Electrical Behaviour of a Li-Ion Polymer Battery

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INTRODUCTION

Lithium batteries have made substantial and significant gains in the last 30 years from becoming a curiosity to becoming the dominant rechargeable battery for consumer portable applications. However, the next market opportunities will be much tougher to conquer as they mostly demand higher power capabilities at lower costs.

A detailed study of one commercial Li-ion Polymer battery (EEMB. LP703048. 1000 mAh)[1], taking into account mainly its electrical behaviour, has been considered.

No.	Item		Characteristics		Remark
2.1	Model		LP703048		
2.2	Capacity	Nominal Capacity	1000	mAh	0.2CA
		Minimum	950	mAh	0.2CA
2.3	Nominal Voltage		3.7	V	
2.4	Weight		Approx. 20	g	
2.5	Internal Impedance		≤ 100	mΩ	AC 1KHz（50%荷电）
2.6	Dimension	Length	≤ 49	mm	
		Width	≤ 30.5	mm	
		Thickness	≤ 7.3	mm	
2.7	Charge	Maximum Current	1000	mA	1CA（CC&CV）
		Limited Voltage	4.200±0.020	V	
		End-of Current	20	mA	
2.8	Discharge	Maximum Current	2000	mA	2.0CA
		End Voltage	2.75±0.005	V	
2.9	Operation Temperature	Charge	0～+45	℃	
		Discharge	-20～+60	℃	
2.10	Storage Temperature	1 month	-20～+60	℃	
		3 month	-20～+45	℃	
		12 month	-20～+25	℃	
2.11	Storage Relative Humidity		65±20	%	

No.	Item	Criteria	Test Instructions
5.1.1	$1C_5A$ rate discharge capacity	Discharge Time≥57min	Full charge at 20 ± 5 ℃, rest for an hour, then discharge at the same temperature with $1.0C_5A$ to 2.75V
5.1.2	High temp. discharge capacity	Discharge Time≥54min	Full charge at 20 ± 5 ℃, store at 55±2℃ for 2h, then discharge at the same temperature with $1.0C_5A$ to 2.75 V
5.1.3	Low temp. discharge capacity	Discharge Time≥4.25h	Full charge at 20±5 ℃, store at -10℃±2℃ for 16h~24h, then discharge at the same temperature with $0.2C_5A$ to 2.75V
5.1.4	Cycle Life	≥300Cycles	Lay aside for 10 min after fully charged. Then discharge at constant current of $1.0C_5A$ to 2.75V and leave it for 10 minutes. Repeat above steps until the discharge time is less than 48 min the charge-discharge cycles.
5.1.5	Capacity Retention	Discharge Time≥4.5 h	After fully charged, store the battery at 20±5℃ for 28 days. Then discharge it with $0.2C_5A$ to 2.75V and record the discharging time.

Figure 1. Electrical Characteristics: Li-Ion Polymer Battery (EEMB. LP703048. 1Ah).

COMPUTATIONAL METHODS

With a view to estimating electrical characteristics of a Polymer Li-ion Battery during specific charge and discharge conditions, a **COMSOL Multiphysics®** model has been developed that accounts for electrochemical phenomena inside the device. In order to accomplish that, the **Battery and Fuel Cells Module** has been used. Cell model has been created using the Li-Ion Battery interface, customizing material properties and electrochemical reactions. The electrochemical parameters required for the calculation have been determined by laboratory tests, manufacturer datasheets and literature survey.

A detailed analysis has been performed to evaluate the influence of the electrode kinetics in the characteristic curve of the device[3]. As shown in ***Figure 2***, the Lithium Insertion electrode kinetics is the most accurate approximation to the device experimental behaviour.

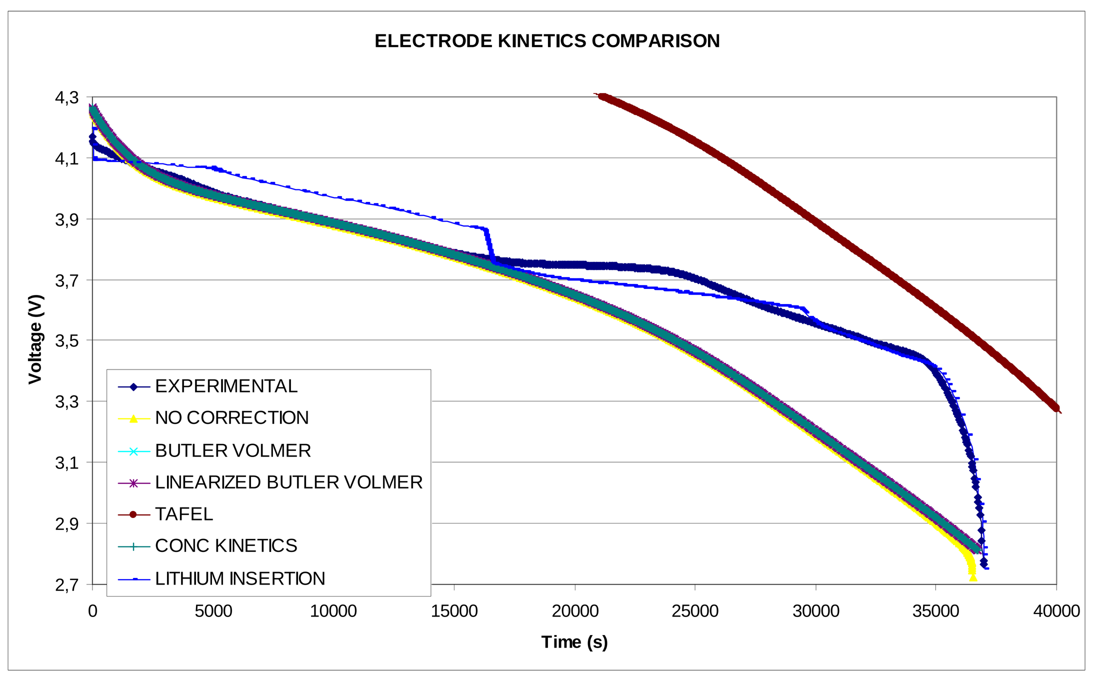

Figure 2. Electrode kinetics comparison.

The equilibrium potential of the Li-ion intercalation electrodes does not follow the Nerst equation due to the solid state redox reaction[2]. The effect of the equilibrium potential correction fitted in the **COMSOL Multiphysics®** model was studied for different discharge rates. As a result, the Redlisch-Kister equation for LiC_6 and $LiCoO_2$ was used. ***Table 1 and 2*** show the equations used for equilibrium potential calculation and the parameters values used, respectively[4].

Table 1. Model equations for equilibrium potential using various equations of state.[4]

Model equations for equilibrium potential using various equations of state

One parameter Margules	$FU = FU^0 + RT\ln\left(\frac{1-x_\alpha}{x_\alpha}\right) + RT[A(2x_\alpha - 1)]$
Two parameter Margules	$FU = FU^0 + RT\ln\left(\frac{1-x_\alpha}{x_\alpha}\right) + RT\left[-A_0 + 2A_0x_\alpha - B_0 + 3B_0x_\alpha - \frac{3}{2}B_0x_\alpha^2\right]$
van Laar equation	$FU = FU^0 + RT\ln\left(\frac{1-x_\alpha}{x_\alpha}\right) + RT\left[\frac{A_0'(B_0'^2x_\alpha^2 - 1 + 2x_\alpha - x_\alpha^2)}{(1 - x_\alpha + B_0'x_\alpha)^2}\right]$
Redlich-Kister expansion	$FU = FU^0 + RT\ln\left(\frac{1-x_{\alpha,t}}{x_{\alpha,t}}\right) + \left\{\sum_{k=0}^{N} A_k \cdot \left[(2x_{\alpha,t}-1)^{k+1} - \frac{2x_{\alpha,t}k(1-x_{\alpha,t})}{(2x_{\alpha,t}-1)^{1-k}}\right]\right\}$

Table 2. Parameter values using Redlich-Kister equation for LiC_6 and $LiCoO_2$.[4]

Parameter values using Redlich-Kister equation for LiC_6 and $LiCoO_2$

Parameters	MCMB	$LiCoO_2$
N	10	7
U_0	-1.7203 ± 0.51308	-29.614 ± 2.3806
A_0	$-0.35799 \times 10^6 \pm 0.99032 \times 10^5$	$0.64832 \times 10^7 \pm 0.45934 \times 10^6$
A_1	$-0.35008 \times 10^6 \pm 0.99055 \times 10^5$	$-0.65173 \times 10^7 \pm 0.45933 \times 10^6$
A_2	$-0.35247 \times 10^6 \pm 0.98397 \times 10^5$	$0.65664 \times 10^7 \pm 0.45969 \times 10^6$
A_3	$-0.35692 \times 10^6 \pm 0.97652 \times 10^5$	$-0.65787 \times 10^7 \pm 0.46137 \times 10^6$
A_4	$-0.38633 \times 10^6 \pm 0.10929 \times 10^6$	$0.63021 \times 10^7 \pm 0.44922 \times 10^6$
A_5	$-0.35908 \times 10^6 \pm 0.11797 \times 10^6$	$-0.50465 \times 10^7 \pm 0.37283 \times 10^6$
A_6	$-0.28794 \times 10^6 \pm 0.52429 \times 10^5$	$0.27113 \times 10^7 \pm 0.21054 \times 10^6$
A_7	$-0.14979 \times 10^6 \pm 0.80161 \times 10^5$	$-0.69045 \times 10^6 \pm 0.56136 \times 10^5$
A_8	$-0.39912 \times 10^6 \pm 0.20291 \times 10^6$	
A_9	$-0.96172 \times 10^6 \pm 0.31894 \times 10^6$	
A_{10}	$-0.63262 \times 10^6 \pm 0.14748 \times 10^6$	

The model has been verified by voltage/ amperage measurements by means of a commercial Battery Testing System (CADEX C8000). These tests have provided a more realistic approach of electrochemical mechanisms inside the device.

RESULTS

Because of validation purposes both, an experimental (CADEX C8000) and a theoretical analysis (COMSOL model) reproducing datasheet test instructions, had been carried out. ***Figure 3*** shows the $1C_5A$ rate discharge capacity test results.

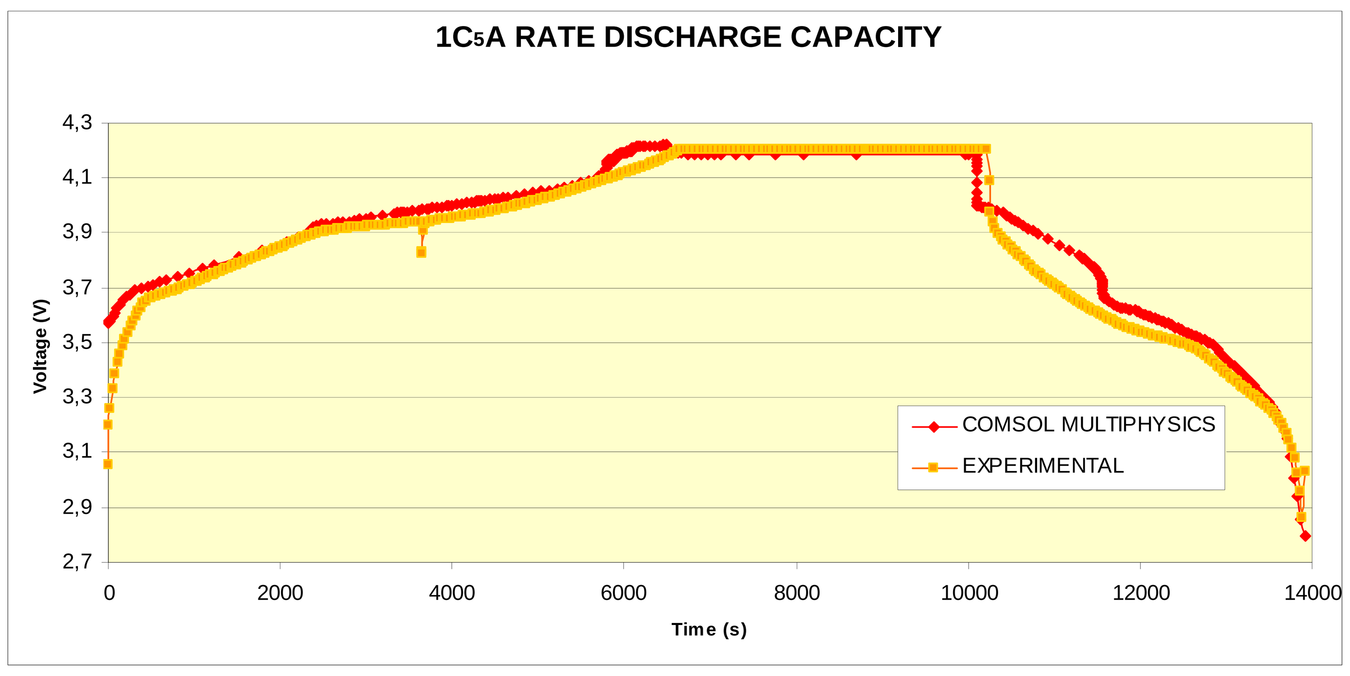

Figure 3. $1C_5A$ rate discharge capacity.

In both cases very similar results are achieved. Some of the differences might be due to differences in the state of charge considered in the theoretical model, intrinsic electrochemical parameters of the battery and/or geometrical aspects entered in the model (electrode/separator length, cell area,…)

Figure 4 shows some battery characteristic curves at different discharge rates predicted by the **COMSOL Multiphysics®** model.

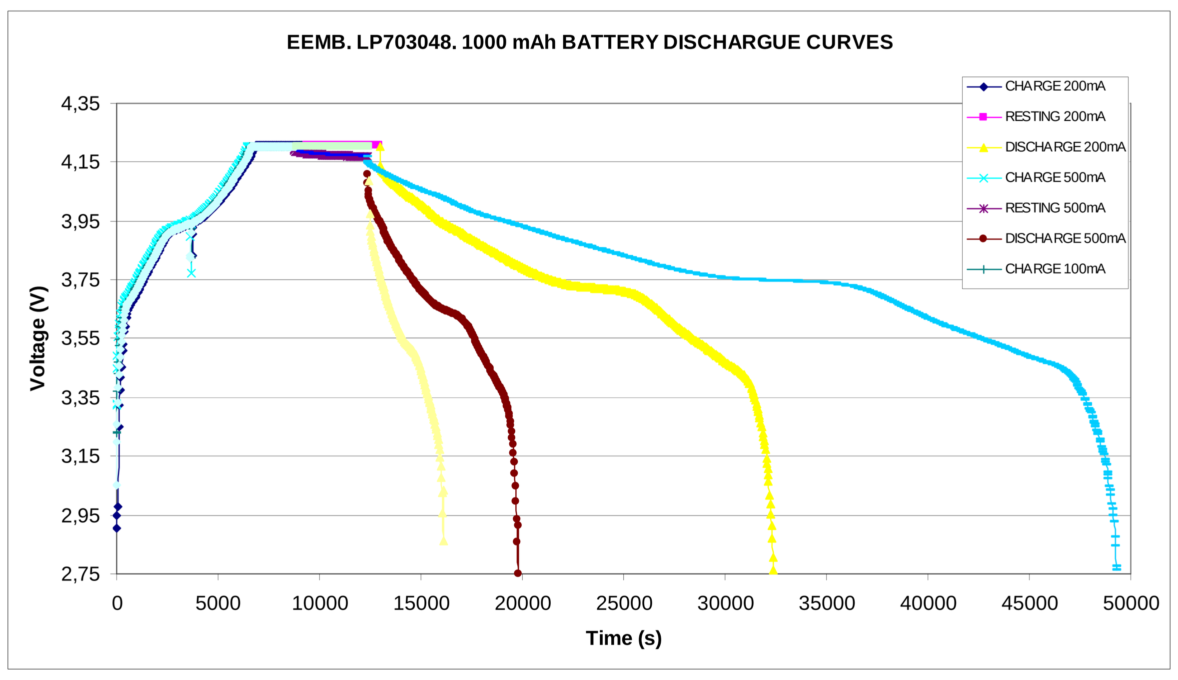

Figure 4. Characteristic curves at different discharge rates.

CONCLUSIONS

Results indicate that **COMSOL Multiphysics®** model is able to predict accurately not only the electrical behaviour of the device under specific operating conditions but also the influence of the materials involved, geometric aspects and other relevant boundary conditions in battery performance.

REFERENCES

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Excerpt from the Proceedings of the 2013 COMSOL Conference in Rotterdam