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Article

Electrolyte Optimization Study on Dry Cell Generator Electrolysis System for Producing Hydrogen Gas Using RSM Method (Response Surface Method)

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Abstract. This study aims to determine the optimum condition of hydrogen gas produced through the electrolysis process of dry cell generators using RSM program. To produce hydrogen gas is done through the method of water electrolysis by decomposing the molecule H_2O into hydrogen gas and oxygen gas with the help of direct electric current. Hydrogen gas productivity by electrolysis method applied to DC generators using 4/4 plate electodes (Cu/Al) as cathodes and $NaNO_3$ solutions as electrolytes. The current and voltage used in this electrolysis process is 0.6 ampere and 2 volts for 1 hour. The concentration of hydrogen gas produced is determined using the MQ-8 sensor. The optimum condition of hydrogen gas concentration obtained is at $NaNO_3$ 1 M concentration and 60 minutes with hydrogen concentration produced as much as 143.393 ppm. The verification result value for hydrogen gas concentration is 144 ppm, so the program's recommended solution is good enough.

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1. Introduction

Population and economic growth in the world is directly proportional to the utilization of fossil fuels and the impacts on the environment [1-4]. Currently, 81% of the entire supply of primary energy, and 66% of power plants are sourced from fossil fuels (coal, natural gas and oil), whichproduces almost 100% of all CO2 gas emissions in the world [5-7]. At the current level of fossil energy consumption, the world's coal, oil and natural gas reserves are proven to be expected for use for approximately 20, 40 and 60 years. Natural gas and liquid fuel output appear to peak around 2005–2015 and 2030, respectively [8]-[9]. After that, those resources will suffer a setback. Conventional fuel that is limited becomes the main concern because of its depleted nature. The rise in global temperatures, which is mostly caused by GHG (greenhouse gas) emissions from its production and burning, is currently receiving considerable attention [10-11].

Only trace quantities of hydrogen (0.07%) are present in the atmosphere, and it is extremely rare (0.14%) on Earth's surface. Although extremely rare, hydrogen has been discovered at higher concentrations in some nitrogen-containing wells [12]-[13]. Only trace quantities of hydrogen (0.07%) are present in the atmosphere, and it is extremely rare (0.14%) on Earth's surface. Although extremely rare, hydrogen has been discovered at higher concentrations in some nitrogen-containing wells [1][14].

Technology has been created on a variety of sizes to manufacture hydrogen, which is widely utilized as a chemical raw material in industry. A multifold boost in manufacturing capacity will result from the widespread use of fuel made of hydrogen. The energy required to create hydrogen is always higher than the energy it produces. As a result, energy and feedstock will be needed to produce hydrogen [15-17]. Given the high level of global the use of energy that damages the environment because of fossil fuel use, renewable energy sources are perfect for producing sustainable hydrogen [18-19].

Another benefit is that hydrogen can be used for domestic purposes and safely transported using conventional transportation methods. To provide It can alternatively be stored as compressed gas, cryogenic liquid, or solid hydride for stationary fuel cells. Currently, there are roughly 0.1 GT of hydrogen produced year, most of which is used locally for treating and refining metals. Utilizations such the production of power and heating in the domestic and industrial sectors are envisaged in the near future. A tiny portion is currently utilized to fuel driving automobiles [20-21].

Water is one of the most plentiful raw materials and infinite resources on Earth, and it can be separated using techniques like electrolysis, thermolysis, and photo-electrolysis to produce hydrogen. The hydrogen generated will be the most environmentally friendly energy carrier available to humanity if the necessary energy input is provided by a renewable energy source [18]. One of the fuels with the highest energy conversion rates for the transportation industry is hydrogen [22-23]. Furthermore, due to its density (0.0899 kgNm3 at 0°C and 1 atm), Compared to gasoline, hydrogen is 2.5 times more efficient. Storage energy for 1.0 kilogram of hydrogen is thought to be higher than for 2.75 kg of gasoline. As a result, 0.27 L of gasoline and 1 L of hydrogen have equivalent amounts of energy [24-25].

Based on literature searches using endnotes, there are about 385 researches on hydrogen renewable fuels that have been developed in the world. Despite being an effective method of energy storage and transportation, electrolysis only produces 4% of the hydrogen produced worldwide [5]. Currently, the method of using energy in containers with water that produces hydrogen gas most frequently employed is electrolysis cells [26-28]. Only around 4% of hydrogen can be created by using regular electrolysis since it takes a lot of energy to break down water molecules into ions. As a result, an electrolyte is required to break apart the molecules of water [29-30]. Design of electric current-based dry cell producing reactors for dispersing hydrogen and oxygen gases in water molecules [31-32]. This study aims to identify the ideal hydrogen gas concentration generated using the Design Expert 6.0.9 (trial version) Response Surface Methodology (RSM) program.

2. Experimental Section
2.1. Tools and Materials
The tools and materials used in this study are arduino uno, Power Supply, Aluminum (0.7 mm thick), copper (0.4 mm thick), acrylic, socket, bolt 13, saw, drill, tube, gasket (2 mm), hose, MQ-8 sensor, Glassware, $NaNO_3$, aquades.

2.2. Generator Prosedure
Copper plate (0.4 mm) and aluminum plate (0.7 mm) in the form of sheets cut with a width of 10 cm and a length of 10 cm as much as 8 sheets and arranged sandwiches as shown in Figure 1. Then the electrodes are limited by gasket and arranged with a plate count of 4/4 (Cu/Al).

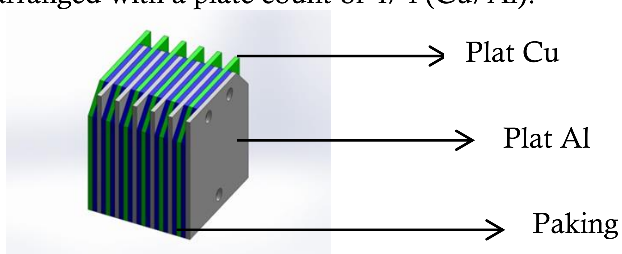

Figure 1. Electrode sandwich model

Prepare tools and materials in the form of reactors, MQ-8 sensors and arduino uno that have been assembled and connected. Then, prepare a power supply that has been paired with electrodes. After that, insert a solution of $NaNO_3$ in the electrode container as a material for electrolysis. Once all the tools are connected and the current and voltage are given then the hydrogen gas readings can be seen on the PC screen like Figure 2.

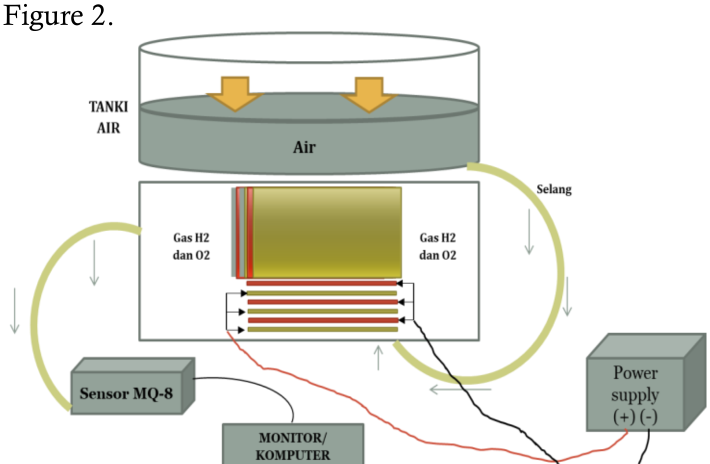

Figure 2. Dry cell generator work scheme

2.3. Formulation and Response Design
Design formulations and responses using Design Expert 6.0.9. The free variables used are NaNO3 concentration 0.25M-1M and 10-60 minutes time. The minimum and maximum limit values are included in the program for combination randomization so that the draft formula will be analyzed

Table 1. Free variable value range

Name	Units	Low	High
$NaNO_3$ Concentration	M	0.25	1
Time	Minute	10	60

2.4. Formulation and Response Analysis

Formulation is a measurement stage according to the formula provided by the program. The measurement process begins with the creation of a solution of $NaNO_3$ with the concentration targeted by the program (Table 1). Each response variable is analyzed using Anova (Analysis of Variance). The model used for variable analysis is a model that generates significant value on Anova and non-significant on lack of fit.

Table 2. Factor formulation design using design expert program 6.0.9

Formulation	Factor	
	$NaNO_3$ Concentration (M)	Time (Minutes)
1	0.625	35
2	0.625	35
3	0.625	35
4	0.625	35
5	0.625	35
6	0.75	35
7	1	35
8	0.625	60
9	0.625	10
10	0.25	10
11	0.25	10
12	1	10
13	1	10
14	0.25	60
15	0.25	60
16	1	60
17	1	60

2.5. Optimization and Verification

At the optimization stage, each response is determined by the optimization objectives with the Design Expert 6.0.9 program. Optimizations performed by the program in accordance with variable data and measurement data obtained are included in (Table 2). The output of the optimization stage in the form of recommendations of optimal new formulas suggested by the program (Table 3).

Table 3. Optimized response components, targets and limitations at the optimization stage

Response Components	Target	Lower limit	Upper limit
$NaNO_3$ Concentration (M)	Within the limits	0.25	1
Time (Minutes)	Within the limits	10	60
Hydrogen Concentration (ppm)	Maximum	-	-

3. Results and Discussion

3.1. Hydrogen Gas Concentration Optimization

As seen from Table 4, the concentration of hydrogen gas varies from 81 ppm to 144 ppm. Analysis of variance (ANOVA) findings showed that the selected response model is quadratic because its R value is larger than that of other models, which is 0.8465 This design is also significant with a p value less than 0.05. (0.0009). The ANOVA findings also revealed a relationship between the response of hydrogen gas concentrations and the concentration of $NaNO_3$ and time, with a negligible lack of fit larger than 0.05 (0.5231). The insignificant lack of fit value indicates the suitability of response data with the resulting model and the condition of a model is said to be good [33-35].

Table 4. Results of measurement of the hydrogen gas concentration response

Formulation	Factor		Responds
	$NaNO_3$ Concentration (M)	Time (Minutes)	H_2 Concentration (ppm)
1	0.625	35	81
2	0.625	35	92
3	0.625	35	90
4	0.625	35	88
5	0.625	35	89
6	0.75	35	83.5
7	1	35	114.5
8	0.625	60	114
9	0.625	10	99
10	0.25	10	101
11	0.25	10	99
12	1	10	85
13	1	10	117
14	0.25	60	100
15	0.25	60	114
16	1	60	144
17	1	60	142

The program suggests up to four formulae for optimization (Table 6). One formula, formula one, is chosen to be validated out of the four optimization solutions. Using table 6, the program's projected value for formula one produced a hydrogen concentration of 143.393 ppm. The estimated interval (PI) ranges from 138.29 ppm to 146.79 ppm.

Table 5. Hydrogen gas concentration model analysis

Responds	Model	Mathematics	Significant ($p<0.05$)	Lack of fit ($p<0.05$)	R^2
H_2 concentration	Quadratik	Y= -112.4654A –1.767007B+ 84.05987A^2 +0.022958B^2+ 0.96000AB	0.0009	0.5231	0.8465

A sandwich-style arrangement with a 2 mm gap was used 4/4 plate (Cu/Al) in this investigation with an electrode model. Ions that are capable of producing hydrogen gas relatively successfully can travel short distances with little resistance. The faster the electrons flow and come into contact with each other due to the shorter cathode to anode distance [36-38]. Research uses the electrode configuration of 4/4 (Cu/Al) (19) Due to the possibility of the generator operating less effectively and producing less hydrogen gas than it might with higher currents, voltages, or plate counts, the generator is designed to function at 0.6 A and 2 V, respectively. The following RSM equation may be used to optimize the $NaNO_3$ concentration factor and the reaction time to hydrogen gas concentration:

$$Y= -112.4654A -1.767007B + 84.05987A2 + 0.022958B2+ 0.96000AB$$

Notes:
A: Concentration of $NaNO_3$ B: Time

The amount of hydrogen gas will be less concentrated as time and the concentration of $NaNO_3$ both rise, according to the aforementioned equation. The drop in the hydrogen gas concentration value, it is believed that be caused by the mobility of anions and cations becoming constrained in the electrolyte solution and the electrode becoming weak over time during electrolysis. This is because the concentration of $NaNO_3$ gradually reaches saturation. The negative constant value serves as a visual cue for this. Positive constant values suggest that the concentration of hydrogen gas created during interactions between $NaNO_3$ concentrations and time are often directly proportional to one another.

Table 6. Formulas produced in the optimization stage

Number	$NaNO_3$ Concentration	Time	H_2 concentration	Desirability
1*	1.00	60.00	143.393	0.990
2	0.25	60.00	105.736	0.627
3	0.25	10.00	101.736	0.416
4	1.00	10.00	103.393	0.355

Note *: Selected

Figure x's graph of a surface contour illustrates a variety of elements that can have an impact on the hydrogen gas concentration value. The impact of $NaNO_3$ concentration and duration on the concentration of hydrogen gas generated may be seen in both contours and 3D forms. The highest concentration of hydrogen gas was maximized at a concentration of $NaNO_3$ 1 M for a period a hydrogen concentration of 143.393 ppm for 60 minutes.

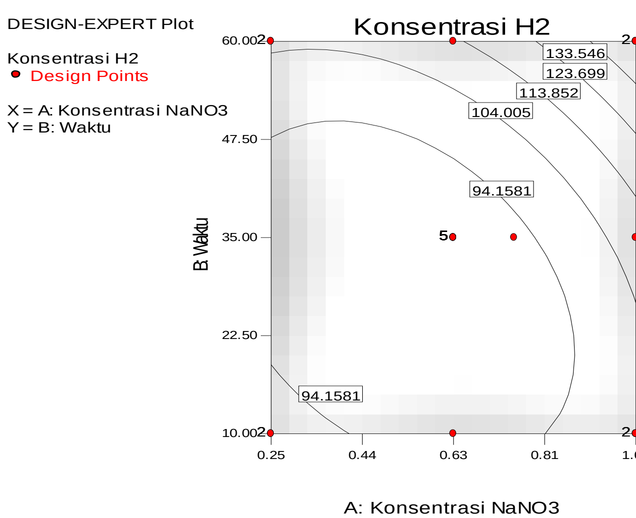

Figure 3. Results of hydrogen gas concentration tests: surface response contours

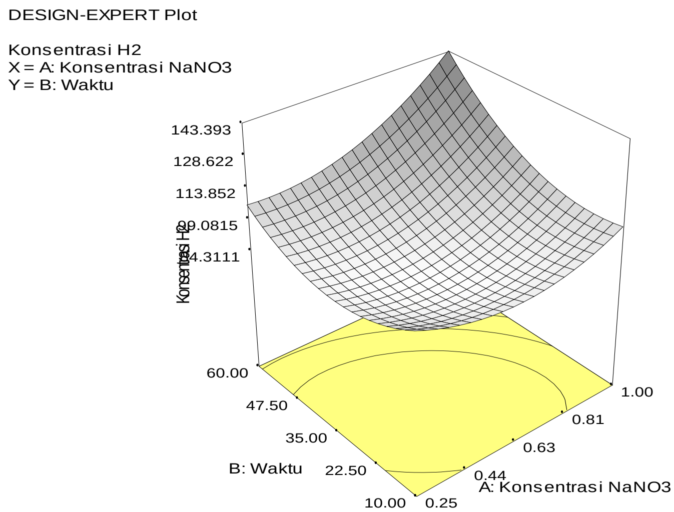

Figure 4. Results of a 3D kind of hydrogen gas concentration test

Figure 3 demonstrates the direct relationship between the concentration of hydrogen gas generated and the time and concentration of $NaNO_3$. With a high concentration of electrolytes, the resistance in the electrolytes may be reduced more quickly, speeding up the transfer of electrons during electrolysis. While the temperature rises during the electrolysis period also speeds up the flow of electrons to break down water molecules into constituent parts, resulting in more hydrogen gas being produced.

3.2 Optimization and Verification Results

It is possible to do optimization after acquiring the mathematical model of the answer [39-41]. The aim of optimization is to find the ideal model combination and produce the appropriate response desired.

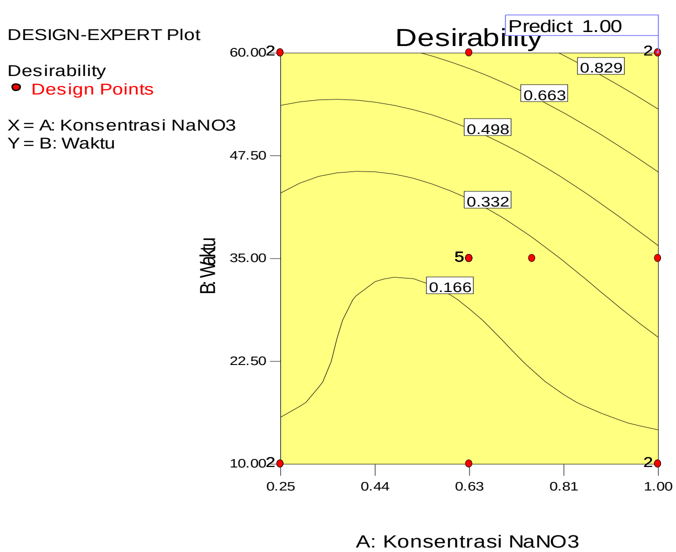

Figure 5. Value of contour desirability in the optimal formula

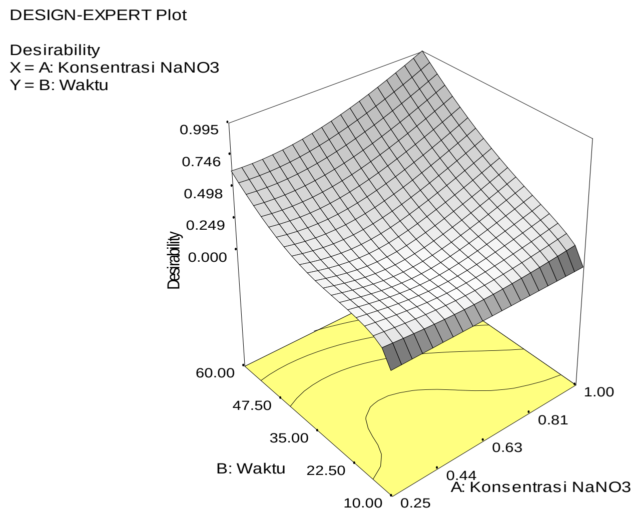

Figure 6. 3D form of Optimum Formula Desirability value

Table 7. The Design Expert Program for Optimal Solution Response Value Verification, Prediction, and Outcome 6.0.9

Responds	Predictions	Verification	95% Prediction Interval	
			Low	High
Hydrogen Gas Concentration (ppm)	143.393	144	138.29	146.79

A value for desirability that is almost one indicates the optimal optimization value [42-43]. The desirability values range from 0 to 1. Table 3 shows the optimized components, targets and minimum or maximum limits. Based on the optimization process, the Design Expert 6.0.9 software presents four optimization possibilities, with a concentration of $NaNO_3$ 1 M and a time of 60 minutes being suggested as the ideal formula solution since it has the greatest desire value of 0.990. A hydrogen gas concentration of 143.393 ppm is expected to be produced by the formula with a concentration of $NaNO_3$ of 1 M and a period of 60 minutes. This hydrogen concentration gas will have characteristics that fit the optimization objective. This can be concluded because the desirability value is approaching one.

Figure 6, explaining the optimization of the results in contour (2D) form. Contour is a two-dimensional representation of the response presented by the model using a predictive model for the value of hydrogen gas concentration. The contour chart's dots represent multiple combinations of $NaNO_3$ concentration and duration that result in the same precise desire value [39][44]. The projected location in the picture combines a $NaNO_3$ concentration of 1M with a time period of 60 minutes, yielding a 0.990 desirability value.

The verification of the optimal design formula yielded results with a hydrogen gas concentration of 144 ppm, which was recommended by expert program 6.0.9. When compared to the predicted value, the value of the verification result falls between the 95% low and 95% high predicted intervals (Table 7). It may be said that the Design Expert Program's advised optimum solution's chosen formula is rather good.

4. Conclusion

By including the concentration of hydrogen gas generated with respect to time and concentration during the electrolysis process may be increased. Four optimization techniques using one confirmed formula, formula 1, were produced from the optimization results. The chosen solution's components include a $NaNO_3$ concentration of 1 M and a 60-minute time period. The Design Expert program's suggested solution is adequate because a measurement used to verify the chosen solution response is a hydrogen gas concentration of 144 ppm.

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