Electrochemical Impedance Spectroscopy Analysis of Lithium Polymer Batteries During Charge/Discharge Cycle

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Abstract

Batteries are portable energy suppliers. One type of batteries are rechargeable and electrolyte polymer membrane-based lithium ion battery. Electrochemical impedance spectroscopy was used to gain information on the behaviour electrochemical reaction on electrode/electrolyte interface of the lithium polymer battery. Impedance spectroscopy measurement shown that the $r_{\text{esr}}$ decreases with the decreasing of constant discharge current. Higher currents (2c and 1c) gave higher resistances compared to lower currents (0.5c and 0.3c) on the charge current of 1c. $r_{\text{esr}}$ tends to decrease with decreasing discharge current is given. With a charge current of 0.7c and 0.2c, it was not show a clear comparison of the impedance between high currents and low currents. $r_{\text{esr}}$ tends to increase with decreasing discharge current is given. These result shows that the impedance of electrical double layer affected by various charge/discharge currents which would affect the performance of the batteries.

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Introduction

Battery is an electrochemical energy source that can convert chemical to electricity energy (Aurora 2004). Battery consists of two electrodes, a positive electrode (cathode) and negative electrode (anode), they are separated by a separator and a liquid electrolyte. The liquid electrolyte serves as a medium for ion transfer and the separator as an insulator for the electron. Lithium-ion batteries have many advantages compared to other type of batteries, it has no memory effect, high working cell voltage, low environment pollution, low self-discharge rate, and high power density in volume and high specific energy and energy density and freedom for material more extensive and more environmentally friendly as constituent material such as polymers (Lee 2005).

Energy density comparison of lithium-ion batteries with other batteries can be seen in Figure 1. The figure shows that the lithium-ion batteries have twice the energy density of batteries compared to other (Chen 2012).

![Figure 1. Comparison of different battery technologies in term of energy density (Chen 2012)](image)

Up to this time, lithium-ion batteries have been widely used in various electronic devices such as mobile phones, laptop, medical devices and even Mercedes Benz in 2010 use them in their electric cars (Arora 2004, Andre 2011).

One of approach used to identify the behaviour or properties of an electrochemical cell are using electrochemical impedance spectroscopy (EIS) (Andre 2011, Rochliadi 2002). EIS can describe electrochemical reactions that occur at electrode/electrolyte interface (Chang 2010), double-layer capacitance and polarography (Lasia 1999). EIS have been widely used also in electrochemical such as...
corrosion, batteries, coating material and fuel cell (Barsoukov 2005).

This paper, impedance of the battery was conducted to determine the behaviour of battery during charge/discharge cycles with various charge and discharge currents.

**Methodology**

The charge/discharge test procedure was performed in 100 cycles for each tested battery. The battery type used is commercial battery with a code by PLH-1R3OF. This battery has rated capacity of 620 mAh and voltage of 3.7 volt.

The charge current uses 1C, 0.7C, and 0.2C. The discharge current uses 2C, 1C, 0.5C, and 0.3C. Cut-off voltage for each of the discharge is 2.75 volt. Figure 2 shows the typical battery analysis routine (BAR) chart used in the charge/discharge regime. A Vencon UBA5 battery analyser is used in the testing procedure (Rochliadi 2013).

**Results and Discussion**

Process charge/discharge has been carried out on the polymer battery and the results have been reported in paper (Rochliadi 2013). in this paper, discusses the impedance with variation charge/discharge current on the polymer battery.
coefficient is a process of diffusion of lithium ions between electrodes.

In Nyquist plot also there is line under $Z_{real}$ axis, semicircle and diagonal line. Line under $Z_{real}$ axis is inductor element (Andre 2011). In a semicircle have two elements, resistor and capacitor, in parallel circuit and it is an effect caused by charge transfer and electrochemical double layer. Diagonal line is Warburg impedance element caused by effect of mass transfer (Jossen 2006).

Figure 4 shows that in charge current 1C, high discharge currents (2C and 1C) show impedance higher than low discharge currents (0.5C and 0.3C). This is consistent like previous research [11]. Figure 5 and Figure 6, the plots showed no clear comparison between the high discharge currents and low discharge currents. That is occurs because the charge current used is very low 0.7C and 0.2C. Impedance measurements for all batteries carried in state of 100% state of charge (SOC).

Figure 7 shows $R_{esr}$ value obtained after fitting with equivalent circuit model used in Figure 3. At charge current 1C, $R_{esr}$ tends to decrease with decreasing discharge current is given, while the charge 0.7C and 0.2C, $R_{esr}$ tends to increases with decreasing discharge current is given.

Table 1 shows the complete result of fitting equivalent circuit of all batteries. It’s shows that charge/discharge currents to affect the value of every electrical element. We can see $R_{esr}$ in Table 1 has various value with various charge/discharge currents and similar of other elements.

![Figure 7](image)

**Table 1. Result fitting polymer battery**

<table>
<thead>
<tr>
<th>Charge</th>
<th>Discharge</th>
<th>$R_{esr}(10^3 \Omega)$</th>
<th>$R_s(10^3 \Omega)$</th>
<th>$Y_{1(10^3SS)}$</th>
<th>$W$</th>
<th>$L(10^9 \text{H})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1C</td>
<td>2C</td>
<td>190.4</td>
<td>58.99</td>
<td>349.6</td>
<td>67.21</td>
<td>504.0</td>
</tr>
<tr>
<td></td>
<td>1C</td>
<td>162.2</td>
<td>63.58</td>
<td>324.9</td>
<td>72.87</td>
<td>552.4</td>
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<tr>
<td></td>
<td>0.5C</td>
<td>153.4</td>
<td>63.55</td>
<td>299.1</td>
<td>65.70</td>
<td>551.3</td>
</tr>
<tr>
<td></td>
<td>0.3C</td>
<td>145.3</td>
<td>67.59</td>
<td>303.6</td>
<td>69.00</td>
<td>510.5</td>
</tr>
<tr>
<td>0.7C</td>
<td>2C</td>
<td>164.8</td>
<td>65.23</td>
<td>407.6</td>
<td>63.26</td>
<td>525.1</td>
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<tr>
<td></td>
<td>1C</td>
<td>150.0</td>
<td>67.80</td>
<td>267.0</td>
<td>55.69</td>
<td>410.0</td>
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<tr>
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<td>145.2</td>
<td>67.81</td>
<td>306.4</td>
<td>67.21</td>
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<td>61.00</td>
<td>285.0</td>
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<tr>
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<td>163.5</td>
<td>60.67</td>
<td>246.9</td>
<td>73.08</td>
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<tr>
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<td>346.6</td>
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<td>65.13</td>
<td>440</td>
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<tr>
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<td>280.7</td>
<td>72.21</td>
<td>303.0</td>
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<td>505.2</td>
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<tr>
<td></td>
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<td>194.7</td>
<td>57.20</td>
<td>248.4</td>
<td>69.97</td>
<td>531.8</td>
</tr>
</tbody>
</table>

**Conclusions**

Electrochemical Impedance Spectroscopy has been performed on the lithium polymer battery with various charge/discharge current. At charge current 1C, high discharge currents show impedance higher than low discharge currents. $R_{esr}$ tends to decrease with decreasing discharge current is given. At charge current 0.7C and 0.2C no clear comparison between the high discharge currents and low discharge currents. $R_{esr}$ tends to increases with decreasing discharge current is given. Impedance of electrical double layer affected by various charge/discharge currents is given.
Acknowledgments

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References


