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Charging Time Influence on Dynamic Lead Acid Battery Capacity with H_2SO_4 Electrolyte

Muhammad Ghufron[1,a)], Kurriawan Budi Pranata[2,b)], Istiroyah Istiroyah[1], Mukhammad Yusmawanto[1] , Nur Khairati, Yofinda E. Setiawan, Riky D. Susilo, Ahmad A. Amirullah and Cholisina A. Perwita[1]

[1]*Department of Physics, Faculty of Mathematic and Natural Science, Brawijaya University, Malang 65145, East Java, Indonesia*

[2]*Program Studi Pendidikan Fisika, Univeristas Kanjuruhan Malang, 65148 , East Java, Indonesia*

[a)]Corresponding author: mghufron@ub.ac.id
[b)]kurriawan@unikama.ac.id

Abstract. Charging time is one of the important things for secondary batteries due to the effectiveness of the battery on charge storage, especially on the dynamic battery. A dynamic battery is a new type of secondary battery with an electrolyte flow from an outside chamber into the battery by using a pump. Dynamic flow battery has been built using Pb and PbO_2 with a size of 22.5 x 7.5 cm^2 as electrodes and 30% H_2SO_4 solution as an electrolyte. Variations of charging time was conducted on a dynamic lead acid battery with variation 0.5 h, 1.0 h, 1.5 h, 2.0 h, and 2.5 h at constant electric current 1 A. The result shows that dynamic lead acid battery single cell has secondary battery character that can be charged at voltages of 1.92-2.17 V and discharged at voltages of 1.97-1.81 V. Experiments show a linear relationship between charging time and battery capacity. The longer charging time, the larger the charge stored in the battery. Charging time of 0.5 h can hold charges until 630 mAh and a discharge time until 0.55 h while a charging time of 2.5 h can hold charges of 3838 mAh and a discharge time 3.83 h.

Keywords: charging time, battery capacity, dynamic lead acid battery, electrolyte, voltages.

INTRODUCTION

Many studies have been conducted to increase the capacity and energy efficiency of batteries.[1] Redox Flow Battery (RFB) is believed to be one of the solutions to that problem. RFB, also known as a dynamic battery, is a battery that can hold a bigger capacity than a conventional battery and have a good energy efficiency.[2] Dynamic battery or RFB is a new type of secondary battery where electrolytes are moved from outside chamber to the battery by using a pump with certain velocity.[3] An RFB based on Vanadium,[4] Zinc-Nickel,[5] and Lead acid[6] is an example of RFB developed by researchers. Lead acid RFBs have an advantage in easily obtainable materials, simplicity in design because they use only a single electrolyte, and they are relatively cheap.[7] The disadvantage of this battery is that some materials are toxic[8] so the user need to be careful when using the lead acid battery.

In the previous research, there is a lot of explanation about lead acid battery characteristics such as State of Charge (SoC),[9] the influence of different current density[10] and electrolytes flow.[11] However, research about influence of charging time against the battery capacity is still limited. This research will report about influence of charging time on battery characteristic and its comparation between lead acid RFB and static lead acid (conventional).

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EKSPERIMENTAL DETAILS

An experiment is conducted by designing a single cell dynamic battery containing 2 electrodes of Pb and PbO_2 with a size of 22.5 x 7.5 cm^2. The electrolytes chamber has a volume 450 mL made from transparent acrylic flown by minimicro submersible water pump motor DC 3V-6V 120 L/H. A Turnigy Accucell-6 50w is used as a Battery Management System (BMS) connected with a PC unit and ChrageMaster 2.02 software to get data real time from the battery.

Electric current, voltage, and capacity was taken in realtime by Turnigy Accucell-6 50w during the experiment (Fig. 1). Initial discharge of lead acid RFB system was conducted as a first treatment to running out the battery capacity. Charging and discharging began by apply 1 A electric current in the system. Variation of charging times 2.5 h, 2.0 h, 1.5h, 1.0 h, and 0.5 h is conducted in a series with a rest from 3 until 5 minutes given at the end of charging before discharging is started. A cyclability test uses two electrolytes treatment, there are static and dynamic (flow) where in the dynamic treatment a 10 ml/minute flow rate is applied.

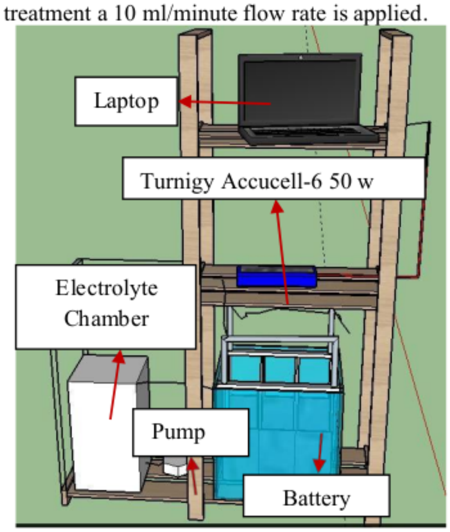


FIGURE 1.Design of RFB Lead Acid System Single Cell.

RESULTS AND DISCUSSION

Initial condition of the battery system shows that the battery cell has a voltage of 2.05 V, called open circuit voltage (V_{op}). The battery gets energy from spontaneous reactions between electrolytes and electrodes. Pb(s) (anode) and PbO_2(s) (cathode) react with H_2SO_4(aq). $PbSO_4$(s) is the product of the sp spontaneous reaction and involves four electrons/reaction. In the beginning, when initial discharge is conducted, the RFB system is forced to flow 1 A electric current. The voltage decreases significantly until 1.92 V, and after that the voltage decreases slowly until 1.81 V called cut off voltage (Vcutoff). Actually, at this voltage, current on the circuit is still constant but the default program on BMS automatically stops the data retrieval for battery security. Based on the data result, initial discharging of the battery generates 4193 mAh and 6381 mAh for static and dynamic state RFB.

Charging is conducted after initial discharging is complete. The battery is charged with 1 A constant current for 2.5 h which is then followed by battery discharging at the same current and then uses the same activity with the charging times of 2.0 h, 1.5 h, 1.0 h, and 0.5 h. Fig. 2 shows the first cycle of RFB and gains some information about RFB characteristics. When the voltage is 1.81 V at the end of discharging, as soon as it obtains electrical energy the battery voltage rises to 1.93 V called the $V_{initial\ charging}$ (V_{oc}). According to the literature, lead acid batteries are capable of having a voltage greater than 2.4 V when the battery is fully charged.[7] So, the voltage value of 2.12 V is not the highest voltage of the battery, this indicates that the battery is still be able to charge again until full. However, this increasing voltage indicates a charge can be stored during the charging process that directly correlates to the difference of the amount of charge on both electrodes. Details of capacity and another characteristic can be seen in Table 1. Before the discharging process, the battery is rested for 3 to 5 minutes so that the stored charge in the electrodes can be more stable (self-arranging). When the discharging process begins, battery voltage drops drastically to 1.92 V called the initial discharging voltage (V_{od}) and starts to drop constantly at voltages of 1.9 V to 1.81 V. According Fig. 2, charging time of 2.5 h generates a discharging time of 3.8 hours. These results indicate that the battery has the ability to charge and discharge. The Vmc and Vmd are the middle charging and middle discharging voltage where in the first cycle of RFB it obtained values of 2.10 V and 1.81 V.

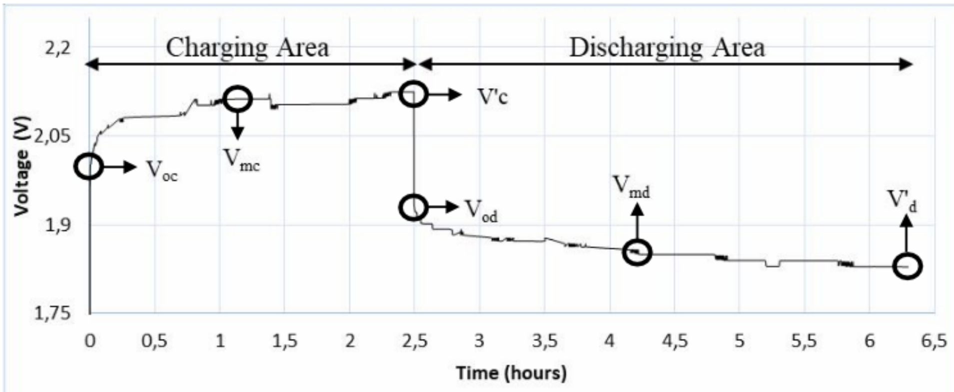
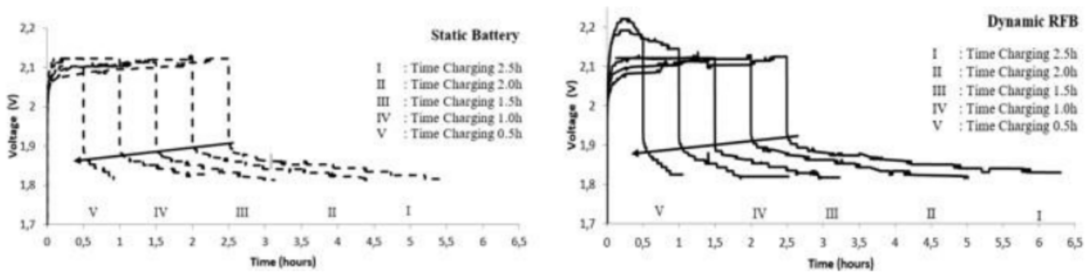


FIGURE 2. First cycle of charge-discharge test lead acid RFB single cell for static electrolyte treatment.

Fig. 3 shows the voltage versus charging time for five charging durations and two electrolyte treatments (static electrolyte in Figure 3a and dynamic electrolyte with a flow rate of 10 ml/minute in Fig. 3(b). Every charging duration generates a higher charging voltage (V_c) than discharging voltage (V_d) and a longer discharging time than charging time. Every graph has the same character, there are increasing voltages when charging and decreasing voltages when discharging indicating that the batteries are rechargeable. The charging voltage for cycle 2, cycle 3, etc. is always higher than the previous charging voltage indicating that there is still a residual charge when the discharge process ends, but the discharging voltage is always lower than the previous discharging voltage because the next charging is always reduced by 30 minutes so the amount of stored charge reduces significantly. RFB or dynamic battery has better performance in terms of discharge time and capacity. RFB has a longer discharge time of 7.4% to 25.4% compared to static batteries while the voltage efficiency of both batteries is around 84% until 86%.



(a) (b)

FIGURE 3. Influence of charging time toward voltage for a) static battery lead acid and b) dynamic lead acid.

Based on the results of the experiment, it is known that the dynamic battery performs better than the static battery for all treatments. The proof is that the dynamic battery discharging time (t_d) is longer than for static batteries and holds a bigger capacity. Table 1 explains that by load 1 A electric current the batteries can raise the voltage from 1.93 to 2.13 V and 1.92 to 2.17 V for static and dynamic batteries, respectively. Initial discharging voltage (V_{od}) for static and dynamic batteries decreases at second, third, fourth, and fifth discharge processes indicating that the stored charge decreases by a reduced charging duration. The best result is the batteries with dynamic electrolyte treatment and a charging time of 2.5h that still flows electric current until 13,779 s or 3.82 h.

TABLE 1. Characteristic of lead acid battery with 30% H_2SO_4, curret 1A, and electrode size 22.5 x 7.5 cm^2.

Charging Time (h)	Battery Characteristic	Static Lead Acid Battery	Dynamic Lead Acid Battery
2.5	V_{oc} - V'_c	(1.99-2.12) V	(1.98-2.12) V
	V_{od} - V'_d	(1.99-1.81) V	(1.97-1.83) V
	t_d	10990 s	13779 s
2.0	V_{oc} - V'_c	(1.98-2.13) V	(1.99-2.12) V
	V_{od} - V'_d	(1.97-1.82) V	(1.96-1.81) V
	t_d	9032 s	10650 s
1.5	V_{oc} - V'_c	(1.97-2.11) V	(1.97-2.12) V
	V_{od} - V'_d	(1.96-1.81) V	(1.95-1.82) V
	t_d	5958 s	6400 s
1.0	V_{oc} - V'_c	(2.01-2.12) V	(1.98-2.14) V
	V_{od} - V'_d	(1.96-1.82) V	(1.95-1.81) V
	t_d	3918 s	4219 s
0.5	V_{oc} - V'_c	(1.93-2.12) V	(1.92-2.17) V
	V_{od} - V'_d	(1.95-1.81) V	(1.97-1.82) V
	t_d	1754 s	1988 s

Fig. 4 is showing a linear relationship between capacity and time charging. The capacity of batteries increases by increasing the charging duration. The highest capacity is obtained at 2.5 hours charging with a value of 3838 mAh. This value is greater than static electrolyte batteries by 204 mAh or 45.7% while on the other variations there is a capacity difference of 1067 mAh (44.4%), 588 mAh (35.8%), 369 mAh (31.4%), and 432 mAh (45.8%) for charging times of 2.0 h, 1.5 h, 1.0 h, and 0.5 h. However, Fig. 4 also gives information that the battery is not fully charged yet and needs more charging time to be fully charged indicated by voltage saturation.

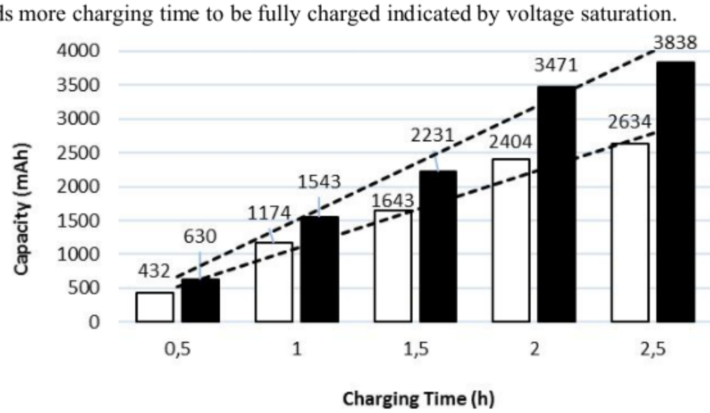


FIGURE 4. Influence of charging time toward voltage characterization for a) static battery lead acid and b) dynamic RFB lead acid.

SUMMARY

Lead Acid RFB (Redox Flow Battery) was successfully made from Pb, PbO_2, and 30% H_2SO_4 as secondary battery type. Based on the experimental results, the capacity of the lead acid RFB decreases along with the decreasing of charging duration. The $V_{work\ discharge}$ of the lead acid RFB is 1.81-1.97 V. Dynamic treatment of RFB has a better performance than static batteries in terms of discharging time and capacity. The optimal capacity is for RFB with dynamic treatment and charging time of 2.5 h that is 7 times higher than the charging time for 0.5 h.

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