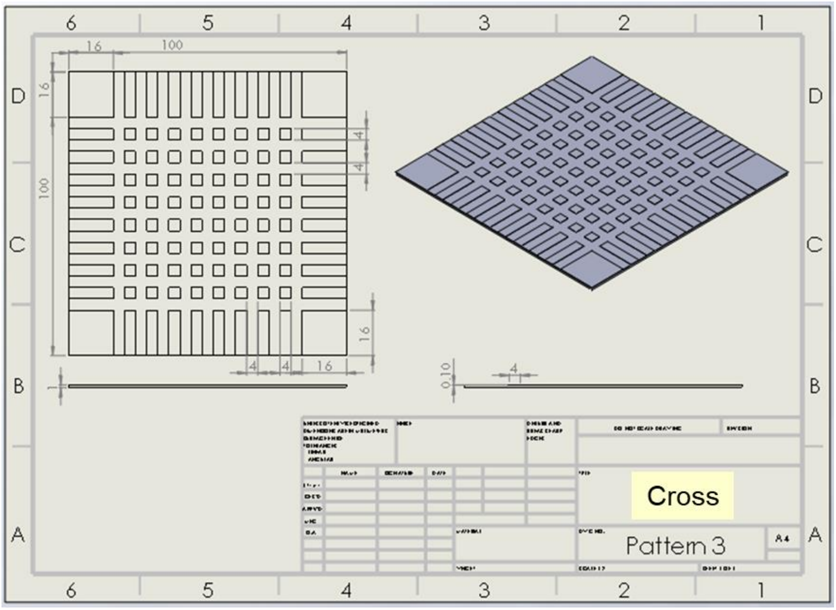
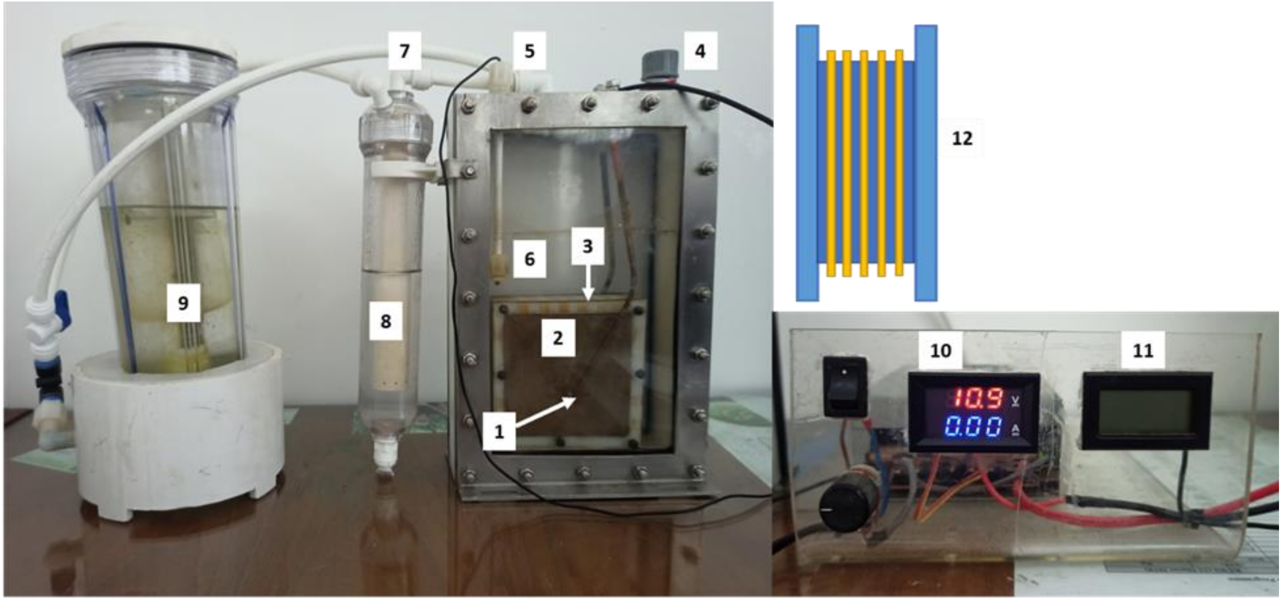


Fig. 3. The design of a cross surface plate

The textured surface plates were prepared using a computer numerical control (CNC) machine. The surface texturing process was conducted at a speed of 1150 mm/min and the fabrication took about 20 minutes for each plate. During the machining process, liquid coolant was added periodically to cool and lubricate the contact area between the plate's surface and the tool, inhibiting the tools from eroding and producing the plates with a good surface finish. Then, make sure that there is no cutting residue attached to the surface of the electrode plate using tool file prior to polishing with isopropyl.

2.3 HHO Generator Set Up

In the present study, the combination of the two types of cells was chosen because it is interesting to be further examined in this study. Meanwhile, the performance of the HHO generator in generating HHO gas can be specified by the calibration method. Initially, the HHO generator was measured using a flow meter gauge to quantify the amount of HHO gas produced (liters per minute). The power supply is then connected to an HHO generator to acquire an electricity supply with a constant input voltage of 12 V. When an electrical current is applied to the HHO generator, the electrolysis process with a KOH solution acting as an electrolyte starts to run and produces HHO gas. More interestingly, different KOH concentrations ranging from 10, 20, 30, 40, 50, and 60 g/L were added to HHO generators. The schematic of the HHO generator used in the present study is presented in Figure 4.



Overview of HHO generator parts:
1. Electric power rod.
2. Spacer module.
3. Electrode plates arrangement.
4. Water inlet.
5. HHO gas outlet.
6. Thermocouple.
7. HHO gas flow pipe.
8. Bubbler tube.
9. Flowmeter.
10. Voltmeter and Amperemeter.
11. Thermometer.
12. Enlargement of no. 3.

Fig. 4. Overview of HHO generator parts

2.4 Measurement Methods

With regard to the output electric current, HHO gas production rate, output temperature, and operating time, it is necessary to know how to measure them based on the experiment that has been carried out, which is briefly explained here. The first step is to fill the vessel with KOH electrolyte solution so that the series of regularly arranged electrode plates are completely submerged. Then the HHO generator system is turned on by connecting the cable to the power plug and pressing the on button, and the HHO generator is allowed to stand for 30 minutes until the condition stabilizes. After 30 minutes, the applied voltage is set to 12 V, and concurrently, the stopwatch also starts to be activated. Then the gas production process takes place, causing the water volume in the flowmeter to rise periodically so that the scale shows a certain value (up to 10 cm), which indicates the increase in water volume due to hydrogen gas production. When it is reached, the generator engine is turned off, the value of the output electric current is displayed on the screen of the digital power supply, the HHO gas production rate can be calculated from the detected volume increase, the output temperature, which comes from the thermocouple installed, is also displayed on the screen. In terms of the operating time, it can be seen from the numbers displayed on the stopwatch. Data are obtained for each parameter investigated in this study, which will be correlated with different electrode plate surface types as well as varying electrolyte solution concentrations.

In addition, voltage variations were also applied to the HHO generator at a constant KOH concentration of 30 g/L. This is basically designed to observe how much the voltage affects the HHO gas production, output current, output temperature, and operating time on various types of electrode plate surfaces at the voltages of 12 V, 12.5 V, 13 V, 13.5 V, and 14 V. This is made based on the results obtained where the electrolyte concentration from 0 to 30 g/L shows a gradual increase in the value of HHO gas production, electric current, and others so that the variation in the applied voltage is also interesting to be observed.

3. Results

3.1 Effect of Varying KOH Concentrations on Output Current for Different Plate Textures

The results of current as a function of KOH concentration at different plate surface textures are shown in Figure 5. In general, the current generated at a constant voltage of 12 V increased with increasing concentration of KOH electrolyte on all different types of plate surface textures. It is evident that the increase in KOH concentration from 0 g/L to 60 g/L causes the percentage increase in electric current to be above 200% in all types of electrode plates, as shown in Figure 6. The increase of electrolyte concentration enhanced the rate of electron transfer between the electrodes as well as the conductance of electrodes, which finally augmented the electric current obtained on all different types of plate surface textures, which in turn affected the water dissociation rate [21]. Nevertheless, the increase in concentration lowers the electrical resistance and intensifies the electric current, whereas the decrease in electrolyte resistance generates an increase in electrical conductivity and a potential reduction. On the other hand, the resistances in the electrolytic solution and electrodes brought on by inverse reactions, side reactions, and impurities in electrode materials would also influence the electric current values obtained [22]. Hence, it is seen that the output current results are different for each type of plate surface, where the output currents are 9.51 A, 7.8 A, and 7.48 A for plain, linear, and crossed surfaces, respectively. This indicates that the texture of the plate surface, i.e., the linear surface and cross surface, may slightly hinder the mobility of ions in the electrolyte solution compared to the plain surface, which is free of obstacles and thus reflected in the results obtained. This is due to the fact that the flow of ions carrying electrons undergoes interactions when passing over a surface that has a specific texture; the flow is thus not like that of a plain surface [23]. In addition, the texturing effect on the cross surface increases the surface roughness due to its more complex shape compared to the linear surface, which in turn can reduce the output current achieved on the cross surface [24].

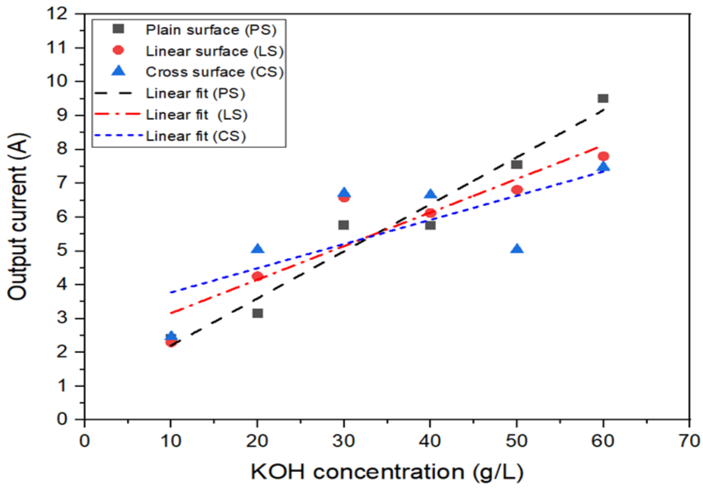


Fig. 5. Output current at varying KOH concentrations for different plate surface textures

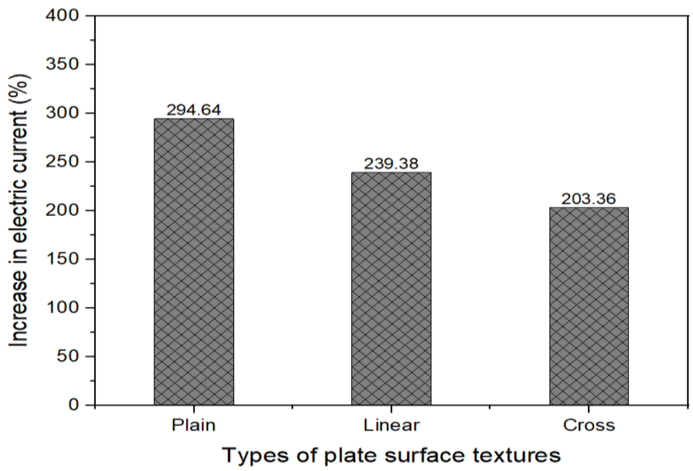


Fig. 6. Electric current at different plate surface textures

In addition, at a very close electrode pair with a distance of about 2 mm, it can reduce the electrical resistance between the electrodes, which has an impact on increasing the electric current [25]. Further observation showed a significant increase in electric current from 0 g/L to 30 g/L KOH concentration, where both textured surfaces had a higher electric current than the plain surface. At 30 g/L concentration, the plate with the cross surface had the highest electric current value of about 6.7 A. The difference in surface area could be the reason for the different electric current values obtained. For more details, see Table 1, which shows the surface area of the various plates with different surface textures. The surface area of the plate means that the area of the conducting plate, which functions to carry electrical current [26]. However, there was a slight decrease in electric current on all electrode plates at a KOH concentration of 40 g/L. At concentrations above 40 g/L, the value of the output electric current experienced a non-linear trend; some values went down and some values went up. While at a concentration of 60 g/L, the maximum output electric current was achieved by the plain plate, which was 9.51 A. As for the plates with linear and cross surfaces, the output electric current ranged from 7.5 to 7.8 A. There is an interesting phenomenon here where, at concentrations exceeding 30 g/L, the output electric current looks inconsistent.

Table 1
Surface area of the plates with different surface textures

Plate surface texture types	Surface area (cm^2)
Plain	100.00
Linear	101.80
Cross	102.30

3.2 Effect of HHO Gas Production at Varying KOH Concentrations

Figure 7 shows that the production rate of HHO generally increased with increasing KOH concentration. At a KOH concentration of 10 g/L, the highest HHO production rate was experienced by the plate with a linear surface of 120.95 L/minute. The highest HHO production rate was obtained with increasing KOH concentration, with a value of 267.27 L/min at a KOH concentration of 60 g/L for plates with a linear surface. Whereas in the second rank, the HHO production rate was achieved by plates with cross surface textures, where the HHO production rates were 67.35 gram/L and 249.16 gram/L at KOH concentrations of 10 gram/L and 60 gram/L, respectively. A plain surface achieved the lowest HHO production rate of 205.48 g/L at a KOH concentration of 60 g/L. The higher concentration of KOH electrolyte will accelerate the movement of molecules in the water, causing more intense collisions between hydrogen and oxygen molecules. As the intensity of the molecule's collision increases, so does the kinetic energy between molecules, resulting in an increase of the production of HHO gas [27]. However, if it is viewed from the percentage increase in the HHO production rate based on the increase in KOH concentration from 10 g/L to 60 g/L, the percentage increase in the HHO production rate on the plate with a cross surface (296.64 %) is higher than the plate with a linear surface (120.96 %) which can be attributed to the change in cross-sectional area of the electrode plate due to texturing of the electrode plate surface. From these results, it is clear that the rate of HHO production is strongly influenced by the electrolyte concentration and surface texture of the plate. As for the R^2 value approach, the R^2 values are 0.961 and 0.967 on the plate with a linear and cross surface, respectively. This indicates that the texture on the surface of the plate has an effect on the HHO production rate. This texture may have an impact on the surface roughness of the plate, which causes changes in the surface area of the plate. This is fit to the results obtained by Kandah [28].

Another reason that can be considered is the nickel content of the plate used. More specifically, 316L steel is frequently used as an electrode where the reaction of hydrogen evolution with an alkaline medium occurs at the cathode due to its high nickel content. With regard to the electrolysis process, the reaction that takes place at the cathode will produce hydrogen, while at the anode it will produce oxygen, where the amount of hydrogen is twice as much as oxygen. For more details, the chemical reactions that will occur are as follows:

Reaction at cathode: $2\ H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2\ OH^-\ (aq)$ (1)

Reaction at anode: $4\ OH^-\ (aq) \rightarrow O_2\ (g) + 2\ H_2O\ (l) + 4\ e^-$ (2)

Overall reaction: $2\ H_2O\ (l) \rightarrow 2\ H_2\ (g) + O_2\ (g)$ (3)

Furthermore, the nickel content in 316L steel can react with KOH as an electrolyte, which causes the formation of nickel hydrate on the surface of the steel plate [29]. Olivares-Ramirez *et al.,* [30] stated that the use of KOH electrolyte proved effective in influencing the hydrogen evolution reaction, leading to an increase in the hydrogen production rate. This is possibly due to the formation of nickel hydrate on the surface of the steel plate, which is less corrosive and thus affects the rate of HHO production. This also confirms that the overall performance of the 316 L steel electrode is at an acceptable level of stability. Therefore, the development of surface texture on the 316L steel plate in the HHO generator needs further attention so that it can be implemented more broadly in the future in order to increase the rate of hydrogen gas production.

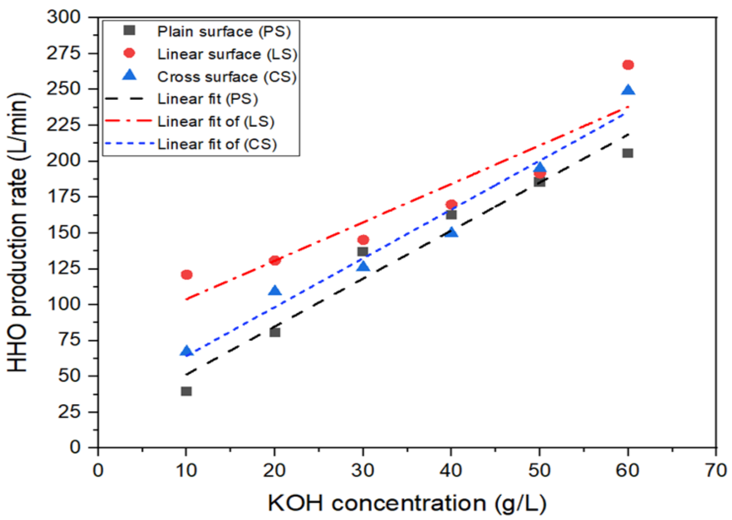


Fig. 7. HHO production rate at varying KOH concentrations using different plate surface textures

3.3 Effect of Output Temperature at Varying KOH Concentrations

The relationship between the output temperature and the concentration of KOH in the HHO generator is shown in Figure 8. Basically, there is a slight, gradual increase in output temperature, and this can be seen with increasing KOH concentration. The output temperatures achieved at 60 g/L electrolyte concentration were 35.59 °C, 34.81 °C, and 38.04 °C for plain, linear, and crossed surfaces, respectively. In general, these relatively low output temperatures require less energy for the production process, so the generator can work more efficiently. This is one of the benefits produced by the texture formed on the plate surface, which is a new approach to improving the performance of the HHO generator. As for the resulting output temperature results, they are in conformity with the previous study [13]. The percentage increase in output temperature ranged between 9.5% and 28.6%. The maximum output temperature rise occurs on the plate with a cross surface, while the minimum output temperature rise occurs on the plate with a linear surface. This is in accordance with the R^2 value obtained from the graph in Figure 8, where the R^2 values of the plates are 0.697 for the cross surface and 0.345 for the linear surface.

Among the factors affecting the electrolysis of water are the quality of the electrolyte and the concentration of the electrolyte. As it is known that KOH is a type of strong electrolyte, when it is dissolved in water, it decomposes perfectly into ions so that it has good electrical conductivity. The collisions between ions will be more intense with an increased KOH concentration, which will ultimately increase the ionic mobility and its conductivity during the electrolysis of water. The increase of conductivity caused the KOH electrolyte solution to become hotter, which resulted in an increase in the output temperature of the HHO generator [31,32].

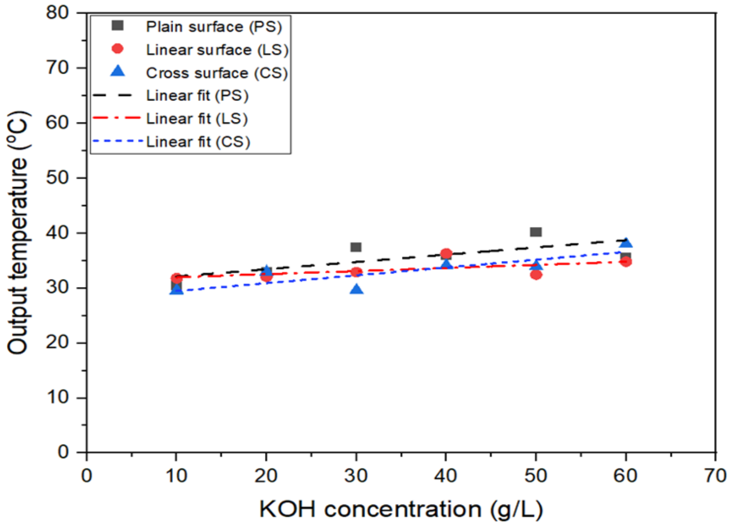


Fig. 8. Output temperature at varying KOH concentrations using different plate surface textures

3.4 Effect of Operating Time at Varying KOH Concentrations

The correlation between operating time and KOH electrolyte concentration is shown in Figure 9. From these results, it is distinct that at high electrolyte concentrations, namely 60 g/L, the time required to produce bubbles is much lower on all types of plate surfaces when compared to low electrolyte concentrations of 10 g/L. Actually, the time it takes for an electrolyte solution to reach a temperature rise is closely related to its concentration. Theoretically, the greater the solution's concentration, the less energy it will require to reach the specified temperature, and thus the time required for the solution to reach that temperature will be shorter. Besides, the addition of KOH electrolyte in high concentrations can induce an increase of water conductivity, resulting in a faster electrolysis process [33]. The shortest operating time was experienced by the plate with a linear surface, with an operating time range of around 112.25 seconds at a KOH electrolyte concentration of 60 g/L. This can be related to the area of the plate on the linear surface acting as the ions' path, which is very important in electrolysis, and also the R^2 value, that is around 0.981, indicating a strong relationship between the variables [34].

4. Conclusions

HHO gas was produced from a combination of wet and dry cells using 316L steel as the electrode plate. The effects of KOH electrolyte concentration and type of surface texture of the plate were studied. The following conclusions can be drawn from the present study, as follows

i. Increasing KOH concentration combined with different plate surface textures has been proven to enhance the performance of the HHO generator.
ii. With increasing KOH concentration, the output electric current increased essentially. At a KOH concentration of 0–30 g/L, the maximum output electric current was achieved by the plate with a cross surface, which was 6.7 A, while at a KOH concentration of 60 g/L, the maximum output electric current was found on the plate with a plain surface.
iii. The increase in HHO production rate was above 200 L/min at a KOH concentration of 60 g/L, and the highest one was 267.26 L/min on the plate with a cross surface.

iv. The percentage of temperature rise is lower than 30% at a KOH concentration of 60 g/L for all types of plate surfaces. The highest temperature of 38 °C was achieved by the plate with a cross surface, and the minimum temperature was 34.8 °C on the linear surface.

v. The fastest operating time of 112.26 s was experienced on a plate with a linear surface at a KOH concentration of 60 g/L. The high concentration of KOH is able to enhance the conductivity, which accelerates the electrolysis of water. From the results obtained, field testing using vehicles is necessary in the future so that the performance of the HHO generator and its limitations are truly proven.

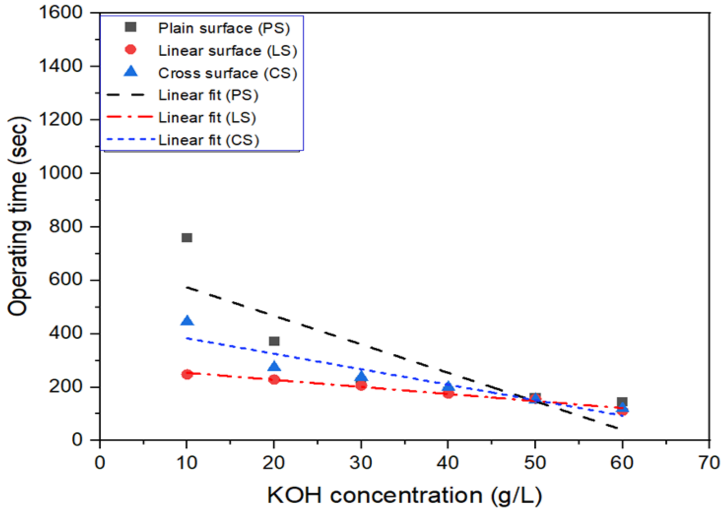


Fig. 9. Operating time at varying KOH concentrations using different plate surface textures

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