TELKOMNIKA, Vol.17, No.6, December 2019, pp.2919~2925
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i6.11913

Electrode size influence on static and dynamic single cell lead-acid battery

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Abstract

Renewable energy such as solar energy, waves and wind require batteries as a storage of electrical energy which still has constraints related to voltage, capacity, and energy efficiency. This experiment aims to determine the effect of electrode size on lead-acid dynamic and static battery capacity and energy efficiency. Dynamic and static single cell lead-acid batteries consist of three different electrode sizes, 13.5x7.5 cm² (A_1); 22.5x7.5 cm² (A_2) and 32.5x7.5 cm² (A_3) have been developed. Continuous and simultaneous charge-discharge test using turnigy accucell-6 50 w and chargemaster 2.02 software as graphic programming. Based on experiments, dynamic batteries perform better than static batteries with a difference in capacity of up to 48% and differences in energy efficiency up to 17%. The best performance is obtained on A3 dynamic batteries with an average capacity capacity of 10357 mAh and an average energy efficiency of 81%.

***Keywords**: charge-discharge, dynamic battery, efficiency, electrode size, renewable energy*

1. Introduction

The consumption of energy increases as the population and economy growth. In 2016, the total primary energy consumption has increased by about 1.3% from the previous year or more than 13,276 mtoe [1] which the majority of energy consumption is used for electric generation. Due to the non-compliance of renewable energy as a power plant with power consumption, the right energy storage technology is needed to improve stability. The battery is an energy storage technology that has been widely used in recent years and is still being developed. Lead-acid based batteries are a type of secondary battery that can be seeded because it cost-effective and can be used for various types of energy storage applications. Lead-acid batteries still play a major role in the battery market today and are widely used in the automotive [2], backup power for uninterruptable power supply, electric and hybrid vehicle, storage energy of electric generator by renewable energy, backup electric power for smart home and other applications [3, 4]. Many innovations can be made to improve energy storage performance, especially when increasing battery capacity. One of the renewable innovations is the redox flow battery (RFB) [5]. RFB is an electrochemical energy conversion device that uses a redox process in liquid form, stored in an external tank and inserted into the system as needed. The most interesting features of this technology are scalability and flexibility, independent measurement of power and energy, highly efficient laps, high depth of discharge, long life, fast response and reduced environmental impact [6]. In order to reduce the environmental impact of lead-acid batteries, the previous research has been carried out to treat waste and synthesize lead-acid battery electrodes for use in new batteries [7, 8]. The application of this battery can be used as energy storage for renewable energy like wind, wave, and solar cell.

Lead-acid RFB has been widely developed by using methanesulfonic acid [9–11] and sulfuric acid [12, 13] as electrolytes. The use of methanesulfonic acid and sulfuric acid produces a standard voltage of 1.62 V and 2.04 V. Battery quality improvement related to efficiency has been done by varying, modify, enrich, and changes the electrode material in one of

Received November 27, 2018; Revised May 30, 2019; Accepted July 2, 2019

the electrodes [14–18], flow rate [19] and the use of different membrane [20]. However, reports relating to the effect of electrode size on battery characteristics are still limited [21], Satriady et al., reporting that the battery capacity incerases when the size of the LiFePO4 battery electrode is enlarged [22]. Based on this report, further research is needed regarding the effect of electrode size on lead-acid batteries, especially on lead-acid flow battery. The size of the electrode will have an important role in determining battery capacity [23–25] because it is related to the number of redox reactions that take place [26], although the too large area will affect the design of the battery in the future application. This research will discuss the effect of electrode size on initial discharge, battery capacity, duration of battery cycle, the energy efficiency in the first three cycles. As a comparison, similar batteries are used with static electrolyte treatment.

2. Research Method

Two plat of Pb and PbO_2 with three different size (A_1=13.5x7.5 cm^2, A_2=22.5x7.5 cm^2 A_3=31.5x7.5 cm^2) used as electrodes [27] then 30% aqueous sulfuric acid add into each cell with volume 350 mL, 450 mL and 550 mL until each electrodes drowning. Real-time data was taken by circulate 450 mL sulfuric acid from chamber (outside) with flow rate 10 mL/minute for dynamic state and 0 mL/minute for static state [28] as shown in Figure 1, using current constant 1 A [29], charging time until battery voltage 2.4 V achieved, discharging time until Vcutoff 1.8 V and using Turnigy Accucell-6 50w as Battery Management System (BMS) connected with PC unit [30–33]. Meanwhile, chargemaster 2.02 software is graphics programming to monitor voltage, current and battery capacity in real-time.

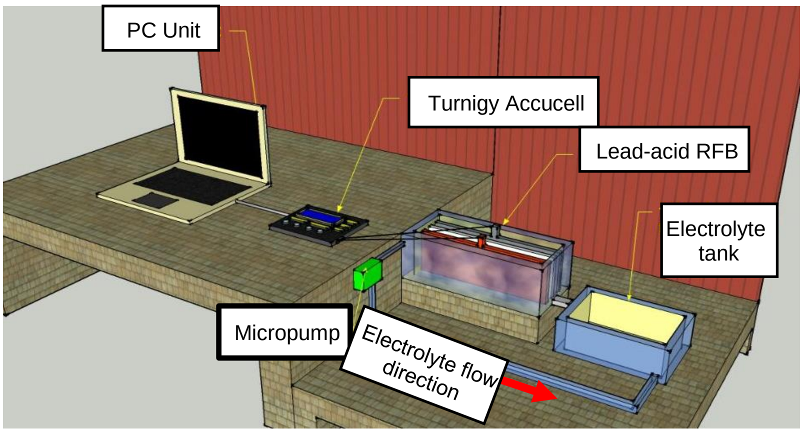

Figure 1. Experiment setup for lead-acid battery (LAB) single cell with two different electrolyte treatments (Static and Dynamic)

3. Results and Analysis

3.1. Initial Discharge of Lead-acid Dynamic Batteries

At the discharge process, the battery generates electricity with a certain capacity until the battery cut-off voltage is reached. The integrated lead-acid cut-off voltage on Turnigy accucell-6 is 1.8 V. Based on the experimental results, variations of the surface area of the electrode affect the discharge characteristic of the battery. Figure 2 presents the initial discharge voltage and current of lead-acid dynamic batteries with 3 different surface area of the electrode. Battery with a larger electrode surface area produces a higher battery voltage. The battery with higher voltage takes a longer time to reach the cut-off voltage and has higher capacity. The initial discharge capacity of the lead-acid dynamic battery with a surface area of electrode A_1, A_2 and A_3 are 3,175 mAh; 6,381 mAh and 10,442 mAh respectively.

The ratio between the surface of A_2 and A_1 electrodes (A_2/A_1) is 1.67 and the ratio between the capacity of A_2 and A_1 electrodes (C_2/C_1) is 2.01. This means that the capacity increases more than 100% with the addition of 67% electrode surface area. In other words, it can be said that the amount of charge per unit area (density) of the battery increases with the addition of the electrode surface area. The dynamic battery density of A_1, A_2 and A_3 are 112.89 C/cm², 136.13 C/cm², and 159.12 C/cm² respectively. A charge density of 23.12±0.12 C/cm² is added per additional electrode surface area of 67.5 cm².

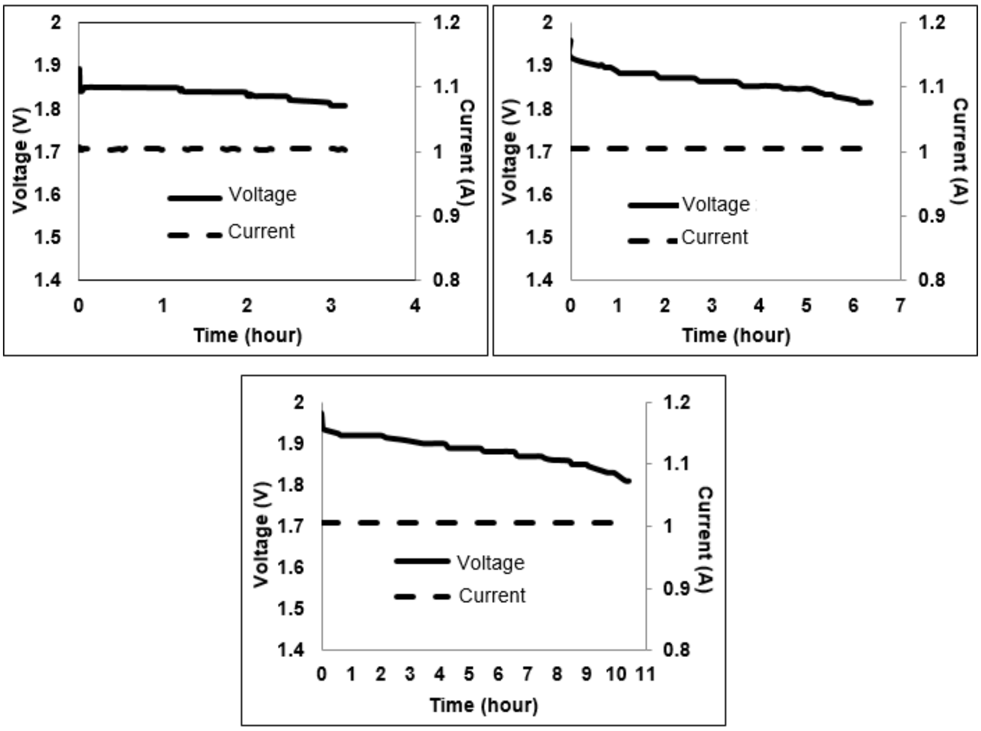

Figure 2. Voltage, current and duration of the initial discharge of lead-acid dynamic battery with 3 variations of electrode surface area:
(a) A1 = 13.5x7.5 cm², (b) A2 = 22.5x7.5 cm², and (c) A3 = 31.5x7.5 cm²

3.2. Voltage of Lead-acid Dynamic and Static Batteries

Voltage is an important parameter of battery performance because it indicates the power stored in the battery. Based on Figure 3 it can be seen that the battery operating voltage is the same in the range of 1.8 V to 2.4 V for all batteries. The charge sent through the charging current 1 A has an impact on the voltage increase rapidly between the two electrodes. However, the addition of surface area has an effect on the behavior of the voltage where the initial charging voltage (Voc open circuit voltage charging) in the larger electrode area is always lower than the smaller area. As a result, a larger battery has a voltage that always moves below or lowers during charging and has a longer charging duration so the battery has the ability to store higher charges even though it stops at the same voltage. After 3 cycles of static and dynamic lead-acid battery charging, it was found that the initial discharge voltage (open circuit discharge voltage Voc) of the larger electrode area is always higher because the charge stored at the end of the charging is bigger.

Dynamic battery who have more electrolytes from the outside tank has an advantage where more electrolyte means more reaction will involve in the cell. Charging and discharging time is an essential parameter to know the capacity of the battery where redox reaction in the cell was proportional with the charge product. Although the graph between the static battery and the dynamic battery is similar one after another, the dynamic lead-acid battery has a longer discharging period shown in Figure 3 means better performance than static.

According to Table 1, the middle charge voltage (V_{mC}) of the static batteries tends to decrease in all 3 test cycles, while the middle discharge voltage (V_{mD}) tends to be constant. The charge duration of static batteries tends to decrease, which indicates a decreasing of the battery stored capacity. The decrease of capacity may be caused by the occurrence of a not complete discharge, which leaves a residual charge in the battery.

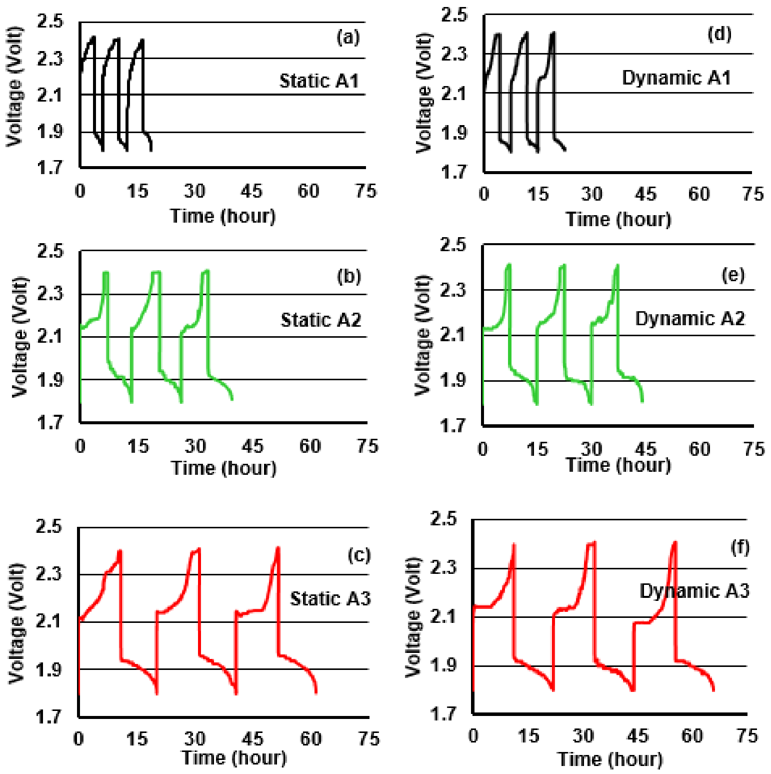

Figure 3. Three cycle of charge-discharge lead-acid battery (LAB) show that dynamic LAB (d,e,f) have longer duration than static LAB (a,b,c) and the bigger electrodes (A_3>A_2>A_1) in the chamber results longer duration.

Table 1. Charge-discharge Voltage and Time of Lead-acid Static and Dynamic Batteries

Battery		Battery variety	Number of cycles 1	2	3
Static	A_1	V_{mC} (V)	2.35	2.34	2.32
		V_{mD} (V)	1.85	1.82	1.87
		t_C (s)	14036	15,286	15,165
		t_D (s)	7,273	7,421	7,359
	A_2	V_{mC} (V)	2.19	2.21	2.16
		V_{mD} (V)	1.90	1.89	1.89
		t_C (s)	26,256	26,446	25,256
		t_D (s)	22,326	21,776	22,515
	A_3	V_{mC} (V)	2.20	2.18	2.15
		V_{mD} (V)	1.90	1.92	1.92
		t_C (s)	39,332	39,551	39,332
		t_D (s)	33,478	34,073	34,891
Dynamic	A_1	V_{mC} (V)	2.26	2.28	2.20
		V_{mD} (V)	1.84	1.84	1.85
		t_C (s)	15,758	16,365	16,375
		t_D (s)	10,976	10,954	10,697
	A_2	V_{mC} (V)	2.14	2.19	2.17
		V_{mD} (V)	1.88	1.89	1.89
		t_C (s)	27,128	27,069	26,064
		t_D (s)	24,555	24,554	24,224
	A_3	V_{mC} (V)	2.15	2.10	2.10
		V_{mD} (V)	1.91	1.90	1.90
		t_C (s)	40,577	40,662	40,907
		t_D (s)	37,520	36,401	37,367

The average ratio between t_C and t_D of static batteries for A_1, A_2 and A_3 are 50.37; 14.49, and 13.34 respectively. This indicates that the static battery produces a relatively low capacity compared to the stored capacity at the charging process. Meanwhile, the ratio between t_C and t_D of the dynamic batteries for A_1, A_2 and A_3 are 32.69; 8.61, and 8.89 respectively. A_1 static and A_1 dynamic batteries have a higher ratio of t_C and t_D than the other 2 surface areas. This will be the limit of the electrode surface area that is needed to produces a large capacity.

3.3. Capacity of Lead-acid Dynamic and Static Batteries

Dynamic batteries produce a larger capacity than static batteries, which is caused by the constantly flowing electrolyte. The flowing electrolyte creates a circulation so that more $PbSO_4$ reactions can occur. Based on Figure 4, Lead-acid battery with a larger electrode surface area produces a higher capacity. The increasing of the electrode surface area increases the battery capacity. The capacity of A_2 and A_3 static batteries are 203% and 361% higher than the capacity of A_1 static battery. Meanwhile, the capacity of A_2 and A_3 dynamic batteries are 125% and 241% higher than the capacity of the A1 dynamic battery.

3.4. Efficiency of Lead-acid Dynamic and Static Batteries

Battery efficiency shows the ratio of the energy the battery produces at discharging process to the battery energy that needs at the charging process. Analysis results from Figure 5 present the battery efficiency increases with the increasing of the electrode surface area. A_1 static and A_1 dynamic batteries have the lowest efficiency compared to the efficiency of static and dynamic battery with the other 2 surface areas. Dynamic batteries have higher efficiency than the static batteries for the 3 variations of electrode surface area. This shows that dynamic lead-acid batteries have a better performance than the static lead-acid batteries.

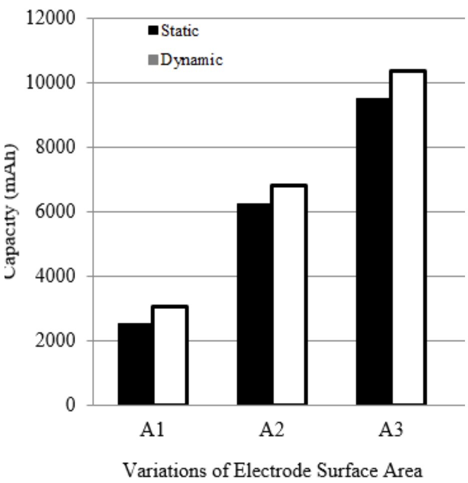

Figure 4. Capacity of static and dynamic LAB; dynamic LAB always shows larger capacity than static LAB; electrodes size affects capacity LAB linierly

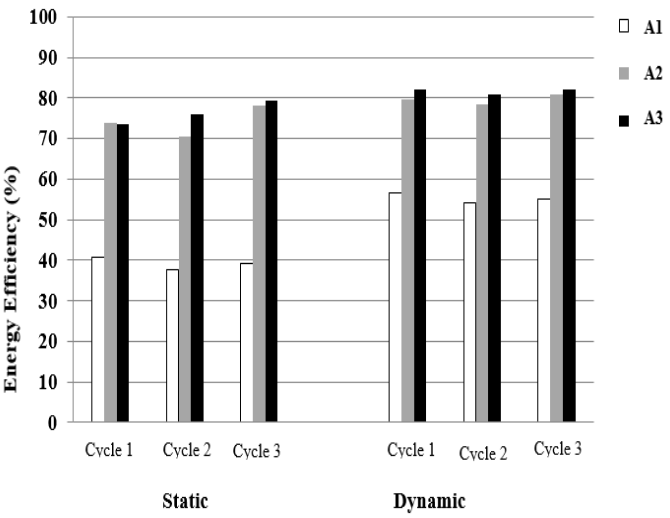

Figure 5. Energy eficiency of lead-acid static and dynamic batteries shows that three is stability value for 3 cycle charge-discharge test; dynamic LAB has better performance than static LAB

4. Conclusion

Dynamic and static single cell lead-acid battery consists of three different electrode size have successfully tested by Turnigy Acuucell-6 50 w for 3 cycles. The result is Dynamic LAB show better performance on capacity, energy efficiency and discharge duration. Another result is the duration discharge, middle discharge voltage, capacity, and energy efficiency increase by increasing the electrode size. However, there is needed a more charge-discharge test to know the durability LAB, after that by using XRD and SEM can be seen the influence of charge-discharge test on electrodes.

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