

Effect of anode depth and conductivity of electrolyte solution on energy consumption in plasma electrolysis

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Abstract. This research was conducted to investigate the effect of anode depth and conductivity of electrolyte solution on required energy for plasma generation in plasma electrolysis. The experimental parameters were composed of different depth of anodes (0, 15, 25, 45, and 65 mm) and various solution conductivity. The difference in electrolyte solution conductivities is presented by different concentration of Na₂SO₄ (0.01, 0.02, 0.03, and 0.05 M). A batch reactor (diameter 130 mm, height 190 mm) with tungsten electrodes (cathode diameter 6 mm and anode diameter 0.5 mm) was used by applying a continuous cooling system. Current was observed in various voltage (40 – 400 V) for 30 second in each voltage. Energy consumption for vapor formation and discharge plasma found higher at deeper position of anode. At higher conductivity of electrolyte solution, although energy consumption for vapor formation was observed lower, energy consumption for plasma discharged was found higher.

1. Introduction

At a sufficiently high voltage, conventional electrolysis changes spontaneously into plasma electrolysis [1] [2]. The process of plasma formation begins with a normal (conventional) electrolysis characterized by the formation of a gas bubble on the electrode. At this stage the voltage increase directly proportional to the increasing current. After the breakdown voltage, gas bubbles containing hydrogen, oxygen and water vapor form a gas layer that encloses the electrode with the smallest surface area [3]. The phenomenon of the formation of gas sheath can be illustrated using the current and voltage characteristic curves during the plasma electrolysis process [4] where the value of voltage and breakdown current (V_B and I_B) and voltage and discharge current (V_D and I_D) can be determined by using the characteristic curves.

The effectiveness of a process can be seen from the amount of energy consumption during plasma electrolysis. During the process of plasma electrolysis, the formation of the sheath caused by joule heating requires the greatest energy consumption [5]. Some variables such as the anode depth and the conductivity of the solution affect the amount of energy required, such as energy breakdown (E_B) and discharge energy (E_D), during the plasma formation process. Previous studies have shown that the value of E_B was greater as the contact surface of the anode is larger. The immersed anode can cause the energy required for the formation of the sheath around the anode is larger. Additionally, hydrostatic pressure in water causes the difficulty of forming a gas layer on the anode so that a larger



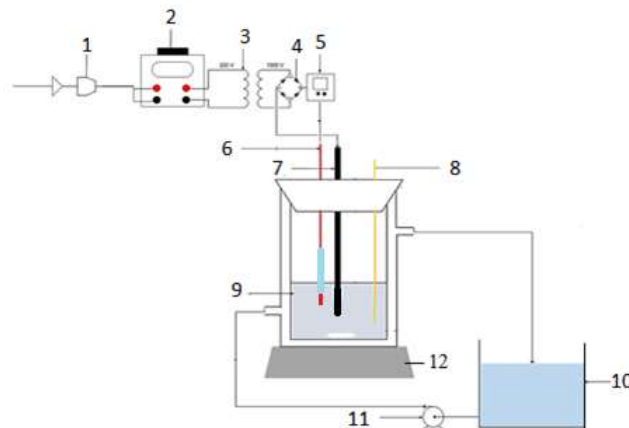
E_B is required [6]. In this experiment the calculation of energy consumption will be carried out with the same anode surface area at the depth variation so that the energy changes that occur are only functions of the anode depth position.

The conductivity of the solution also affects the value of V_B and I_D [7]. The increase in the conductivity of the solution can decrease the V_D [1] and increase the I_D , but does not affect the E_D value [5]. The results of the research have shown that the value of E_B and E_D is lower with increasing concentration of solution [8]. While in experimental results conducted by Ahmed et al. [7] showed that the value of E_B will decrease with increasing the conductivity of the solution, but the value of E_D will increase with increasing the conductivity of the solution. In this research, the calculation of energy consumption is also performed on various conductivity where the conductivity changes with the addition of Na_2SO_4 at various concentrations.

2. Materials and Methods

The circuit of plasma electrolysis reactor can be seen in figure 1. The plasma electrolysis reactor is made of transparent tube with tungsten electrodes, 6 mm diameter of cylindrical cathode and 0.5 mm diameter of anode which is coated by glass (quartz). The voltage source at the reactor electrode comes from the PLN's voltage-controlled electricity using a slide regulator, transformer, and bridge diode. Then the flowing current is observed with multi-meter. Tests conducted to determine the energy consumption of plasma formation in the anode depth position variable and the conductivity of the solution. The change in the conductivity of the electrolyte solution was made by mixing Na_2SO_4 at a concentration of 0.01 M; 0.02 M; 0.03 M; 0.05M into the distilled water. While the variation of anode depth position is at 5 mm, 15 mm, 25 mm, 45 mm and 65 mm.

Measurements are made to the voltage, current, time, temperature and conductivity of the solution from the beginning of the electrolysis to the establishment of stable plasma electrolysis. Based on the data obtained, a curve of voltage-current characteristics is used to find out the values of V_B , I_B , V_D and I_D at various anode depths and the conductivity of the solution and also the amount of energy during the plasma electrolysis process.



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|--------------------|-----------------|-------------------------|----------------------|
| 1. MCB | 4. Diode bridge | 7. Katode | 10. Cooler water |
| 2. Slide regulator | 5. Multi-meter | 8. Thermometer | 11. Pump |
| 3. transformator | 6. Anode | 9. Electrolyte Solution | 12. Magnetic stirrer |

Figure 1. The circuit schematic of plasma electrolysis reactor.

3. Results and Discussion

3.1. *I - V characteristic curve on plasma electrolysis*

From the experimental results there is a relationship between the current (I) and the voltage (V) as shown in figure 2. The I-V curve has a characteristic during the plasma electrolysis of which the image can be identified for several zones:

- Ohmic zone: $0 < V < V_B$; the current increases linearly with the added voltage applied in accordance with the ohm law. In this section there is conventional electrolysis in water characterized by gas bubbles around the anode. V_B is referred to as breakdown voltage [9]. The absence of a current line at the beginning of the curve at a very low voltage (0 - 40 V) indicating the absence of current flowing from the electrolysis process that has not yet taken place.
- Transition zone: $V_B < V < V_D$; the current begins to decrease with increasing voltage due to the formation of gas sheets around the anode, which occurs the process of forming and breaking gas bubbles that occur oscillations in the current. When a gas layer is formed on the anode, the current cannot rise again and the current will begin to decrease as the anode and the solution do not come into contact anymore. V_D is called the discharge voltage.
- Plasma zone: $V > V_D$; the current begins to increase as the voltage increases and the light emitted becomes lighter. The colors emitted correspond to the metal ions in the electrolyte solution [2].

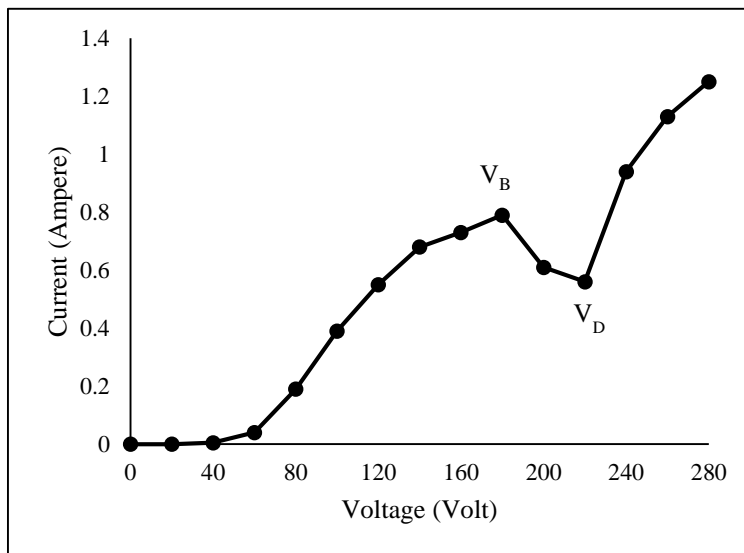


Figure 2. The voltage-current characteristic curve in the 0.02 M Na_2SO_4 electrolyte solution at a depth of 15 mm and a temperature of 65 °C.

3.2. *Effect of parameter changes*

At various experimental parameters it is found that the values of V_B , I_B , V_D and I_D are influenced by the anode depth position and the conductivity of the electrolyte solution, which also affect the energy consumption during the formation of the plasma shell.

3.2.1. Effect of anode depth position. The deeper the anode, the higher the energy required to begin the formation of the gas shell (E_B), as shown in Figure 3. Several previous studies have shown similar results [4] [8] despite differences in the extent of contacts of dyed anodes. In the previous experiment the area of anode contact increased with the deepening of the dyed anode causing the energy consumption for the formation of the envelope to become larger. While in this experiment the area of contact is made fixed by mounting the glass sheath on the anode. Thus the increase in energy occurs in

the addition of depth occurs due to the growing hydrostatic pressure. The deeper the anode position, the greater the hydrostatic pressure, the higher energy (E_B) required to form the plasma shell.

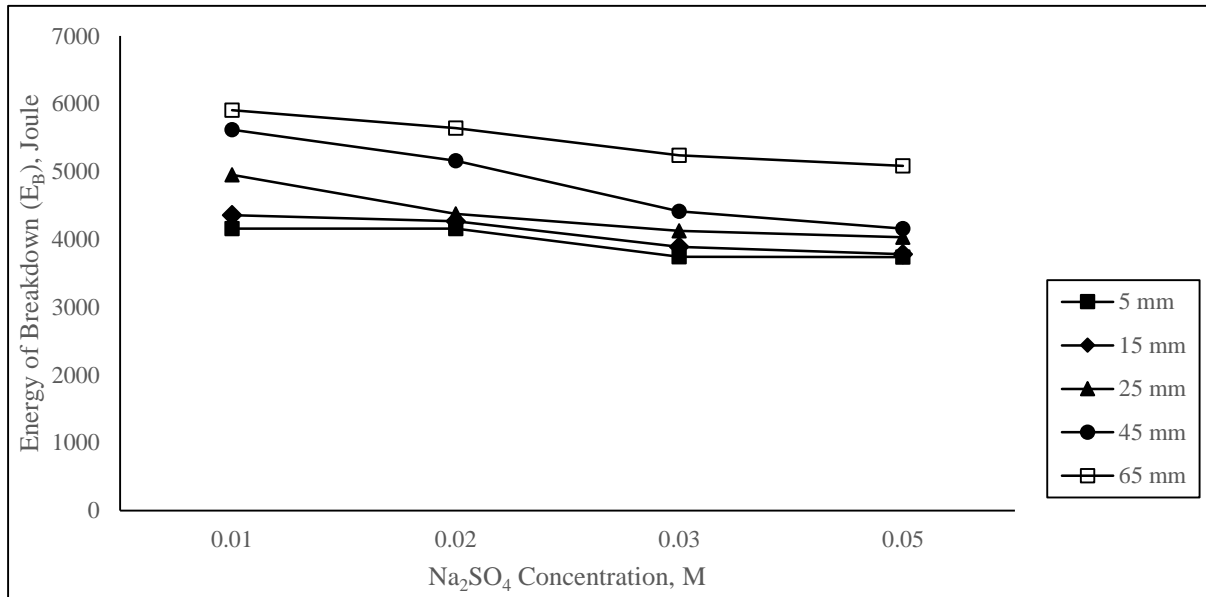


Figure 3. Energy consumption at breakdown voltage (E_B) at temperature 65°C.

3.2.2. Effects of conductivity of electrolyte solution.

Table below shows the values of breakdown voltages and currents (V_B and I_B) as well as the voltage and current discharge (V_D and I_D) on various conductivities using the Na_2SO_4 concentration variations. Changes in the conductivity of the solution affect the breakdown voltage (V_B) on the plasma formation in solution. Figure 4 shows that the higher the conductivity, the V_B required for the formation of the gas shell is lower. At higher conductivity, conduction current increases, ohmic heating increases, requiring a lower breakdown voltage [7]. Conversely, at low conductivity, the resistance in the solution becomes higher so that the conduction current decreases, the ohmic heating decreases, requiring a higher breakdown voltage.

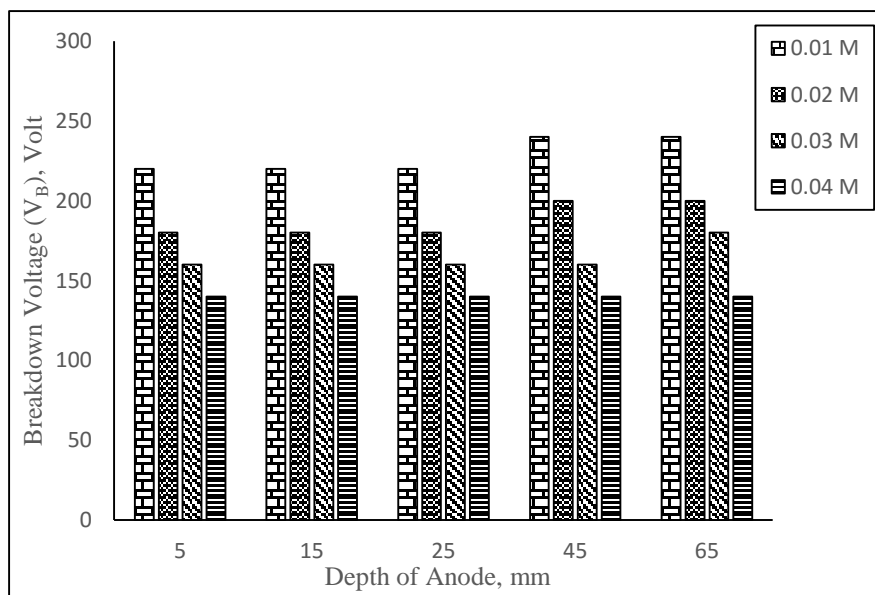
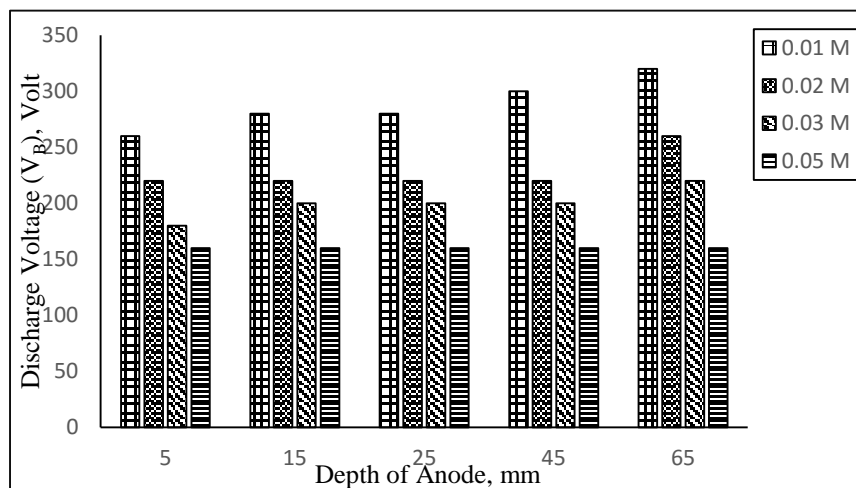
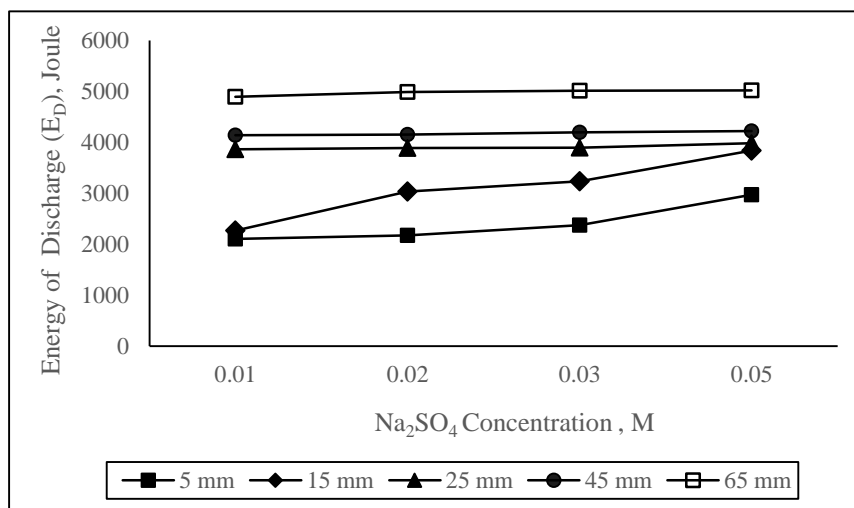


Figure 4. Breakdown voltage (V_B) on the anode depth variation and the conductivity of the solution at 65°C.

Table 1. Effect of conductivity change on V_B , V_D , I_B and I_D values at 25 mm anode depth and temperature 65°C.

Concentration of Na_2SO_4 (M)	Conductivity (mS)	V_B (Volt)	I_B (A)	V_D (Volt)	I_D (A)
0.01	3.48	220	0.75	280	0.46
0.02	7.01	180	0.81	220	0.59
0.03	10.67	160	0.86	200	0.65
0.05	15.13	140	0.96	160	0.83

Changes in conductivity also affect the discharge voltage (V_D) where higher conductivity, discharge occurs at lower voltages (figure 5). However, although the discharge voltage decreases, the discharge energy in plasma formation will increase as the conductivity of the solution increases (figure 6). This is due to the resistivity between the anode and the anolyte. In addition, the high dielectric strength of the solution causes the discharge strength to occur lower in the lower conductivity solution [7]. The higher the conductivity, the greater the power (discharge), which can be seen from the formation of the lighter plasma.

**Figure 5.** The discharge voltage (V_D) on the anode depth variation and the conductivity of the solution at a temperature of 65°C.**Figure 6.** The discharge energy at the anode depth variation and the concentration of the solution at 65°C.

4. Conclusion

In this study, the effect of anode depth and conductivity of electrolyte solution on required energy for plasma generation in plasma electrolysis was studied. At deeper anode position, the energy required for plasma formation (E_B) and discharge (E_D) were observed higher. Changes in the conductivity of the solution also affect the breakdown and discharge energy on the plasma formation in solution. At large conductivity, the breakdown energy (E_B) was lower, while the discharge energy (E_D) becomes higher.

5. References

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