Seawater Battery with Al-Cu, Zn-Cu, Gal-Cu Electrodes for Fishing Lamp

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Abstract- The key problem in application of seawater battery is lies on the expensive cost of anode material manufacture, especially for fishing activity. Seawater battery with common electrode such as Al-Cu, Zn-Cu, Gal-Cu are expected for selecting fixed lift net application through innovation of Light Emitting Diode (LED) fishing lamp. This research is evaluated the performance of seawater battery with various common electrodes to drive LED lamp during discharge process. Laboratory experiment was conducted on December 2016 to January 2017, in order to measure potential and current output of aluminium (Al), zinc (Zn), and galvalume (Gal) anode of seawater battery without load and load condition. The results showed the zinc anode had the higher performance in term of voltage and current output than galvalume and aluminium anode. The maximum power output of zinc (704.17 mW) was not significantly different to galvalume (726.41 mW), nevertheless these have a significant different to aluminium (175.75 mW). It was a good evident that the performance of seawater battery was affected by anode material. Zinc and galvalume were sufficient enough to be developed as seawater battery anode due to their higher number of potential, current and power output. Further development of seawater battery with DC/DC converter and Dual in-line Package (DIP) LED is appropriate for the new innovation of an effective and efficient fishing lamp for lift net fisheries.

Keywords Anode, cathode, electricity, lift net, seawater battery.

1. Introduction

Renewable energy sources (RES), such as wind, seawater, and solar systems, are smart alternatives to fossil fuels due to their inexhaustible and environmental friendly features [1-4]. The performance of sustainable energy technology can be improved to empower the more efficient utilization of renewable electricity sources. Many scientists explore and develop the power source of renewable energy for various application, such as portable electronic devices, electric vehicles (EVs), and energy storage system (ESS) which are easily accessible, and low cost of technology [5-8]. However, their intermittent and non-predictable nature are requires the development technology which is low-cost, efficient and safe energy as power sources for the general electricity requirements [9].

Seawater is an important alternative of RES to generate low cost, efficient, and green electricity for various supplies such as military device and commercial equipment [10-13]. Seawater battery also is developed for emergency lighting, reserve power, long-lasting silent power for communication equipment and lighting on yachts and other marine objects, lighting for camping [10] and fishing lamp for small scale fisheries [15]. Fixed lift net is one of the small scales fishing gear that using artificial light to attract phototaxis fish around the fishing gear during fishing operation. Fishers are usually use gasoline generator as a power sources to drive a various number of compact fluorescent lamp (CFL) as the light source. The number and power of lamps is chosen based on traditional knowledge and fishermen experience. Furthermore, lift net fishing is consumed a great amount of electric energy, fuel and became inefficient activities [16].

The seawater batteries application in the small-scale fisheries is highly apparent to be developed through the innovation of Light Emitting Diode (LED) fishing lamp. Seawater battery is feasible for the realization of eco-friendly energy power supply and energy storage systems [17]. LED lamp has a high intensity, low energy consumption [18-19], high efficiency, a long lifetime, fast response and together with climate resistance [20], technically and economically for small-scale fisheries applications [21]. The combination of LED lamp and sea water battery is expected to become an efficient and effective technology to develop fishing activity for small scale fisheries [15].

Meanwhile, the previous research indicated the main problem of sea water batteries application is a high cost in the electrode material production. The common electrode is produced by combination of several metals such as magnesium, nickel, stannum or lithium which are expensive and limited for fisheries communities. Moreover, the performance of seawater battery to generate electricity is highly affected by the proper combination of electrode. Therefore, the performance of sea water battery using common electrodes material for fixed lift net application will be analyzed in this research. Aluminium, zinc and galvalume used as anode, due to cheap, environmentally friendly and boundless material [23]. Copper used as cathode material due to large amount, easily available, high efficiency and suitable in seawater [15, 24]. Finally, the performance of each battery will be evaluate based on voltage, current and power outputs during discharge process in unload and load condition.

2. Materials and Methods

2.1. Experimental Set-Up

The experiment was conducted on December 2016 to January 2017 in Fisheries Laboratory, Faculty of Agriculture, University of Sultan Ageng Tirtayasa, Banten Province of Indonesia. The different in anode materials were chosen as electrode. The copper plate used as cathode. The anodes were consisted of zinc (Zn), aluminium (Al) and zinc with galvalume coating (Gal). The study was applied one surfaces area of electrodes (300 cm²), and one distances of electrodes (3 mm). The size of electrodes in all experiment combination shows in Fig 1.

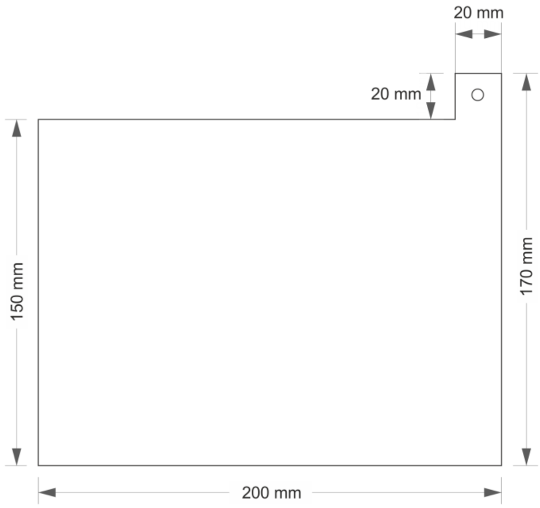

Fig 1. The size of electrodes (length of 200 mm, width of 150 mm)

Each cell comprised six layers of anode and cathode respectively, and connected through six screws as shows in Fig 2. The surface of separator screw (3 to 6) covered by cellophane tape to prevent the short circuit current between the electrodes. The anode and cathode of each cell were separated by 3 mm thickness of rubber tube, which have 5 mm hole to join the separator screw (screw 3 to 6). Furthermore, the copper connector used to link the anode and cathode for collected the current and voltage in parallel connection (screw 1 and 2). The sequence of production involves assembling of six anodes and six cathodes: bolt with rubber separator (3-6), anode (A1-A6), rubber separator, cathode (C1-C6), bolt with copper connector (1-2). Prior to use the single cell of zinc-copper, aluminium-copper and galvalume-copper battery will be activated spontaneously by immersing in to sea water.

We used one set of glass aquarium (420 x 220 x 170 mm respectively) as experiment tank. It was consisted of six compartments, which were each compartment had 70 mm width as shows in Fig 3. Level of sea water in all compartments was 150 mm, related to immersing area of electrodes.

2.2. Procedure

The discharge performance of each cell battery was analyzed through three steps. First step, the voltage and current for single cell battery for each anode were measured for 60 minutes without load condition. The second step, the voltage and current of six cells battery connected in series was quantified during 60 minutes in free load situation. Third step, voltage and current during discharge process was measured in different load. Zinc anode was connected to 1 watt LED lamp (white, high power LED) that had forward voltage 3.2 V. Aluminium anode wired to a yellow LED lamp (5 mm Duel In-Line Package/DIP LED) which have forward voltage 2.0 V. Moreover, zinc with galvalume coated connected to five LED lamps in parallel connection (1 W, white high power LED).

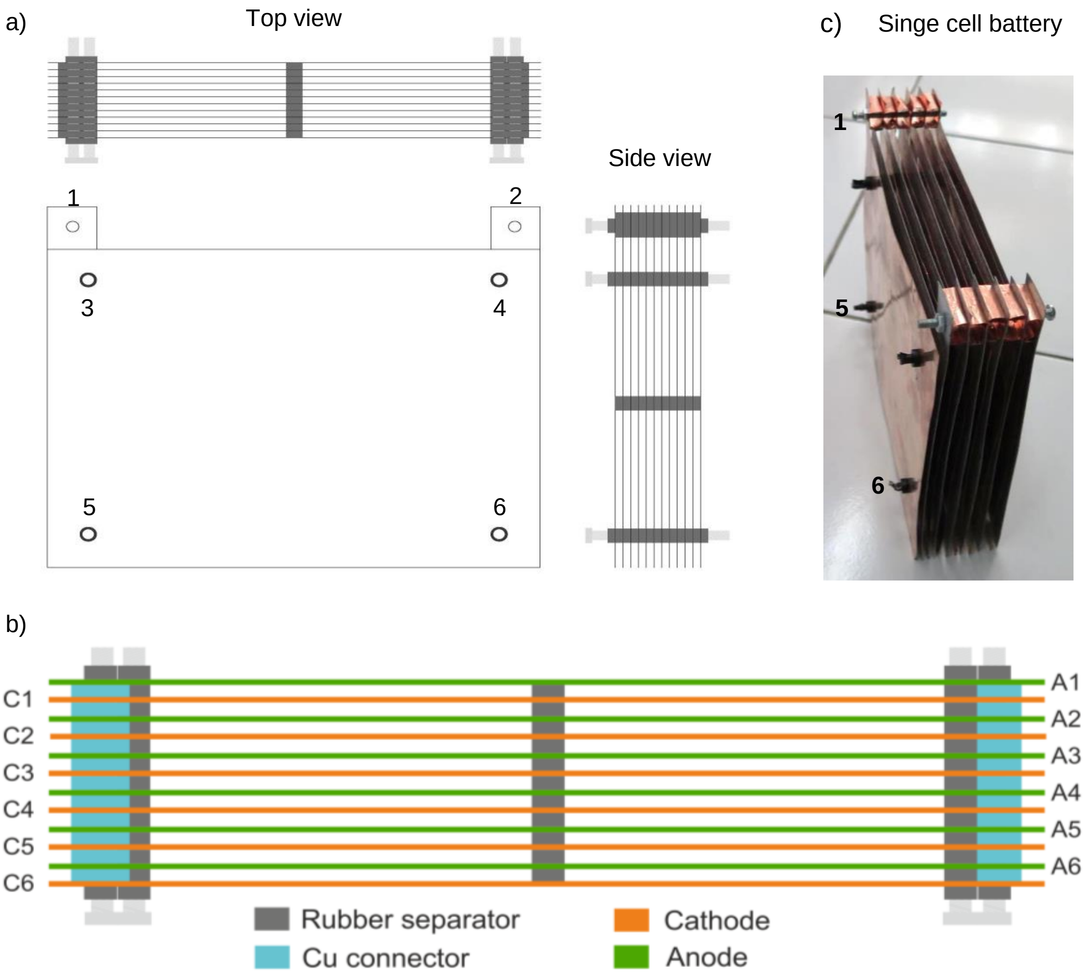

Fig 2. Planar layout of single cell battery (a). Side view of single cell battery (b). Single cell battery assembled (c).

In all steps of the experiment, seawater was prepared in the same salinity (31 psu) and dropped to each compartment of experiment tank in the room temperature (25-28 °C). At the first step, measuring of voltage and current of single cell battery was conducted in three compartments (each compartment as the replication). The voltage and current from the cell measured by multimeter (Dekko, DM-1330) in 10 minutes interval [11, 25, 26] during 60 minutes experiments. After that, multimeter was changed to the next compartment on the same measuring process. Six cells battery was connected in the series system using alligator clip for measuring the voltage and current in unload condition at the second step. Voltage and current from the battery was recorded using multimeter in 10 minutes during 60 minutes. The investigation was carried out also for three different anode materials.

The observation at third step was divided into three cycles that consisted of eight hours in every cycle. Six cells were connected in series using alligator clip and wired a LED lamp and multimeter as shown in Fig 4. Voltage and current was measured in 10 minutes interval at the first two hours. It was related to the effective of lighting duration at fishing operation of lift net fishing. After that, voltage and current was recorded in 20 minutes interval during six hours later. The cell battery removed from the compartment and splashed using tap water at the end of each cycle. Afterward, the cell battery dropped into compartment for the next cycle observation without replacing seawater in the experiment tank. The light intensity from each lamp was measured in every 60 minutes using lux meter (Lutron model LX-103 min scale of 1 lx) at 30 cm distance. The research was conducted for three different anode materials with each load condition.

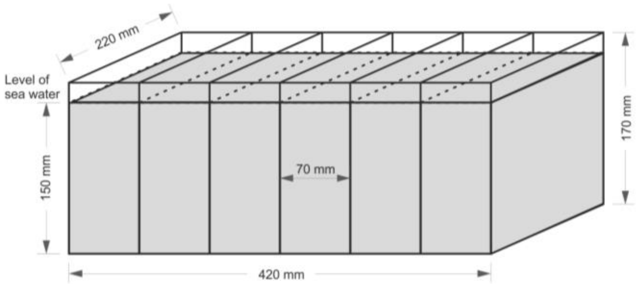

Fig 3. Experiment tank

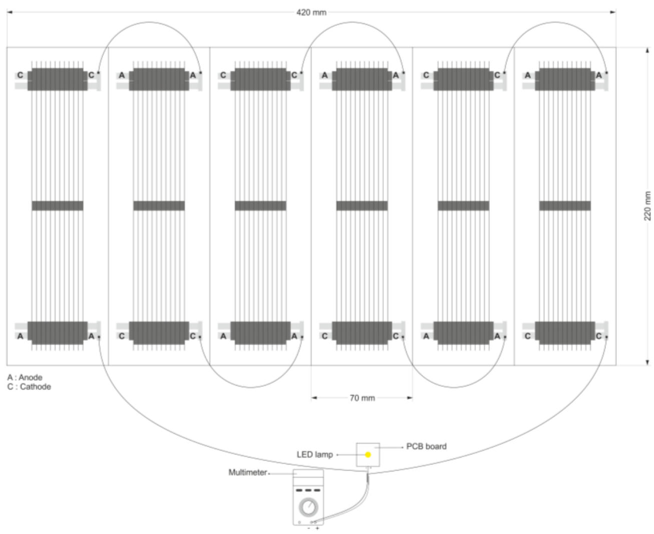

Fig 4. The experiment set-up of load condition

Voltage (V) and current (mA) were described descriptively using graph and table related to anode combination and discharge time period [27-28]. The power of each battery based on anode materials was calculated according to P=I×V, where P = power (W), I = current (A), and V= voltage (V) [29]. The effect of anode materials to voltage and current was determined using analysis of variance (ANOVA) and Tukey post hoc test.

3. Results and Discussion

3.1. Battery Performance in Free Load Condition

The average voltage and current of single cell and six cells battery using different anode materials is shown in Table 1. A single cell and six cells of zinc anode were produced the highest voltage than other anode materials by 0.81 V and 4.72 V, respectively. Furthermore, the aluminium anode was generated the lowest voltage for a single cell and six cells by 0.46 V and 2.39 V, respectively. The average of current output also has a similar pattern, which zinc anode was created the higher current than other anode. The highest current was generated by six cells zinc anode by 112.86 mA and the lowest at aluminium anode by 71.90 mA.

Anode material had the significant influenced to the voltage output of sea water battery with the same cathode [30-32]. Zinc generated higher voltage than aluminium in seawater battery, so that it is sufficient enough to develop as anode matter for commercial seawater battery [33-36]. Zinc anode as a commercial galvanized steel has a small aluminium composition, normally it has 98% Zn and 2% Al [37-38] which is affected to the voltage output of the battery. Moreover, the galvalume anode are produced higher potential and current than aluminium, which was related to the composition of surface coating. The main component of galvalume is alumunium and zinc (55% Al, 43.4% Zn and 1.6% Si by weight) that is developed in the 1970s, have two to four times greater durability and corrosion resistance than the conventional galvanized coating [39-40]. The high concentration of Zn in Zn-Al alloy anode is generated a high voltage of seawater battery application [41-42]. The potential output and cell capacity of $Zn_{67}Al_{33}$ (1.56 V and 800 mAhg-1) were higher than $Zn_{59}Al_{41}$ (1.54 V and 750 mAhg-1) [43]. Zn-Al alloy electrode with 9.5% of Zn also generated higher voltage output (0.961 V) than 1.2% of Zn (0.917 V) in seawater battery during discharge process [41].

The voltage profiles of single cell battery was gradually decreased during 60 minutes observation as shown in Fig 5. The highest voltage (0.82 V) was recorded using zinc anode at the beginning (t=0) until 30 minutes during observation, and the lowest (0.43 V) was generated by aluminium anode at the last minutes (t=60) of experimentation. The aluminium anode has the highest decreasing of voltage by 10 %. Furthermore, zinc and galvalume anodes have same declining of voltage by 4 %. Meanwhile, the current profiles during observation have a significantly dropped; therefore the aluminium anode has the lowest decreasing than each anode. The zinc anode was generated the highest current (121.87 mA) at the first time of observation. The lowest current (45.33 mA) was recorded using aluminium anode at the end of 60 minutes. The declining current of aluminium, galvalume and zinc were in 30 %, 36 %and 38 %, respectively.

The potential and current profiles of six cells battery in series connection is shown in Fig 5. Zinc and galvalume anode were generated a similar high voltage at the beginning of observation by 4.81 V. Voltage output of each anode was slowly decreased during 60 minutes observation. The voltage were dropped from the initial maximum of 4.81 V to 4.56 V; 4.81 V to 4.51 V; 2.54 V to 2.27 V for zinc, galvalume and aluminium anode, respectively. The percentage of voltage declining using aluminium, galvalume and zinc were 11%, 6% and 5%. Zinc anode generated high current by 157.2 mA, followed by galvalume (130.7 mA) and aluminium (94.8 mA). The current outputs during observation of each anode have a significantly declined. The current output by galvalume, zinc and aluminium anode fall from maximum of 130.7 mA to 56.4 mA (57% decreased), 157.2 mA to 78.3 mA (50% decreased), and 94.8 mA to 56.5 mA (40% decreased) respectively.

Table 1. Voltage (V) and current (mA) of single cell and six cells battery using different anode materials (number in average ± SE)

Anode	Voltage (V)		Current (mA)	
	Single cell	Six cells	Single cell	Six cells
Zinc	0.81 ± 0.0055	4.72 ± 0.0348	107.10 ± 6.2448	112.86 ± 9.7468
Galvalume	0.75 ± 0.0047	4.63 ± 0.0413	76.93 ± 4.0400	94.27 ± 9.9649
Aluminium	0.46 ± 0.0062	2.39 ± 0.0334	50.99 ± 2.5018	71.90 ± 4.8189

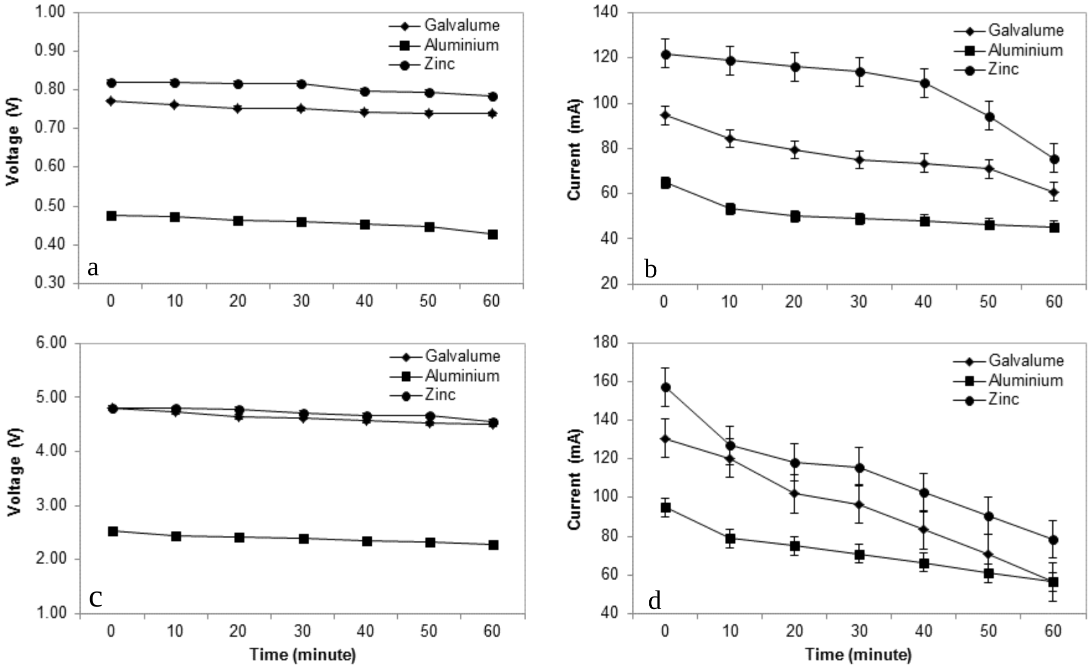

Fig 5. The voltage and current profiles based on time elapsed observation. Single cell battery (a-b). Six cells battery (c-d). Vertical bar denote standard error.

There were a significant different ($p < 0.05$, ANOVA single factor) between voltage and current output by single cell and six cells battery on each anode. The potential output of single and six cells also have a similar decreasing profiles during observation in all anode materials. It was related to typical characteristic of activated seawater battery which have continuous drop in voltage and current during discharge process [27, 44, 45]. The observation in water-activated manganese dioxide battery shown the voltage are declined due to internal reactions produces OH^- ions which increase the pH value and decrease the cathode potential. The drop continued until the pH inside the cathode pores settled [46].

3.2. Battery Performance with Load Condition

Voltage profiles of aluminium battery during three cycles is shown in Fig 6 (a1-a2). The maximum voltage was 2.86 V was recorded at the first cycle. There was significantly decreased of voltage output from the beginning of the cycles up to 20 minutes observation. The voltage were dropped from the maximum of 2.86 V to 2.16 V in the first cycle, 2.40 V to 2.01 V at the second cycle, and 2.40 V to 2.08 V at the last cycle. Nevertheless, it became steady at 30 minutes observation until 120 minutes for all cycles. There was a slightly decreased of potential output from 120 minutes to the end of each cycle. During six hours observation, the voltage dropped by 10.29% at the first cycle, 7.53% at the second cycle, and 9.52% at the last cycle.

The potential output of galvalume battery was slightly declined during 480 minutes experiment as shown in Fig 6 (b1-b2). The highest voltage was generated at the beginning of the first cycle by 4.70 V and the lowest by 3.85 V at the end of third cycle. During 120 minutes observation, voltage output fell from the initial maximum of 4.70 V to 4.32 V at the first cycle, 4.56 V to 4.28 V at the second cycle, and 4.65 V to 4.16 V at the last cycle. The percentages of output drop (from 120 minutes to 480 minutes) were 4.63%, 5.37%, and 7.45% at each cycle respectively.

Zinc battery has similar voltage profile to aluminium battery at 120 minutes observation. There was significantly droped of potential output during 20 minutes observation shown in Fig 6 (c1-c2). The voltage decreased from 4.92 V to 4.45 V at the first cycle, 4.96 V to 3.57 V at the second cycle, and 4.91 V to 3.14 V at the last cycle. After that, the voltage became stable until the last minute of each cycle except at the first cycle. It has a higher drop of voltage output during 120 minutes to 480 minutes experiment than the other cycle. The declining percentage of potential output at the first, second, and last cycle were 11.27%, 4.67%, 5.17% respectively.

Potential output of aluminium anode had a significant difference ($p < 0.05$) between zinc and galvalume during discharge process. Furthermore, zinc and galvalume battery have similar performance due to the voltage output. The content of Zn in alloys for seawater battery anode obviously affected the performance of the alloys [41]. The potential of 98Zn-2Al alloy is higher (1.050 V) than 75Zn-25Al (1.0250 V) and 45Zn-55Al (1.020 V) [37]. The related result of magnesium alloy in seawater battery with high content of zinc had sufficient performance. Its alloy with more zinc content (6%) generated higher voltage (0.60 V) than alloy with less than 1% zinc (0.41 V) [10].

Current output profiles of aluminium battery is shown in Fig 7 (a1-a2). The high current generated at the first cycle was gradually decreased during observation. Current output at the second and third cycle had a similar pattern and relatively closed of each value. The highest current was presented at the beginning of first cycle by 93.20 mA and the lowest is presented at the end of last cycle by 3.50 mA. The current significantly dropped during 480 minutes observation of each cycle which is range 93.31-94.28%.

Galvalume battery was generated a higher current than aluminium battery as presented in Fig 7 (b1-b2). The highest current was produced at the first cycle by 210 mA and the lowest was produced at the last minute of third cycle by 7.80 mA. During three cycles, current outputs significantly decreased at 120 minutes observation, and get slightly dropped at 120-480 minutes experiment later. The percentage of current drop ranged from 89.33% to 89.50% at two hours in the beginning of each cycle and 92.20% to 93.14% at eight hours during all cycles.

Transient current profiles of zinc battery is shown in Fig 7 (c1-c2). The current output dropped gradually from the start to the last cycle. The highest current was generated at head cycle by 170.4 mA and the lowest was generated at end cycle by 9.8 mA. The percentage of declining current ranged from 55.69% to 72.08 in 120 minutes and varied 82.92% to 91.76% during eight hours observation in all cycles.

Current output of all anodes have significant difference ($P < 0.05$), except galvalume and aluminium electrode. Battery with zinc anode generated highest current in all cycle. It was related to the concentration of Zn in anode coating matter. Magnesium alloy for seawater battery anode which had more zinc composition are generated higher current output (85 mA) than less zinc anode (50 mA) [10]. Magnesium alloy of 5.68Al-2.68Zn had lower current density (18.7 μA.cm-2) and current efficiency (59.4%) than alloy of 5.75Al-2.90Zn by 52.7 μA.cm-2 and 68.6% respectively [48].

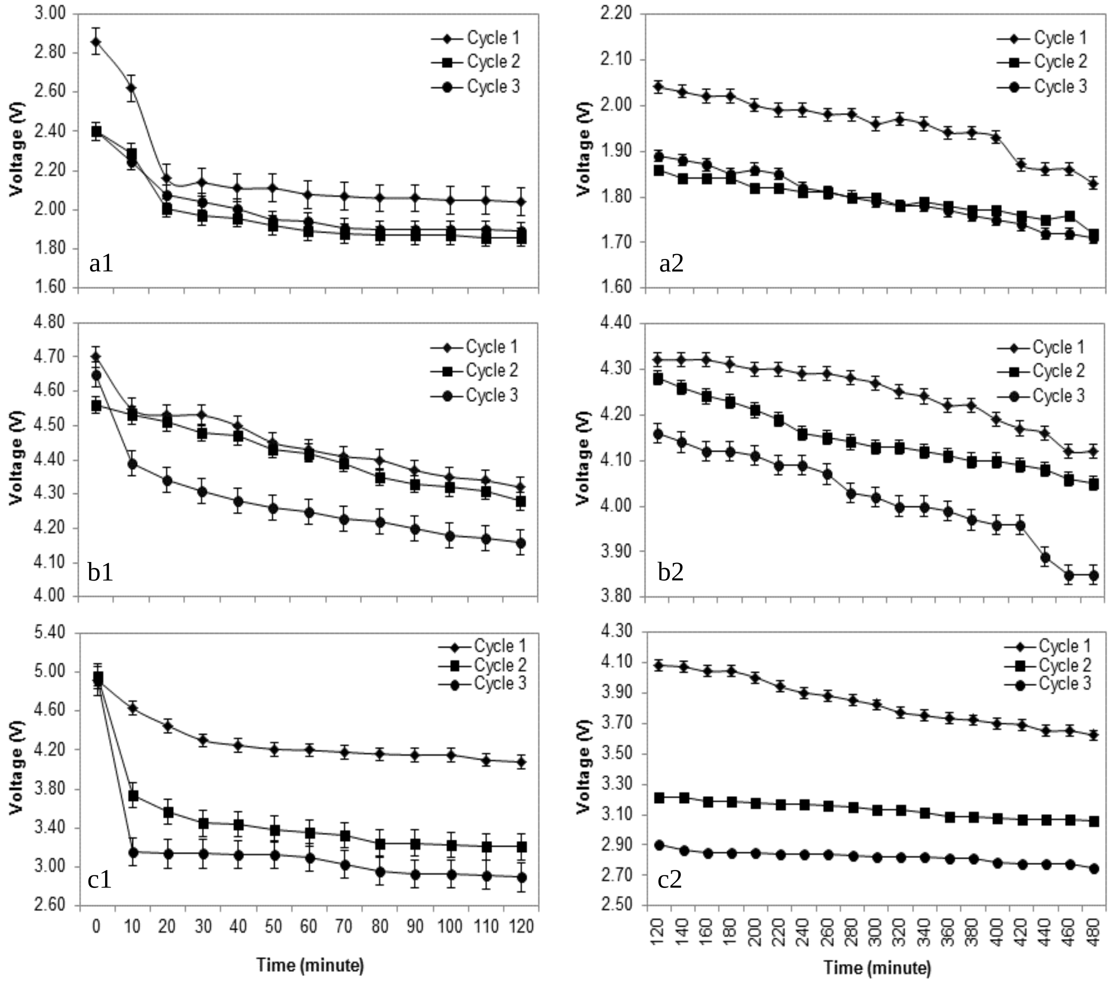

Fig 6. Voltage profiles of aluminium battery (a1-a2), galvalume battery (b1-b2), zinc battery (c1-c2) based on time elapsed observation. Vertical bar denote standard error.

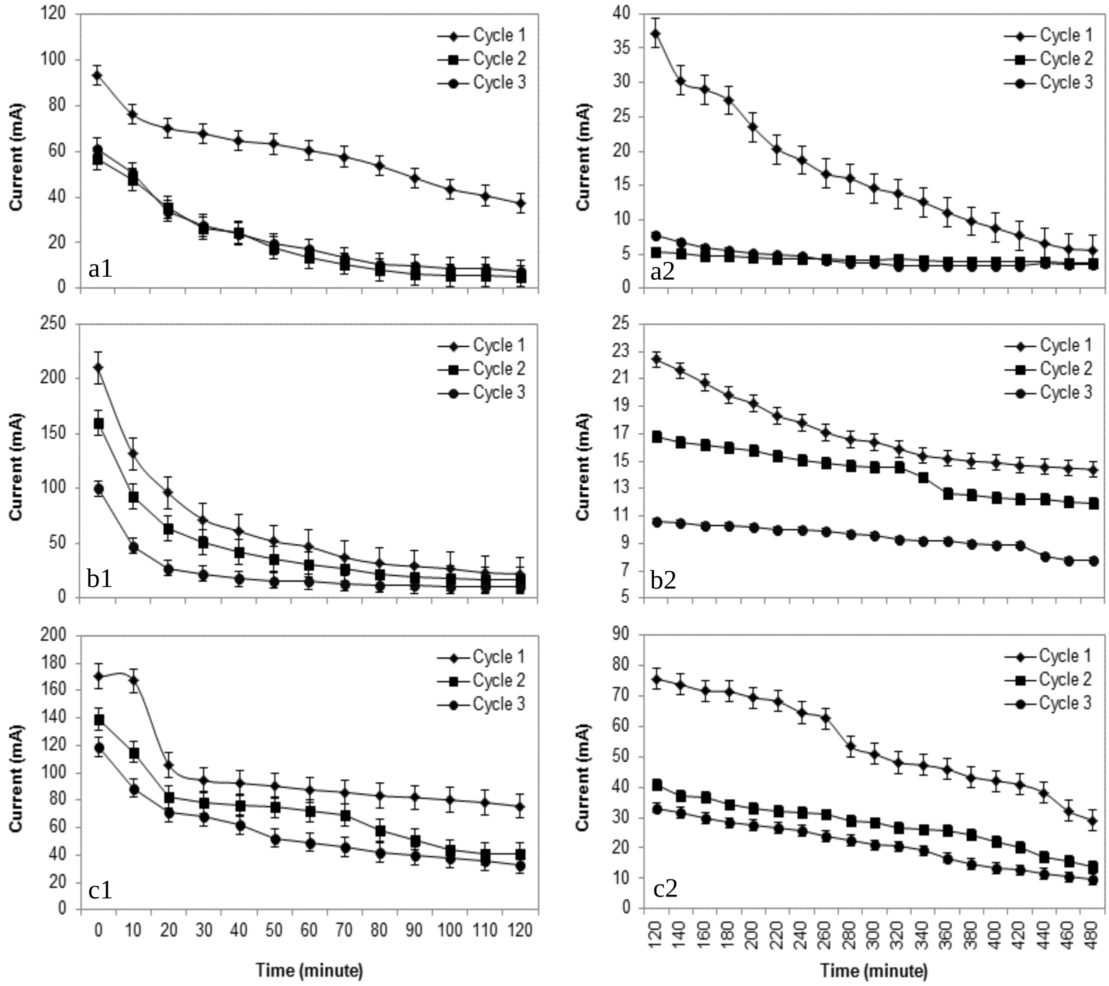

Fig 7. Current profiles of aluminium battery (a1-a2), galvalume battery (b1-b2), zinc battery (c1-c2) based on time elapsed observation. Vertical bar denote standard error.

3.3. Battery Power Output

The average power output of each battery during three cycles discharge process in different load of LED lamp is presented in Fig 8. The galvalume battery generated higher power output (726.41 mW) than zinc (704.17 mW) and aluminium (179.75 mW). The power output was significantly declined from the beginning to the end of each cycle. Power of galvalume battery extremely dropped in 120 minutes observation from 726.41 mW to 70.61 mW (90.28%). After that, it became fairly stable to the end of each cycle.

Power profiles of zinc battery have different pattern with galvalume battery. The power output was significantly decreased from 704.17 mW to 169.15 mW (75.98%) during 120 minutes discharge process. It also gradually declined during 480 minutes observation. This form was similar with aluminium battery power output which dropped slowly during discharge. The maximum power output at the beginning of cycle was 179.75 mW and significantly dropped to 32.42 mW at 120 minutes observation. The power became steady at the half of discharge period until the end of discharge process.

Fig. 8 showed that zinc and galvalume anode generated higher power output than aluminium, especially at the beginning of observation (t=0-120 m). The power generation of seawater battery was limited by several factors; part of anode area, anode matter, electron transfer and external resistance [17, 29, 49]. The seawater battery with high power output was sufficient enough to be developed as power source for lift net fisheries. Zinc and galvalume plate was common anode matter which was easily available, low-cost, and available in large quantities. These anodes also presented high voltage, current, and power output during experiment at the similar area. Thus, we plenty appropriate to selected zinc and galvalume as common anode matter in developing seawater battery for lift net fishing.

3.4. Power Supply for Fishing Lamp of Fixed Lift Net Fisheries

Fixed lift net fisheries used artificial light for attracting schools of fish which are phototaxis positively around the platform of fishing gear during fishing operation. LED lamps are highly potential light sources for developing efficient and effective lift net fishing activity. It has many advantages, such as; high efficiency, a long life time, fast response and together with climate resistance [21]. Furthermore, LEDs also do not contain mercury (as opposed to CFL), tolerant of low voltages, very small and portable, and have high optical efficiency. LEDs are often submersible, and it can be compared favorably, technically and economically with all other forms of lighting for small-scale applications [22].

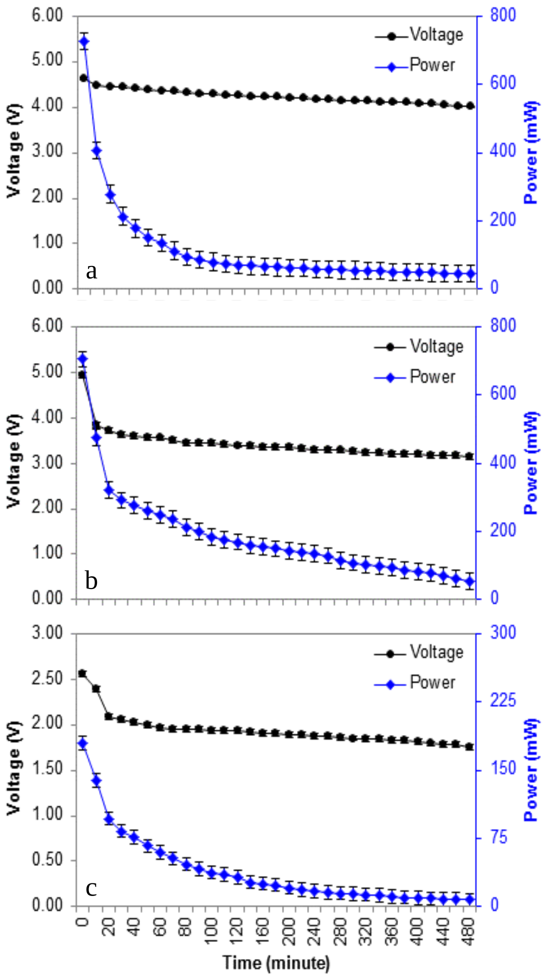

Fig 8. Comparison of voltage and power output of galvalume battery (a), zinc battery (b), aluminium battery (c). Vertical bar denote standard error.

Among results analysis from this experiment, six cells of sea water battery can regularly provide sufficient power for each LED lamp for 24 hours through three cycles discharge process as shown in Fig 9. The yellow DIP LED generated intensity by 27 lux, 65 lux for single high power LED and 75 lux for five LEDs. The aluminium and zinc battery drove LED in the same intensity during 24 hours. However, power output of galvalume battery at the first cycle (after 300 minutes) only could drive LED by 22 lux. It was related to the load condition and power output of each battery. Five LEDs in parallel connection were consumed current five times greater than single LED at the same voltage. It caused the power output of galvalume battery drained rapidly during discharge process and generated low light intensity.

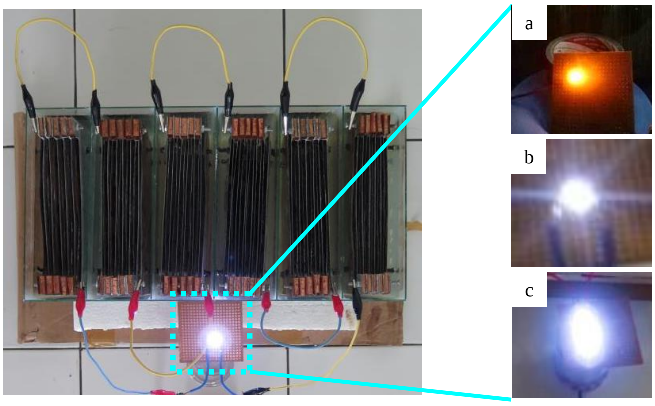

Fig 9. Six cells battery in series connection drive LED. (a) Yellow DIP LED, (b) single high power LED (1 watt), (c) five high power LEDs.

Aluminium battery was generated lower power output than zinc and galvalume, thus it could be eliminated as the power source for LED lamp in the lift net fishing. The power output was decreased under regularly discharging condition, which was observed from delay time activated of LED lighting and declining of light intensity output. High power LED consumed more power than DIP LED for generating the maximum light intensity, thus the battery exhausted quickly. Furthermore, we compared the light output of 5 DIP LEDs and high power LEDs at the same distance (30 cm). The single DIP LED had higher light output (175 lux) than high power LED (65 lux). Combination of five DIP LEDs also generated high intensity (256 lux) than high power LED (75 lux) is shown in Fig 10. The DIP LED was sufficient enough for the light source in lift net fishing due to low-cost, high intensity output and low energy consumption.

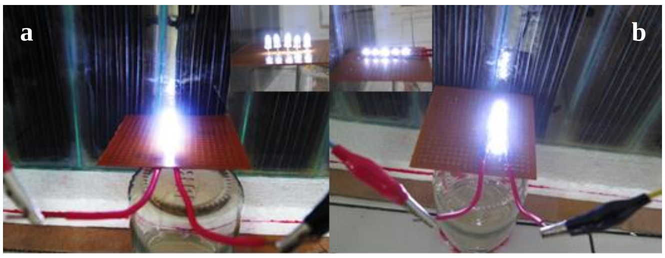

Fig 10. Lighting of five LED lamps (a) white DIP LED, (b) high power LED

Application of zinc and galvalume seawater battery in lift net fisheries could be developed through innovation of DIP LED and using of DC/DC converter. The low voltage of seawater battery could be transformed by DC/DC converter into high voltage [31, 50, 51] which is useful for fishing activities. The previous research is shown the DC/DC converter is increased the voltage output of seawater battery from 0.9 to 12.0 V [52], 1.0 V to 28.0 V [24], 0.8 V to 12.0 V [53], 1.6 V to 24.0 V [49] and 1.5 V to 12.0 V [54]. The improvement of design and construction of DIP LED fishing lamp with seawater battery have to consider the response of fish, behavior, and light distribution at catchable area of lift net. Development of LED fishing lamp and seawater battery becomes new invention to increase the effectiveness and efficiency of lift net fisheries. Moreover, these improvements also become sufficient manner to utilize a renewable energy in fishing activities to drive the sustainability of small fisheries.

4. Conclusion

The mean peak of potential output during discharge process of zinc (4.93 V) was higher than galvalume (4.64 V) and aluminium (2.55 V). The peak power output of zinc (704.17 mW) was not significantly difference with galvalume (726.41 mW), nevertheless these had a significant difference with aluminium (175.75 mW). The anode materials obviously affected the performance of seawater battery. Zinc and galvalume were a sufficient enough to be developed as seawater battery anode due to their higher number of potentials, current and power output than aluminium.

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