Discharge studies of Lithium ion coin cells at various C-Rates

[1]Harika Sunkara,[2] China Malakondaiah Kaniganti,[3]Koteswara Rao M.

Assistant Professor,[2] Assistant Professor [3]Assistant Professor
[1]Chemical Engineering,
[1]ANITS,Visakhapatnam, India

Abstract: **Till date, enormous increasing demand of lithium ion cells usage for electronic gadgets like cellular phones, laptops, i-pods etc.,which are motivated with the continuous effort towards development of better life cycle batteries. Lithium ion batteries are the state-of-the-art power sources for portable electronic devices and considering their superior energy and power densities and these cells are promising candidates for the demanding energy storage applications. The development of lithium ion batteries reckon on the fabrication and electrical performance evaluation of the coin cells. The quality of the materials during the fabrication gets identified by the performance of coin cells and necessary measures were taken to improve them. Subsequently, the same can be scaled up for higher capacity and energy for adapting to under water applications. The present work depicts the study of discharging voltage under constant current mode using C/10, C/5, C/2 rates. Further, Charging characteristics of coin cell were also studied at C/5 rate.**

***Key words* – C-Rates, charging, discharging, Lithium ion coin cell.**

1 INTRODUCTION

Approximately 68% of today's electrical energy is supplied from fossil fuels. Recent increase in the demand for oil, associated with the price increase and environmental issues continue to exert pressure on an already stretched world energy infrastructure. Significant efforts have been made in the development of renewable energy technologies such as solar cells, fuel cells and biofuels. Electrochemical energy production is also considered as a different energy source, such as the lithium-ion battery system.The lithium ion batteries are more suitable candidates to meet the various power generation applications since they provide high energy density compared to other existed secondary/ rechargeable batteries refer to lead acid, nickel-cadmium, nickel- metal hydride etc.
In recent years, the secondary battery market further expanded and tends to increase continuously [1]. The global saleof Li ion portable batteries is around 63% and it is larger than those of Ni-Cd (23%) and Ni-MeH (14%). Therefore it is anindication that lithium battery technology receives most attention. Ever growing demand for batteries, the industry and government are ready to invest in battery research and development. This investment is focused on improving battery technology for communication, mobile electronics and computer technology in one hand and in other hand majority of government funded research is for military, spacecraft, transportation, etc [2]. Requirement for improving the battery properties included cycleability, reversibility, high energy and power densities, safety, environmental impact, low cost etc [3]. Hence, a wide range of materials (anodes, cathodes and electrolytes) have been developed and investigated for the improvement of lithium battery technology.

Most of the commercial lithium batteries are based on the lithium carbon (anode) / lithium cobalt oxide (cathode) chemistry [4]. In order to develop high energy density batteries with extended cyclic life, it is necessary to find the electrode materials with high specific charge (current density) as well as more structural stability. Most of the efforts are concentrated on developing new cathode materials not only to improve the cell voltage but also the specific capacity of lithium batteries which much depend on their intercalation behavior during charge / discharge cycles [5]. Among them, lithium transition metal oxides have been studied as promising positive electrode materials, since they show large stability region with respect to lithium content than other class of intercalation compounds.

Layered $LiCoO_2$, $LiNiO_2$ and $LiMnO_2$, spinel $LiMn_2O_4$, inverse spinel $LiNiVO_4$ and olivine $LiFePO_4$ are the most studied cathode materials in the last two decades. Although, numerous classes of cathode materials were studied, only 40 to 65% of the theoretical capacity of the cathode materials could be practically utilized owing to the chemical and structural instabilities due to the lithium intercalation during the charge and discharge process [6].

2 EXPERIMENTAL PROCEDURE

The procedure was followed for setting parameters of load bank for testing the capability of a Li-Po battery has been described in detail. A coin cell was employed for charge and discharge studies. Battery was discharged at various modes. One such mode was the Constant Current (CC) mode. Other modes were constant voltage, constant resistance and constant power. To perform the capability test, the Electronic Load Bank (ELB) employed to maintain CC. mode of operation. Initially set the voltage of load bank when load was not connected. The ELB was terminated the test when the battery reaches lower voltage than the set voltage. The sequence of steps involved in the testing operation is presented below (Figure 1).

I. Turn off the load and then connect the tested battery.
II. Press I-set button, then Variable Frequency Drive (VFD) displays current reading A. Set the discharge current of the battery to 200 milli amps, then press Enter button to confirm.
III. Press Shift + 8 (means the battery is connected to load), VFD displays MINVOLT as V. Set the minimum voltage to 2.7 volts. The system will turn off when the minimum voltage becomes less than the specified MINVOLT value. This is required to ensure the safety of the Battery system.

IV. Press Enter button to start the capacity testing. During the testing, use '▼'and '▲' buttons to change the voltage, actual discharge current, the electronic load power and the released discharge capacity of the battery. (The voltage is reduced due to internal resistance).

V. Then press Shift + 8 to exit from the battery capacity testing mode.

Figure 1 : Image of electronic load bank for discharging a cell.

The charging was done by connecting the cell to the charger. During charging, red light appears and once charging is completed red light turns into green light. Then the cell was disconnected from the charger, and kept for 5 to 6 hours rest period for stabilization.

In the present experimental study, the discharge voltage characteristics of a lithium ion coin cell have been studied under constant current mode of operation. The discharge voltage has been measured in the case of a single cell with different C-rates (Appendix A). The charging voltage for coin cell, CR 2032 (which has an outer diameter of 20 mm and height of 3.2 mm) at constant current mode has also been obtained.

3 RESULTS AND DISCUSSION

The measured data consist of discharge voltage at various current rates (C- rates), charged voltage, and discharge voltage. The calculated data consisted of theoretical capacity of four coin cells made as part of experiment in laboratory. The theoretical capacity calculations and experimental data on discharge characteristics have been compiled. The experimental conditions and the range of variables for 5 mAh cell employed in the present investigation have been compiled and presented in Table 1.

Table 1: Experimental conditions and output capacity in the present experiment

Parameters studied		**Range of parameters**	**Output Capacity**
Charging rate (Input capacity)		1 mA if it is 0.2 C rate	5 mAh
Discharging rate		C/10, C/5, C/2.	
C-rate	Current	Duration	Output Capacity
C/10	0.5 mA	564 min	4.7 mAh
C/5	1 mA	270 min	4.5 mAh
C/2	2.5 mA	96 min	4.0 mAh

The discussion is presented in four sections. The theoretical capacity calculations are presented in the section 3.1. The variation of battery voltage during stabilization after fabrication of the cells is shown in section 3.2. The charging characteristics of a cell are shown in section 3.3. The discharge characteristics at various C rates are provided in section 3.4.

3.1. Theoretical capacity calculations of the cell

Weight of electrode disc with current collector = W_{ED}

Weight of unwanted current collector disc of the same diameter = W_{CC}

Weight of electrode material, W_{EM} is given by

$$W_{EM} = W_{ED} - W_{CC}$$

Weight of active material in the electrode, W_{AM} is given by

$$W_{AM} = W_{EM} \times 0.8$$

Theoretical capacity of the electrode disc, C_{ED} is given by

$$C_{ED} = W_{AM} \times C$$

Where C is theoretical specific capacity of active material. (For anode C = 330 mAh/g and for cathode C = 145 mAh/g)

Theoretical capacity of the cell C_T, is given by

$$C_T = \text{Theoretical capacity of anode} + \text{Theoretical capacity of cathode}$$

3.2. Voltage stabilization in the first one hour

The variation in voltage during this stabilization process is plotted against time and is shown in Figure 2. It is observed that the voltage raised rapidly and is stabilized beyond the time of 20 min.

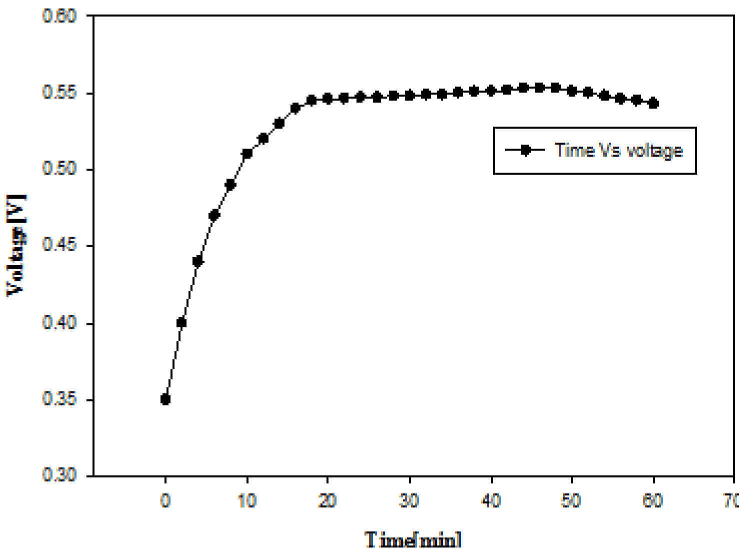

Figure 2: Voltage stabilization during the first one hour

3.3. Charging characteristics of a cell

It is very important to know the charging characteristics of a cell. In the present experiment, charging was done at a constant rate of 1mA. The battery is charged fully about in 5h time. Then the cell was disconnected from the charger, kept idle for 2 hours for stabilization before subject to discharge. The voltage reading during charging against time was plotted and shown in Figure 3. During charging, an observed voltage from the Figure 3, the voltage increased from 3.01 V to 3.6 V in a time period of 5h.

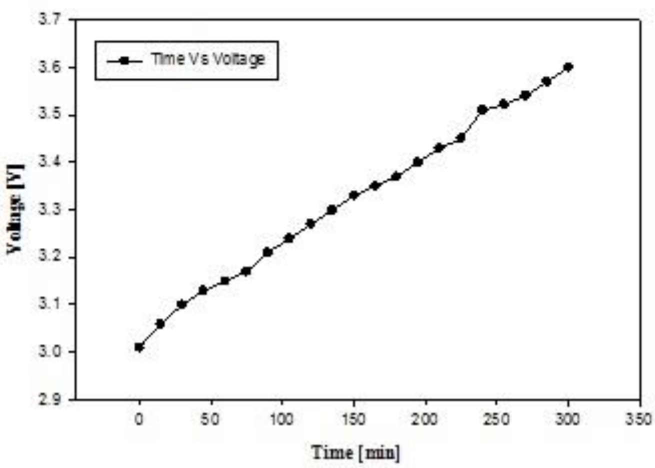

Figure 3: Variation of voltage with time during charge phase at current of 1mA

3.4. Discharge characteristics of coin cell at different C - Rates

Discharge voltage characteristics were examined by obtaining discharge voltage data versus time for the constant current mode operation as described below. This data was obtained for three different C-rates as shown in Table 1.

3.4.1Discharge at C/10 Rate:

The discharge voltage obtained by keeping current constant at 0.5mA was plotted against time and was shown in Figure 4. Open Circuit voltage (OCV) of the cell was 3.6V and it was immediately fallen to operating voltage of 3.35V when load was applied and thence to cut off voltage of 3V over a period of 564 min. This yields an effective and realizable capacity of 4.7 mAh. This indicates the good health of the cell that is fabricated. It is generally not possible to realize the 100% of input capacity due to loss of capacity in the form of heat and other polarization effects. In the present case more than 90% of input capacity is realized, which is high as expected.

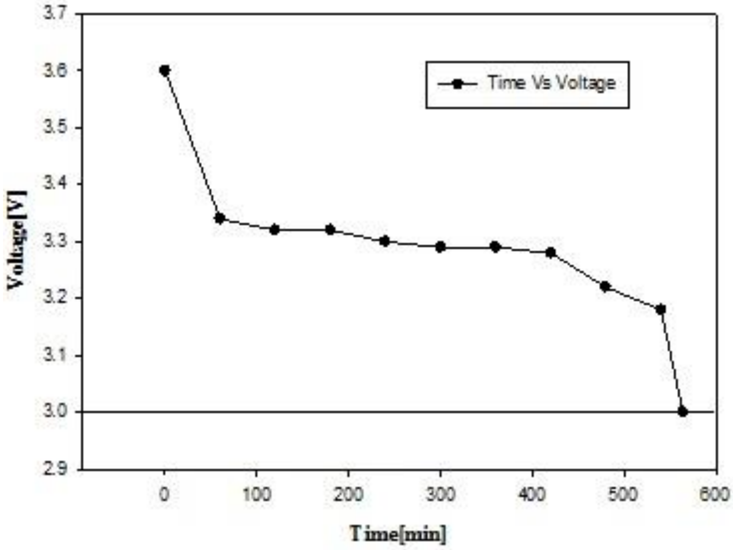

Figure 4: voltage decline of coin cell with time taken when discharged at C/10 rate (0.5mA)

3.4.2Discharge at C/5 Rate

The discharge voltages obtained by keeping current constant at 1mA were plotted against time and shown in Figure 5.

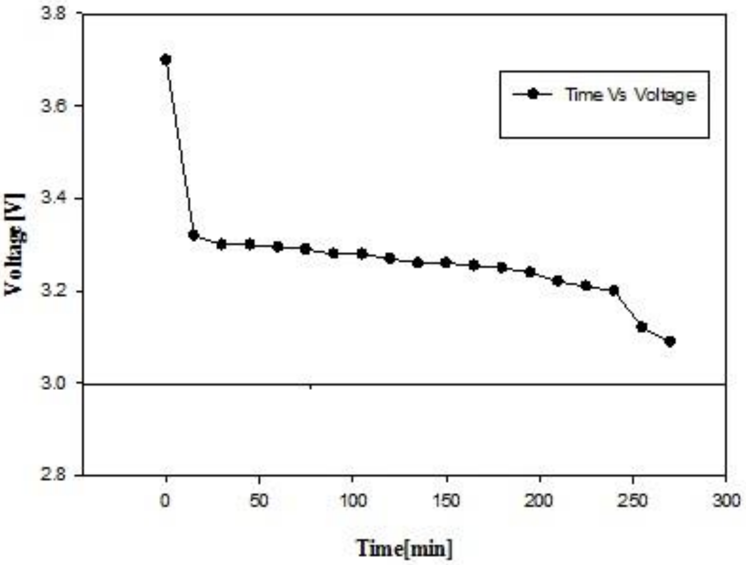

Figure 5: Decline of voltage of coin cell with time taken when discharged at C/5 rate (1mA)

It can be seen from Figure 5, the realized capacity is 4.5 mAh which is nearly 90%, as can be observed, when the cell is discharged at 1mA current. This is marginally less than the capacity realized when discharged at 0.5 mA. It is known that the capacity realized is less at higher current loads and more energy is lost as heat.

3.4.3Discharge at C/2 Rate:

The discharge voltages obtained by keeping current constant at 2.5 mA were plotted against time and shown in Figure 6. As the current loads are higher and more energy is lost as heat and other polarization effects. The same can be evinced from Figure 4-6. The realized capacity is relatively less as compared to discharge at C/10 and C/5 rate. The overall realized capacity is only 80% when discharged at C/2 rate.

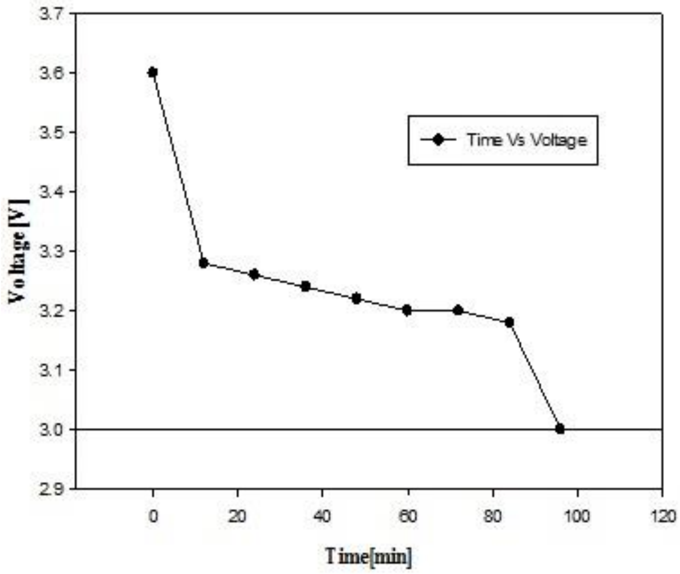

Figure 6: Fall of voltage of coin cell with time taken when discharged at C/2 rate (2.5mA)

3.4.4Comparison of discharge characteristics at various C - Rates

The consolidated discharge voltage curves at different C-rates as shown in Figure 7. It was observed that the realized voltage was less when the cell was discharged at C/2 rate than the cell discharged at C /10 and C/5 rates (or) cell discharge rates were rapid when the applied load was high.

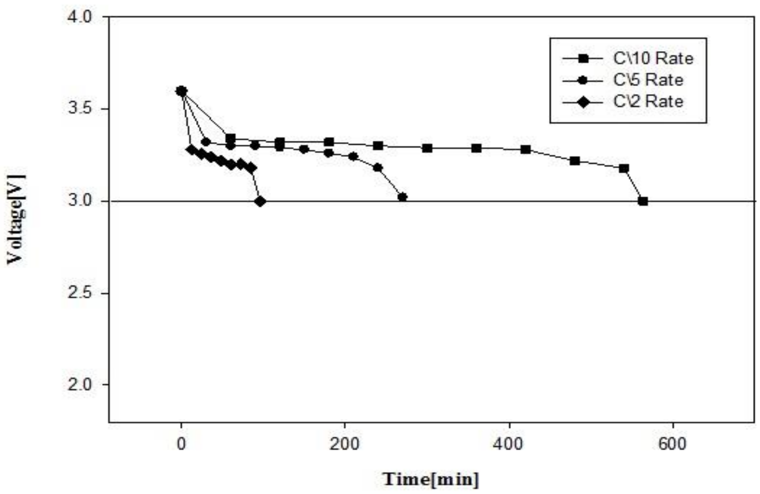

Figure 7: Consolidated discharge curves at different voltages

4 CONCLUSIONS

The present investigation was carried out to study the discharge characteristics of lithum ion coin cell at various C – Rates. Based on the rigorous analysis of this data, the following inferences were highlighted:

1. A coin cell with graphite and lithium cobalt oxide of capacity 5 mAh is fabricated successfully.
2. Gain of voltage and / or capacity is very gradual and is in line with the standard voltage - time history during charging.
3. The discharge profiles at different C – rates also were normal and as per typical profiles. As the discharge load currents increased the realized capacities decreased. This is attributed to loss of energy as heat and polarization effects.
4. The realized capacity is less when the cell is discharged at C/2 rate than the cell was discharged at C /10 and C/5 rates.

REFERENCES

1. B. B. Owens, W. H. Smyrl, J. J. Xu, R &D on Lithium ion batteries in the USA, high energy electrode materials, J. Power Sources, 81, (1999), 150-155.
2. M. Salomon, Lithium batteries: Present trends and prospects, 936, (1996), 666 – 678.
3. S. Yoda, K. Ishihara, Development of Lithium batteries for energy storage and EV, J. Power Sources, 68, (1997), 3-7.

4. Y. Nishi, Development of Lithium ion secondary batteries, Chem. Record, 1, (2001), 406-413.
5. K. M. Abraham, Directions in secondary lithium battery research and development, Electrochemical Act, 38, (1993), 1233-1248.
6. R. T. Carlin, K. S. Lyons, Recent advances in lithium ion batteries, Journal of power sources, 6, (2002), 25-30.

Appendix A:

C-rate: A charge or discharge current equal in Amperes to the rated capacity in Ah. Multiples larger or smaller than the C-rate are used to express larger or smaller currents. For example, the C-rate is 600 mA in the case of a 600 mAh battery, whereas the C/2 and 2C rates are 300 mA and 1.2 A, respectively.