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The Effect Of Electric Current On Hydrogen Gas Production Using Water Electrolysis Process

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Abstract

New renewable energy sources are being developed to replace conventional energy sources such as biofuels, electric cars, and solar cars in the transportation sector. However, this generation has limitations in that it requires external energy sources to be converted into electricity. This study examined the development of alternative energy sources through water electrolysis to produce hydrogen. The factors affecting the electrolysis process, such as the catalysts and external voltage, were investigated. The study successfully implemented hydrogen production using a wet cell electrolysis reactor design involving components such as an Arduino, MQ-8 gas sensor, and DS18B20 temperature sensor. This study used a reactor with electrodes of six plates, where the electrode plates were the anode and cathode of three plates each. Hydrogen levels were measured using an MQ-8 semiconductor sensor. The test results showed that varying the current in the electrolysis reactor increased the hydrogen concentration to a maximum of 3405.77 PPM. A decrease in hydrogen levels occurred after 20-40 minutes due to the saturated electrolytes. Factors such as the ion concentration, hydration, ion attraction, and temperature also influence the conductivity of the solution during electrolysis. The results of this study obtained a minimum average hydrogen content of 646.054 PPM and a maximum of 2932.306 PPM. The reactor temperature conditions were stable at an average temperature of 27°C.

Keywords:
Hydrogen concentration, hydrogen gas, MQ-8 gas sensor, water electrolysis process.

1 Introduction

Energy is important for human life. Indonesia has an abundance of natural resources to produce renewable energy, including hydro, solar, wind, biomass, geothermal, oil, natural gas, coal, and nuclear energy, from uranium and thorium [1]. Energy consumption in Indonesia is dominated by non-renewable energy sources, such as petroleum and coal. However, the availability of fossil fuels is dwindling; therefore, renewable energy sources are an important solution. The Indonesian government needs to prioritize the use of renewable energy to reduce its dependence on fossil energy and realize clean and environmentally friendly energy [2]. Hydrogen is attracting considerable attention as a potential replacement for conventional fossil fuels as the global community attempts to shift towards a more environmentally friendly and renewable energy paradigm [3].

Currently, much research is directed towards alternative energy sources, with reserves from fossil fuels becoming increasingly limited. Given these conditions, intensive research is needed to find, optimize, and use alternative energy sources. Many studies have been conducted to replace the dependence on the use of fossil fuels. One such untapped energy source is water. Water contains two elements, hydrogen and oxygen, which can be used as fuel.

Hydrogen energy is a current topic in renewable energy development. The renewable hydrogen production process continues to evolve, allowing production prices to become more affordable in the future. The development of devices, gas engines, and transport systems aims to use hydrogen as a safe energy source.

Many methods have been used in research for the production of hydrogen gas, one of which can be produced from the water electrolysis process using metal electrodes. This water electrolysis process is carried out by breaking down the H_2O (water) compound into flammable Hydrogen Hydrogen Oxygen (HHO) using an electrolysis process with the help of a direct electric current [4]. This method is one of the most efficient ways to transform water into fuel [5]. The most important components of this electrolysis process are the electrode and the electrolyte solutions. The electrodes that are generally used in electrolysis are carbon electrodes, but they are damaged quickly because carbon is not rustproof and brittle [6].

There have been many studies on hydrogen gas production, one of which has been carried out by comparing the effect of cross-sectional area on the concentration of electrolyte solution using 316 L stainless steel-type electrodes and electrolytes in the form of NaCl[4]. From the results, it can be inferred that the highest volume of H_2 gas can be found at 35 ppt of salinity, electrode size of 0.5 inches and current strength of 35 amperes which generates 2.118693 litres of H_2 gas within 120 seconds.

MQ-8 sensor connected to the Arduino Uno was used alongside gas measurement instruments to determine the presence of hydrogen gas in water as a result of the water electrolysis method. In this study, the optimum conditions for hydrogen gas concentration were a $NaNO_3$ concentration of 1 M and 60 min with a hydrogen concentration of 143.393 PPM. [7]. Another factor that affects the water electrolysis process is electrolyte concentration. KOH was used as an electrolyte material in the form of a catalyst in the electrolysis process to accelerate the reaction and reduce the energy required for the reaction to take place [8].

In previous studies, variations in the electric current, which can affect the amount of hydrogen production, have not been carried out. This research is expected to determine the optimal effect of variations in electric current on hydrogen electrolysis.

Based on this explanation, during water electrolysis, many factors can affect gas production, including the use of catalysts, the dipped surface area, the raw material of the electrode, the concentration of the electrolyte solution, and the amount of external voltage. To obtain ideal production results, monitoring the concentration of hydrogen gas and the temperature in the electrolyte solution is required.

In this study, electrolysis was conducted using a tube-type reactor with a square-shaped electrolysis plate, stainless steel plates, and a wet cell.

2 Method

In general, this research was completed in several stages: 1) preparation of tools and materials and hardware and software design, 2) prototype making and panel installation, and 3) testing and analysis.

2.1 Designing the System

The production of hydrogen gas using a wet cell electrolyzer system was designed to produce hydrogen gas via water electrolysis. In this production process, two parameters are monitored by the value of the process: the gas produced from the process of monitoring the hydrogen content using the MQ-8 gas sensor and the electrolyte solution in the electrolysis reactor using the DS18B20 sensor integrated with the Arduino UNO microcontroller [9], [10]. This gas monitoring will be displayed through an HMI, namely LCD I2C 16×2 and Labview. In this design, the software and hardware require several supporting components to assemble the system.

Tools and materials used to support the assembly of hardware wiring include Arduino Atmega328P, MQ-8 gas sensor, DS18B20 temperature sensor, buck converter, LCD I2C16×2, power supply, 12V DC submersible pump, buck-boost converter, relay, pilot lamp, selector switch, and adapter, where the wiring design is shown in Fig. 1.

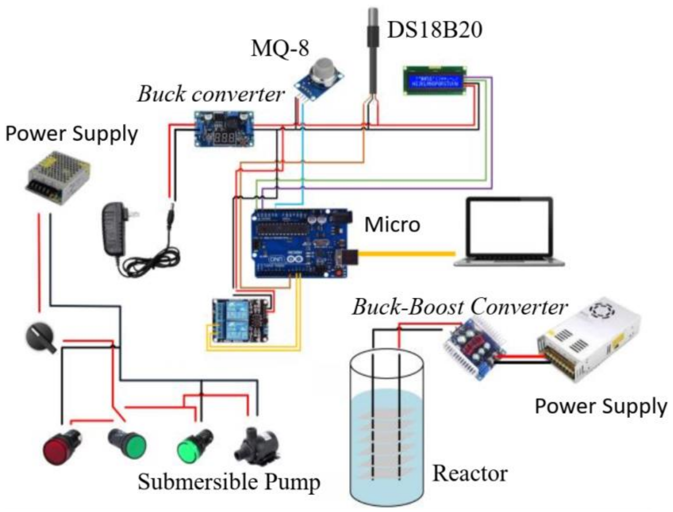


Fig. 1. Wiring diagram.

The material used in this study requires a KOH catalyst solution with a concentration of 0.5 M which is dissolved in 13 litres of distilled water solution so that the calculation of the mass of KOH that will be used is carried out. The catalyst solution experiment at a concentration of 0.5 M produces a calculation value for the mass requirement of the electrolyte to be dissolved in the solution using the mole concept formula in Eq. 1.

$$M = \frac{m}{Mr} \times \frac{1000}{v} \quad (1)$$

$$0.5 = \frac{m}{56} \times \frac{1000}{13000}$$

$$m = 0.5 \times 56 \times 13 = 364 \text{ grams}$$

Notes:
M = Molarity (mol/l)
n = Mol
V = Volume (L)
m = Massa
Mr= Relative molecular mass (g/mol)

Thus, a mass of 364 grams of KOH is needed to be dissolved with 13 liters of distilled water solution.

The electrolysis reactor in Fig. 2 is constructed using acrylic tubes that have a diameter of 20 cm and a height of 40 cm, allowing for a maximum volume of 8.164 liters. The reactor is equipped with a flange cover to restrict gas movement, and bolt nuts are added to maintain its tightness. The electrolysis solution is input and discharged through ½ inch channels, while the gas production output is channeled through a 3/8 inch tube. This design is an improvement from previous research, which used much smaller acrylic tubes with a diameter of 10 cm and a height of 17 cm, with a capacity of 1000 ml [11]. The electrode plate design consists of six plates, each measuring 15 cm × 10 cm, with three plates serving as the anode and three plates as the cathode.

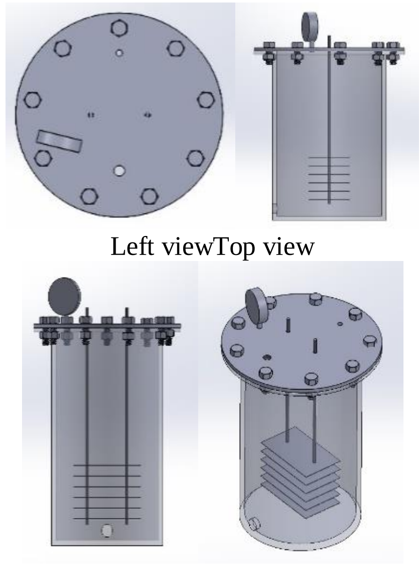


Fig. 2. Electrolysis reactor design.

Fig. 3 depicts hardware implementation results of the hydrogen production system prototype. The whole system is integrated and run according to its function to measure the gas concentration and temperature of the electrolyte solution in the reactor. In this design, the main component used to measure the concentration of hydrogen gas is an MQ-8 gas sensor. This sensor is connected to Arduino Uno as a controller. The MQ-8 gas sensor is placed in an airtight space. So silica gel was added to capture water vapour particles that are included in the hydrogen production from the electrolysis reactor.

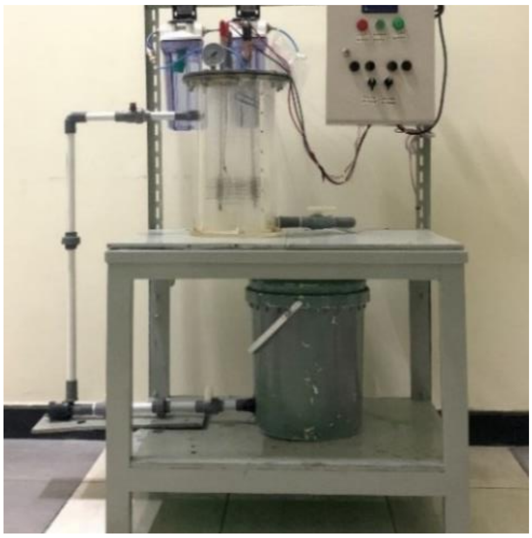


Fig. 3. The implementation of the prototype design.

This study utilized a 24 V 20A switching power supply for different current settings ranging from 5 A, 8 A, 10 A, 12 A, and 15 A. In this study, the basic conditions of 5 A, 8 A, 10 A, 12 A and 15 A were taken because of the ability of the power supply used. The range of increase in electric current used to represent the addition of every 2 to 3 Amperes.

Before entering the reactor plate rod, the wiring is connected first to the positive (+) and negative (-) of the buck-boost converter, and then the output is connected to the electrolysis plate rod.

The readings of gas concentration results and electrolyte solution temperature at each current supply will be displayed on the 16×2 I2C LCD. Fig. 4 is the implementation of the wiring design attached to the panel box.

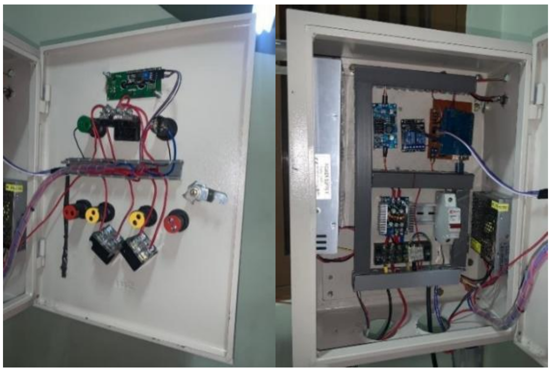


Fig. 4. Wiring in the panel box.

The MQ-8 sensor is utilized in this study, operating at a voltage of 5V and providing output in either analogue form (resistance) or digital form. The MQ-8 sensor can be used for hydrogen gas detection but the highest sensitivity of this sensor is at concentrations of 100 - 10000 PPM. The MQ-8 sensor works on the principle of resistance changes in detecting gas levels which are then converted into analogue output in the form of voltage. Fig. 5 shows the datasheet of the Rs/Ro comparison graph against hydrogen gas concentration in the use of the MQ-8 gas sensor [12]. Calibration of the MQ-8 gas sensor was conducted with the following steps:

2.1.1 Find the Regression Factor of the Sensor

In calibration, the a and b values are obtained from the gas characteristic graph of Fig. 5 to fulfil the parameters of the PPM equation. The a and b values are mathematical parameters used to model the relationship between sensor resistance and gas concentration. To obtain the X and Y variable values from the gas characteristic line on the MQ-8 sensor data sheet, the Web Plot Digitizer service is utilized through the browser.

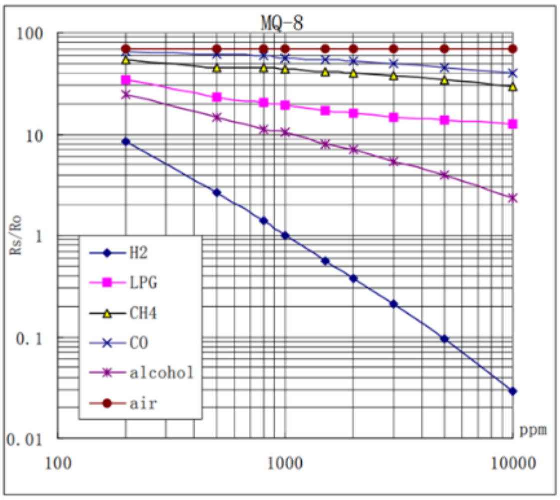


Fig. 5. The MQ 8 sensor gas characteristic curve.

So that the value of the regression factor of the hydrogen characteristic curve is obtained with a and b values of 973.8690234 and -0.6846049335 respectively and visualized on the graph in Fig. 6.

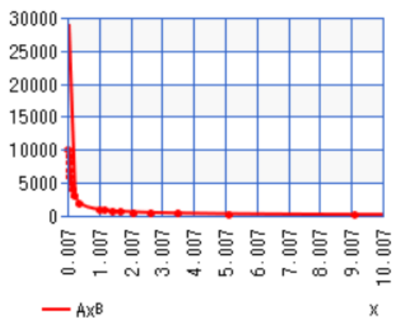


Fig. 6. Regression factor of hydrogen characteristics.

2.1.2 Find the Sensor Output Voltage Value

To determine the Vout value of the MQ gas sensor, no conversion value from analogue signal to voltage was discovered. As a result, direct measurements were taken using a multimeter. The Vout value of the sensor can be calculated using the Eq. 2.

$$Vout = adc \cdot volt \tag{2}$$

The sensor voltage is obtained from the output value read on the sensor. So that the Vout value is 1.39 V, the analogue value is 284 and the voltage of one analogue signal is 0.0052922535211268.

2.1.3 Finding the Value of Rs

The value of Rs can be found by knowing the circuit in the sensor in the form of a voltage divider, where the input voltage value (Vin), output voltage value (Vout), load resistance value (Rl), and sensor resistance value in the surrounding air (Rs). The parameter values contained in the MQ-8 gas sensor datasheet include an Rl value of 10 KΩ and a sensor input voltage of 5 V. The final value is obtained to determine the value of Rs in Eq. 3.

$$Vout = \frac{Rl}{Rl + Rs} . Vin$$

$$Rs = \frac{Vin - Vout}{Vout} . Rl$$

$$Rs = \frac{5 - Vout}{Vout} . 10 \tag{3}$$

Notes:
Vin = Input current (V)
Vout = Output current from the analogue sensor reading (V)
Rs = Sensitivity resistance (KΩ)
Rl = Load resistance (KΩ)

2.1.4 Finding the Value of Ro

After getting the value of the sensor output voltage and Rs. The next step was obtaining the value of Ro in a state of clean air. Ro is resistance in clean air or resistance in clean air. This refers to the resistance of the sensor when no gas is detected, or when it is exposed to air that is clean and free of target gases such as hydrogen. In this condition, the sensor resistance has a certain value as a reference. In Eq. 4, the known parameters such as a, b, and PPM can be substituted, so that the Ro value equation is obtained.

$$PPM = a \times (\frac{Rs}{Ro})^b$$

$$Ro = Rs \times (\frac{a}{ppm})^{1/b}$$

$$Ro = Rs \times (\frac{973.0964002}{1000})^{1/-0.6874520374} \tag{4}$$

2.1.5 Finding the PPM Value

After all the regression factor values and resistance values on this gas are known. Then find the value of PPM levels with the formula for finding PPM by substituting known parameters such as a, b. Thus, the PPM formula is obtained by Eq. 5.

$$PPM = a \times (\frac{Rs}{Ro})^b$$

$$PPM = 973.0964002 \times (\frac{Rs}{Ro})^{-0.6874520374} \tag{5}$$

The results of the parameters of Eq. 2 – Eq. 5 are used for the calculation value of the concentration of hydrogen content which will be implemented in the program in the Arduino IDE software.

2.2 The System Testing

The system testing is divided into two sections, which include the testing of ADC measurements from the MQ-8 sensor and the DS18B20 sensor. The purpose of this test is to assess the precision and error margin of each sensor.

2.2.1 The MQ-8 Sensor Testing

Testing the accuracy between the ADC value of the sensor and the multimeter as a reading comparison tool, obtained each reading value from the ADC displayed on the Excel data streamer and multimeter on the display. The results recorded on the multimeter displayed value and the sensor voltage are compared to the reading value to get the calculation of the error value and the average error. From Table 1, the results of the average error value are very small, namely 0.05336, where this value is still within the error range of the sensor, which is ≤ 0.6.

Table 1. The Comparison value between multimeter and the ADC voltage of MQ-8 gas sensor

Number	The voltage reading		Error
	Multimeter	ADC	
1	2.762	2.79	0.028
2	2.764	2.78	0.16
3	2.763	2.79	0.027
4	2.758	2.78	0.022
5	2.759	2.79	0.031
	Error average		0.0536

2.2.2 The DS18B20 Sensor Testing

DS18B20 temperature sensor testing is done with the help of a thermometer with a testing range of 25°C-100°C, then compared with the reading of the temperature sensor read on the LCD. There is a difference in value between the thermometer and the DS18B20 sensor in Table 2 in the form of an error value with an average of 0.4858. This error value is categorized within the DS18B20 sensor accuracy range of ±0.5ºC.

Table 2. The result of comparing the DS18B20 temperature sensor and thermometer

Standard	Reading		Error/accuracy
	Thermometer	DS18B20 sensor	
25	26	25.38	0.62
50	49.98	50	0.1
75	74.96	75.50	0.54
100	93.5	94.63	1.13
	Error average		0.458

3 Results and Discussion

3.1 Testing the PPM Value of the MQ-8 Sensor

Testing the MQ-8 sensor in ambient temperature conditions, the PPM value obtained is shown in Table 3. This normal air condition is carried out in a room with room temperature during testing as high as 25°C. The use of the MQ-8 hydrogen gas sensor is very efficient in the application of IoT technology [13]. This MQ-8 gas sensor is used to measure the concentration of hydrogen gas in the air using a microcontroller circuit such as Arduino. This MQ-8 sensor is very sensitive to hydrogen gas. The gas material detected by the MQ8 gas sensor is hydrogen gas (H_2). The gas concentration measurement range starts from 100 to 10000 PPM.

Hydrogen gas sensor testing is done by measuring the output voltage of the MQ-8 sensor and then recording the ADC value and hydrogen gas level data (PPM) displayed on the Arduino IDE serial monitor. The measured voltage from the calculation of the ADC value is then compared with the voltage measured by a multimeter. The process of reading data on hydrogen gas levels is carried out continuously by Arduino. Hydrogen gas testing is carried out under the condition that the sensor is placed in a room temperature room with normal air conditions (without smoke).

Table 3. The readingresults of MQ-8 sensor in normal air condition (without smoke)

ADC	Voltage	Rs	Ro	PPM	Status
			14.52		
308	1.47	23.92		691.93	In range
308	1.47	23.92	14.52	691.93	In range
308	1.47	23.92	14.52	691.93	In range
308	1.47	23.92	14.52	691.93	In range
308	1.47	23.92	14.52	691.93	In range
307	1.47	24.04	14.52	689.75	In range
308	1.47	23.92	14.52	691.93	In range
308	1.47	23.92	14.52	691.93	In range
307	1.47	24.04	14.52	689.75	In range

3.2 Calculating the Truth Value

Data samples during testing from the 6th to the 10th minute. From these data samples, each truth value is calculated with the relationship between Rs/Ro and PPM. The value of the gas sensor characteristics, the scale factor value obtained in the form of a is 973.8690234 and b is -0.6846049335, the calculation is visualized in the form of a comparison of the reading value and the calculation value of $y = a\left(\frac{R_s}{R_o}\right)^b$ in Table 4. The scenarios run using data samples during testing at the 6th minute to the 10th minute. From these data samples, each truth value is calculated with the relationship between Rs/Ro and PPM.

Table 4. The comparison of reading value of MQ-8 sensor and PPM formula

Current (Ampere)	Time (minutes)	Rs/Ro	PPM measurement	PPM formula	Error PPM
	6	0.731	1206.540	1206.380	0.161
	7	0.726	1212.899	1212.655	0.245
5	8	0.721	1218.534	1218.254	0.281
	9	0.717	1223.366	1223.086	0.281
	10	0.714	1226.966	1226.704	0.262
	6	1.685	681.562	681.321	0.241
	7	1.606	704.097	703.975	0.123
8	8	1.588	709.617	709.508	0.109
	9	1.541	724.294	724.167	0.127
	10	1.479	744.996	744.891	0.105
	6	0.400	1823.338	1822.381	0.957
	7	0.371	1919.670	1919.074	0.596
10	8	0.349	2003.185	2002.605	0.580
	9	0.330	2080.013	2079.148	0.865
	10	0.313	2158.129	2158.619	0.491
	6	0.657	1301.172	1298.073	3.100
	7	0.556	1456.497	1455.400	1.097
12	8	0.512	1539.778	1539.530	0.248
	9	0.505	1555.793	1555.389	0.404
	10	0.508	1549.016	1548.621	0.394

	6	1.077	926.626	925.691	0.935
	7	1.023	959.204	958.902	0.303
15	8	1.216	854.684	851.650	3.033
	9	1.640	696.688	694.090	2.598
	10	1.929	621.453	621.198	0.254

The results displayed in Table 4 demonstrate varying measurements for each experiment conducted under different scenarios of changing the electric current from 5 to 15 Amperes. The use of electric current at 10 Amperes obtained PPM which is greater than the use of other electric currents. This is due to the ability of the MQ-8 sensor to take measurements and temperature limits in specifications. In addition, the ability of the saturated electrolyte to be able to produce hydrogen.

3.3 The Relationship of Current Effect on Production Yield

The results of the five experiments were compared with the value to get optimal performance results of hydrogen production. The results of data observations and graph curves displayed in Fig. 7, the hydrogen gas monitoring process will be stable when run first for ± 5 minutes, after more than 5 minutes the results of the hydrogen gas monitoring process can be stable as it experiences a significant increase in hydrogen content values. A comparison of the lines of each test shows that the greater the value of the current flowed, the more hydrogen production levels is increasing rapidly within a short time. The formation of hydrogen gas in the electrolysis process has a directly proportional relationship between gas yield, time, and current strength. For gas yields with the highest hydrogen content reading the value of 3405.77 PPM at a current flow of 8 A. Table of maximum and minimum values of the overall process conditions in Table 5. From the five trials of the current variation, there is a decrease in PPM levels as the process runs. The saturation level of sensor readings from these five process conditions after reaching the peak reading of the sensor, with a maximum average hydrogen content of 2932.306 PPM.

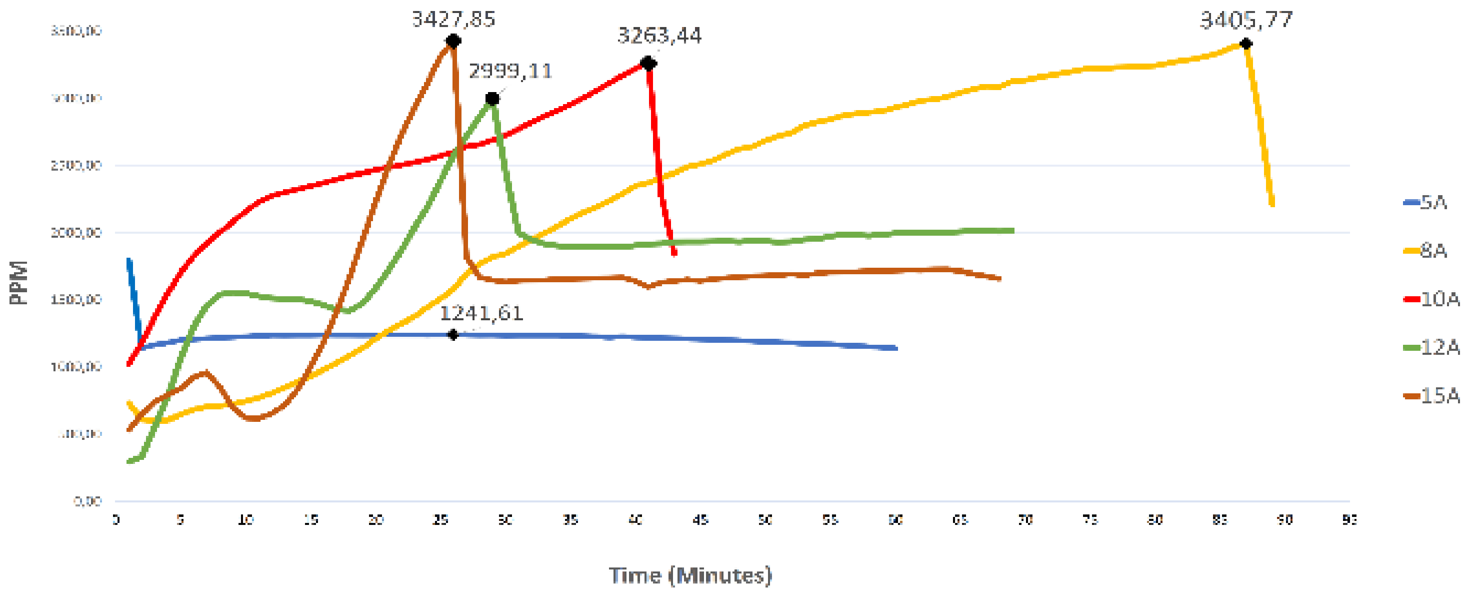


Fig. 7. The graph of current transformation testing of 5 A, 8 A, 10 A, 12 A and 15 A.

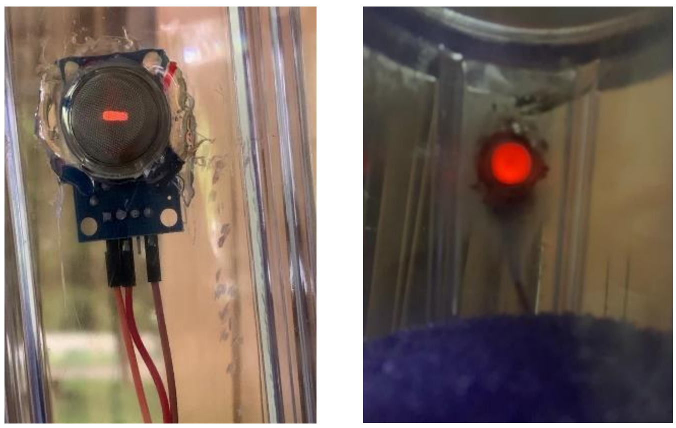
Table 5. Themaximum and minimum values of PPM reading

	Max value (PPM)	Min value (PPM)
5 A Condition	1239.7	960.46
8 A Condition	3446.04	598.39
10 A Condition	3303.12	847.54
12 A Condition	3196.62	293.16
15 A Condition	3476.05	530.72
Average	2932.306	646.054

In all four process conditions, namely 8 A, 10 A, 12 A, and 15 A after passing the value of ± 3000 PPM, it will drop and make the MQ-8 sensor readings experience a decrease in performance reading the measured hydrogen levels.

The cause of this decrease in hydrogen concentration in terms of sensor electronics as the main sensing element is because the MQ-8 gas sensor has a voltage divider working principle, where the change in output voltage (Vout) which can be used to indicate the concentration of gas detected from measurements at the variable resistance point (Rl) changes in value according to the amount of gas detected. Over time the gas sensor experiences wear and tear or ageing that can change the sensitivity and resistance characteristics of the sensor resulting in the physical sensor becoming hotter as shown in Fig. 8. This can cause changes in voltage readings and unwanted voltage drops.

Another cause of this decrease in hydrogen concentration is the presence of a saturated or concentrated electrolyte, which results in the restriction of anion and cation movement in the solution. The restriction of the movement of ions leads to a reduction in the ability of the solution to conduct electricity and reduces the efficiency of the electrolysis reaction. As a result, hydrogen gas production will also be reduced. Some of the factors that affect the movement of ions in solution to conduct electricity include ion concentration, hydration, attractive forces between ions, and temperature [14].



(a) (b)

Fig. 8. Sensor observations during the process. (a) Range 100-300 PPM, (b) maximum range.

3.4 The Interaction between Current and Electrolyte Temperature

Monitoring the temperature of the electrolyte solution to see the effect of current on the condition of the solution. In Fig. 9, there is a distinguishing phenomenon from the five current setting parameters to the temperature reading results. In the condition of 5 A, the temperature read shows a stable/constant value at an average temperature value of 27°C in the process period of 43 minutes, there is a decrease in temperature value from the initial minute to the final minute with a difference of -0.06°C.

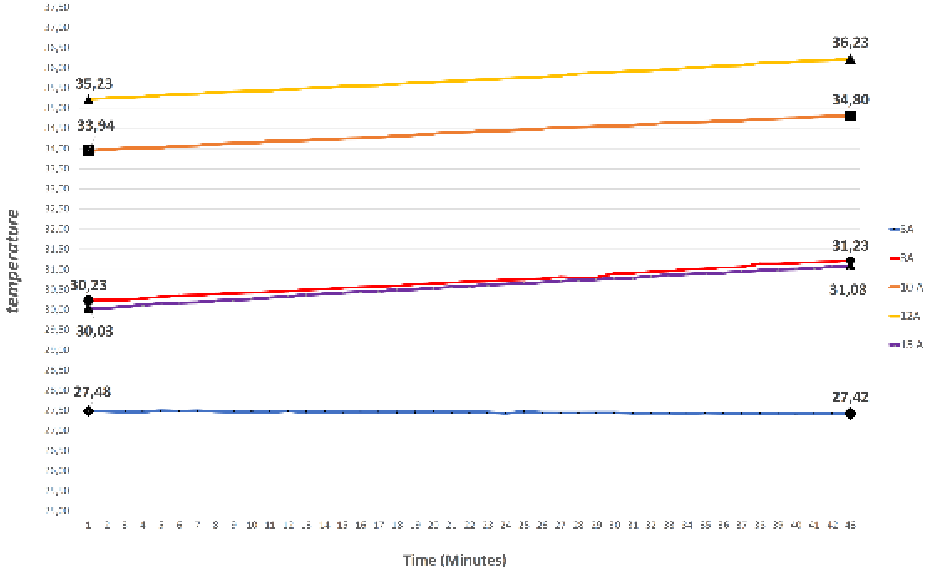


Fig. 9. The current testing of the electrolysis reactor temperature.

The other four parameters such as 8 A, 10 A, 12 A, and 15 A have process characteristics the longer the process time runs, the temperature value also increases. This proves that the rising in temperature is directly proportional to time. The magnitude of the gas concentration of the growing production is due to the extended production time of hydrogen gas. Along with the increase in time, the heat temperature of the solution in the electrolysis reactor is also escalating [15]. Table 6 is the changes that occur during the 43 minutes process. The target results of this research on the amount of PPM in hydrogen and temperature in the electrolysis reactor.

Table 6. The deficit between theinitial and final temperature value

Current (A)	T_1 (°C)	T_2 (°C)	$\Delta T = T_2 - T_1$(°C)
5	27.48	27.42	-0.02
8	30.23	31.23	1
10	33.94	34.80	0.86
12	35.23	36.23	1
15	30.03	31.08	1.05

4 Conclusion

The implementation of the hydrogen electrolysis reactor design has been successful with several tests. Based on the results of testing the MQ-8 gas sensor with a variation of the supply current flowed to the electrode plates of 5 A, 8 A, 10 A, 12 A, and 15 A has a different characteristic value produced. The higher the current supplied to the electrolysis reactor, the faster the PPM value reading rises. The rise in PPM is also the same as the rapid filling of the gas bag container. However, it makes the process very quickly become saturated. The researchers observed that the measurements of hydrogen gas during the monitoring process reached a stable state approximately 5 minutes after starting the experiment. However, there was a decrease in hydrogen levels after more than 20-40 minutes of running in the current variation experiment, the maximum concentration value was 3405.77 PPM. This decrease is due to the presence of a saturated or concentrated electrolyte, which limits the movement of ions in the solution. This reduces the ability of the solution to conduct electricity and the efficiency of the electrolysis reaction, resulting in reduced hydrogen gas production. Factors such as ion concentration, hydration, attractive forces between ions, and temperature also affect the movement of ions in solution to conduct electricity.

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