

# ICSC 2019

Core Competence Enhanced by MBD



## IDAJ CAE Solution Conference

### GT-Autolion在锂离子电池及电池系统中的应用

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# Autolion模拟软件介绍

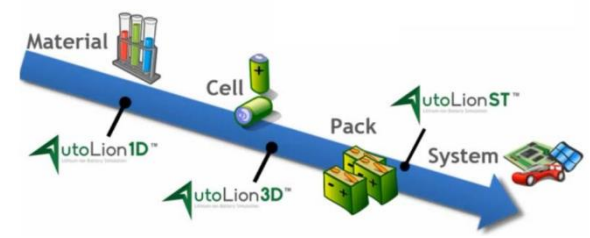
## 电化学反应

- 电化学反应
- 固体扩散
- 离子传递
- 电子传递
- 老化模型\*

双向耦合

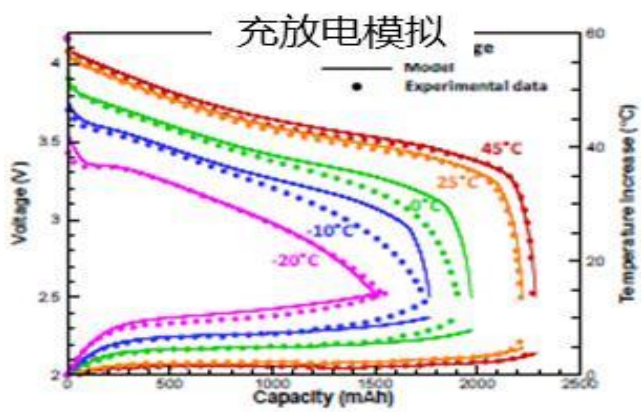
## 热力学效应

- 能量守恒

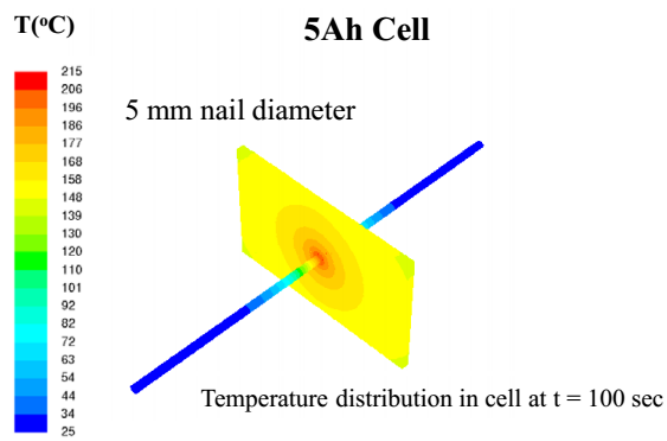


## 软件主要功能

- 多种不同电池体系的快速评价和极端工况下的电池设计
- 影响电池输出性能和安全性的电池内部机理研究
- 宽广工况范围内电池老化的可靠预测
- 针对电池系统架构的选择、设计和操作的非经验软件在环仿真工具
- 可对任何具有一个或者多个能量源的能量存储系统进行精确的系统寿命-成本优化



电池性能模拟

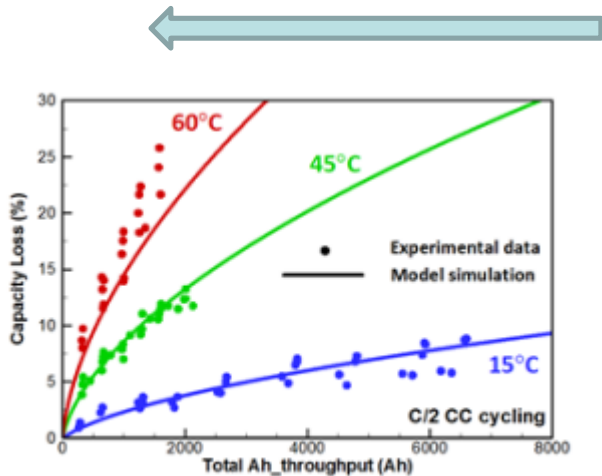
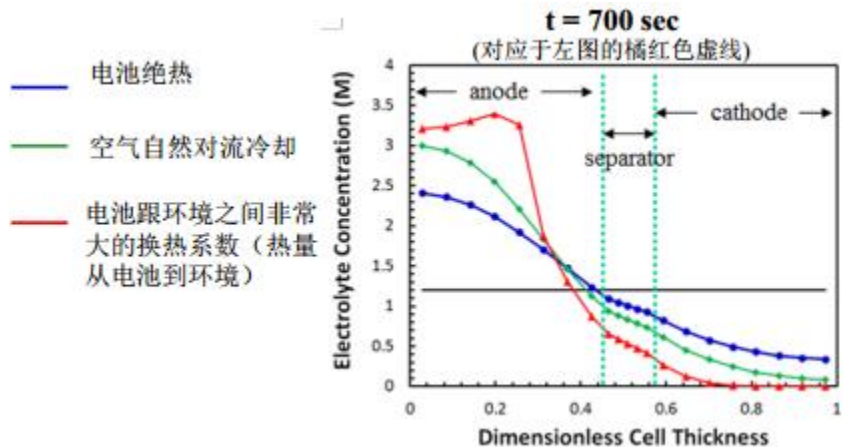
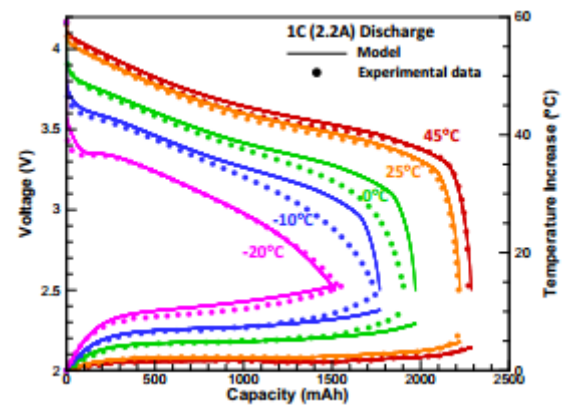


电池安全模拟

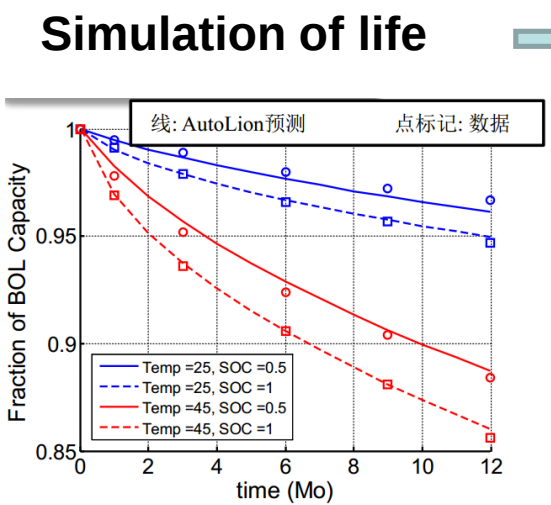
# Autolion模拟软件介绍

电芯仿真

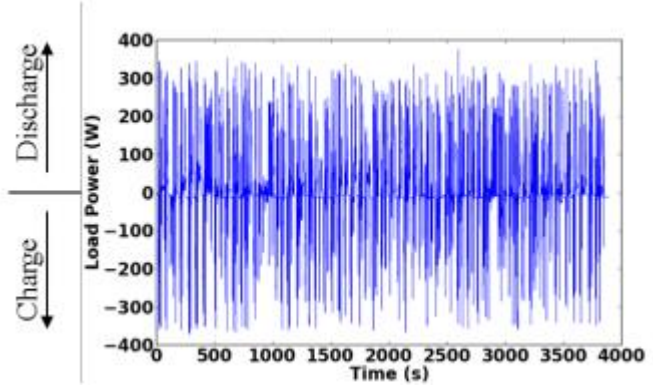
- 倍率C-rate
- 寿命Life
- 内阻DCIR
- 功率Power
- 温度Temperature



循环Cycle



存储Storage



工况Driving cycle

# Autolion理论方程

## Governing Equation

Transfer of electrons in solid phase:

$$\nabla \cdot (\sigma_s \nabla \phi_s) = j^{Li}$$

Transfer of ionic charges in electrolyte phase:

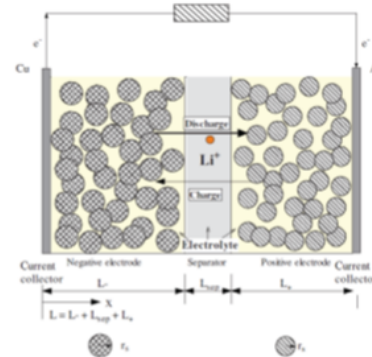
$$\nabla \cdot (\kappa^{eff} \nabla \phi_e) + \nabla \cdot (\kappa_D^{eff} \nabla \ln c_e) = -j^{Li}$$

Transfer of  $Li^+$  in electrolyte-phase:

$$\frac{\partial(\varepsilon c_e)}{\partial t} = \nabla \cdot (D^{eff} \nabla c_e) + \frac{1-t_+}{F} j^{Li}$$

Transfer of  $Li^+$  in solid active material particles:

$$\frac{\partial c_s}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left( D_s r^2 \frac{\partial c_s}{\partial r} \right)$$



## Energy Conversation Equation

$$\frac{\partial(\rho C_p T)}{\partial t} = (q_r + q_j + q_c) A_{cell} - h_{conv} A_s (T - T_{amb})$$

$q_r$  --- heat generation due to reaction

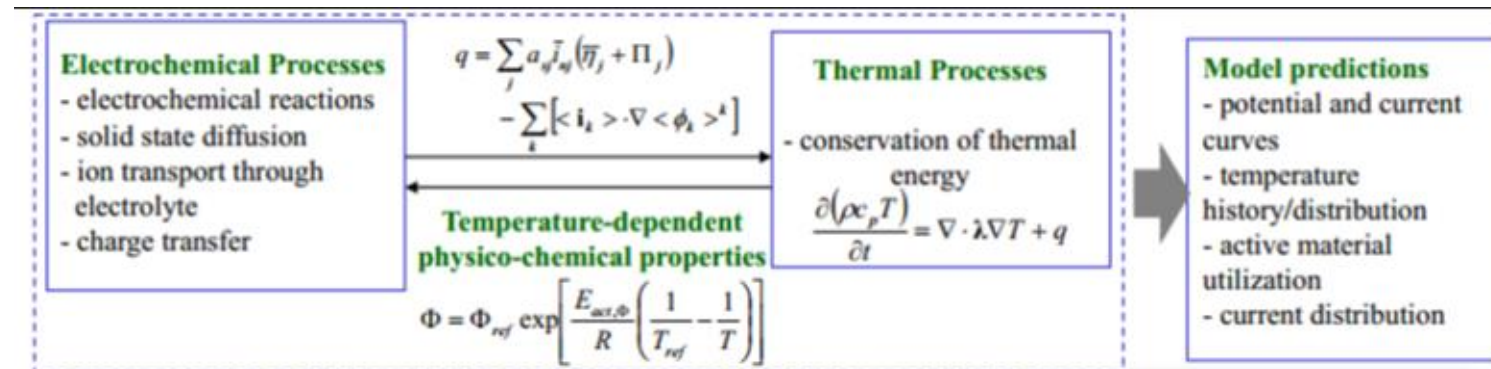
$q_j$  --- ohmic heat generation rate

$q_c$  --- contact resistance heat generation rate

## Electrochemical-Thermal Couple model

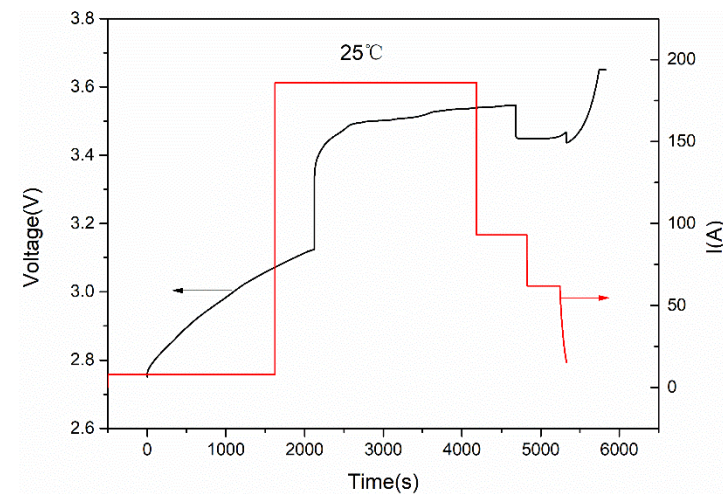
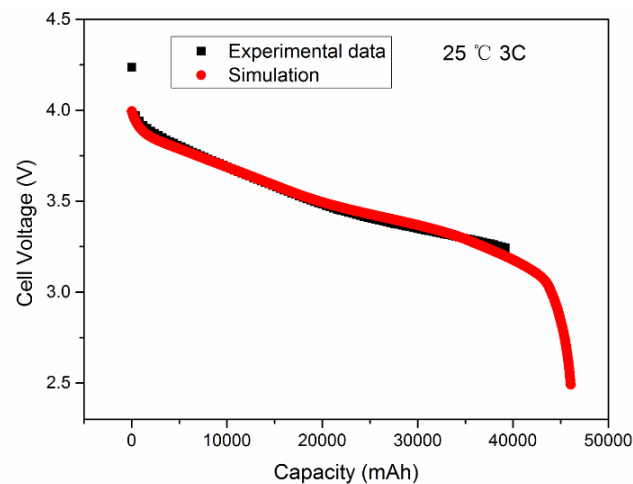
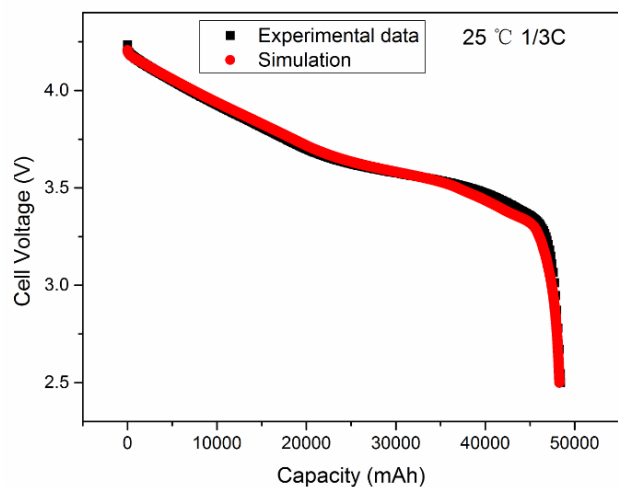
## Butler-Volmer Equation

$$j^{Li} = a_s i_0 \left\{ \exp \left[ \frac{\alpha_a F}{RT} \left( \eta - \frac{R_{SEI}}{a_s} j^{Li} \right) \right] - \exp \left[ \frac{\alpha_c F}{RT} \left( \eta - \frac{R_{SEI}}{a_s} j^{Li} \right) \right] \right\}$$

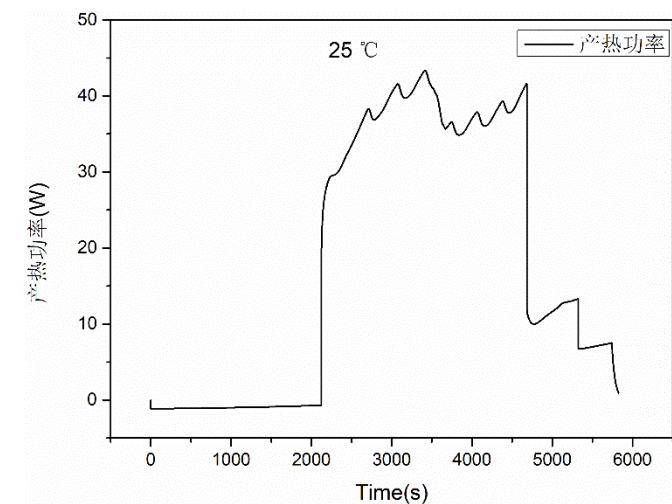
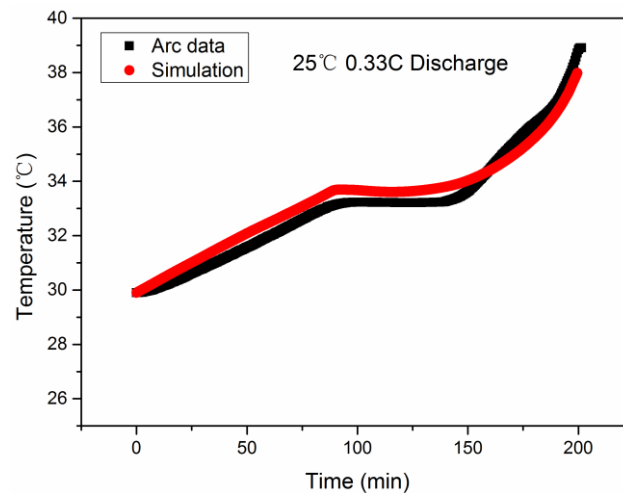
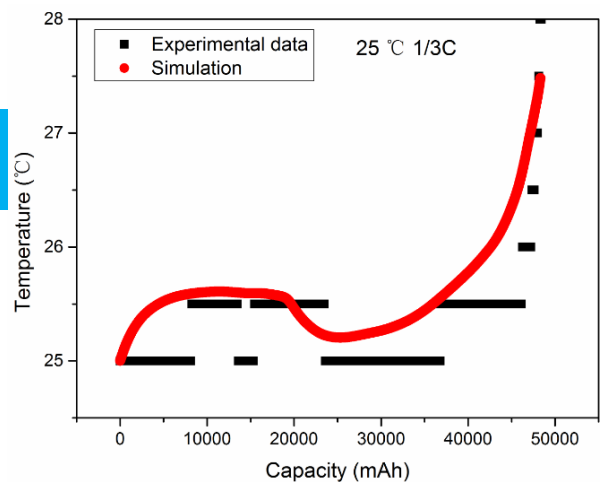


# Autolion电池仿真分析

Discharge  
Charge



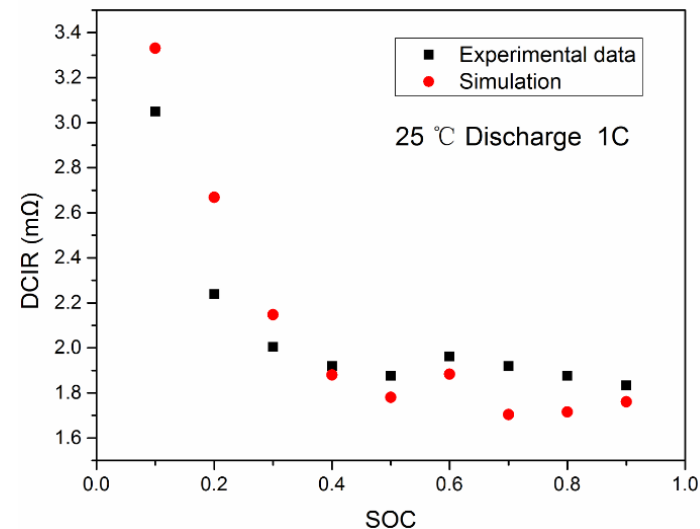
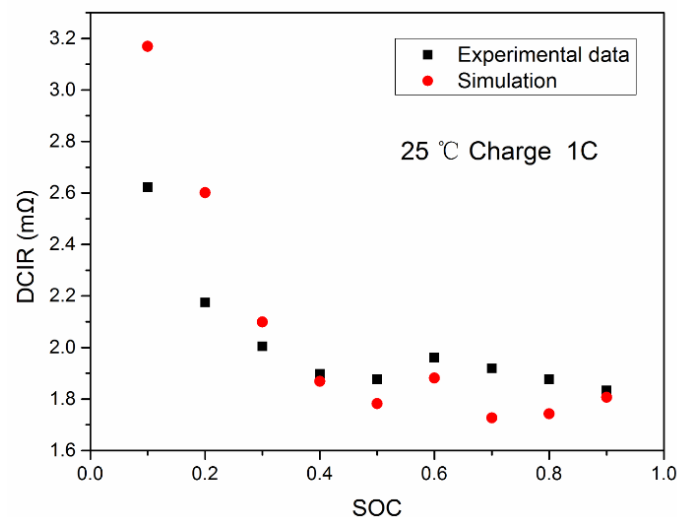
Temperature



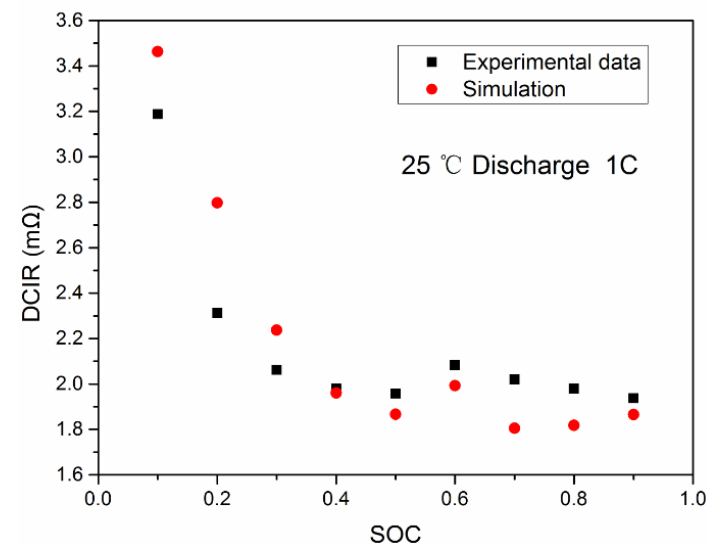
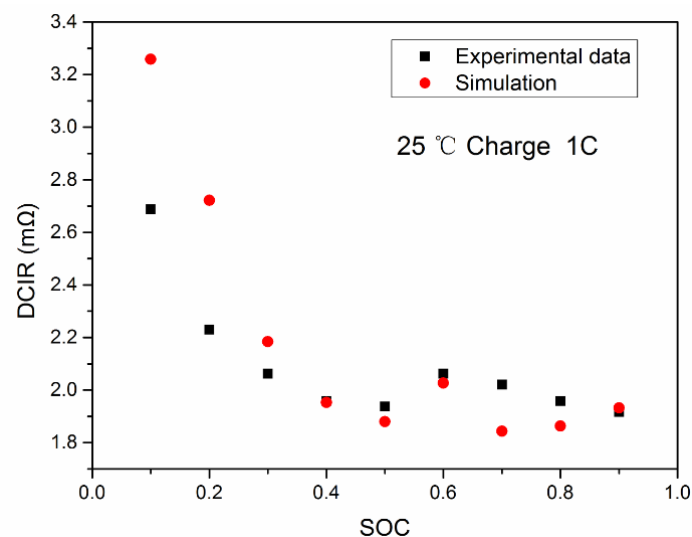
# Autolion电池仿真分析

## 内阻DCIR

10sec



15sec



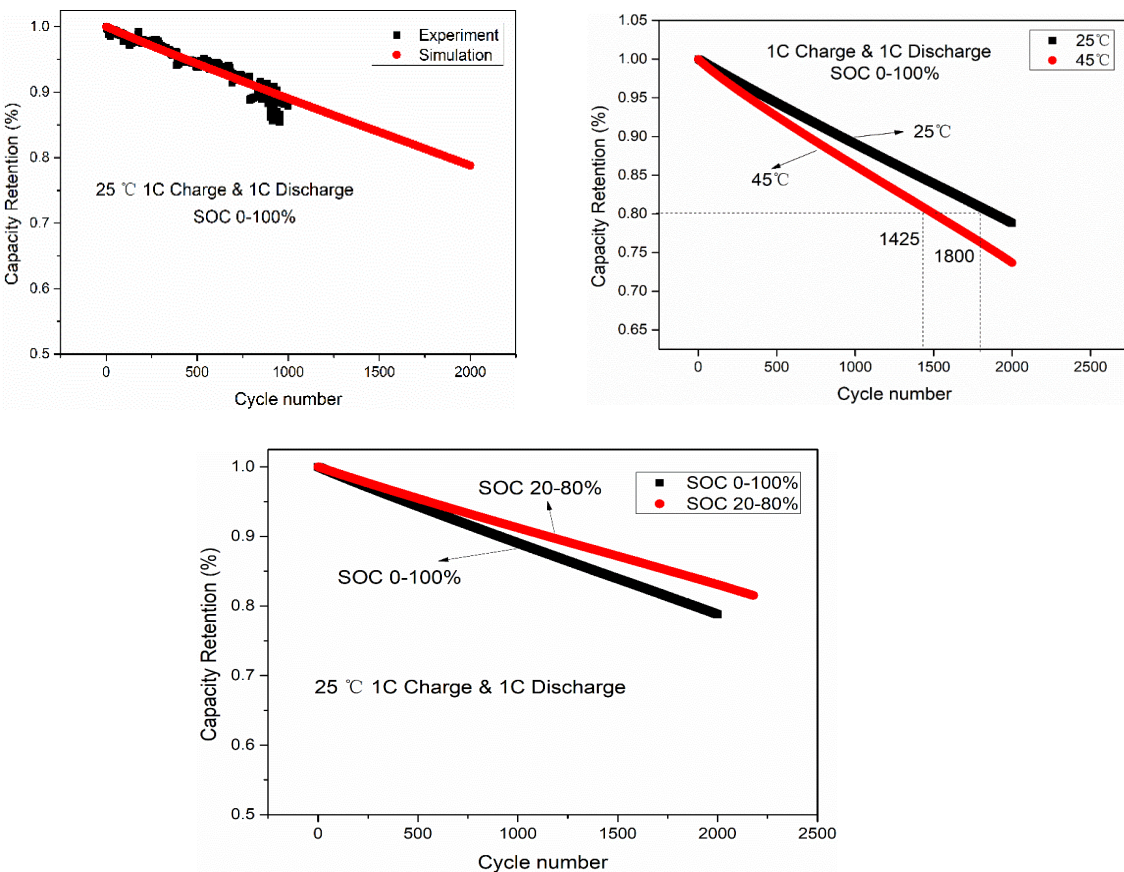
Autolion电池仿真分析

POWER MAP

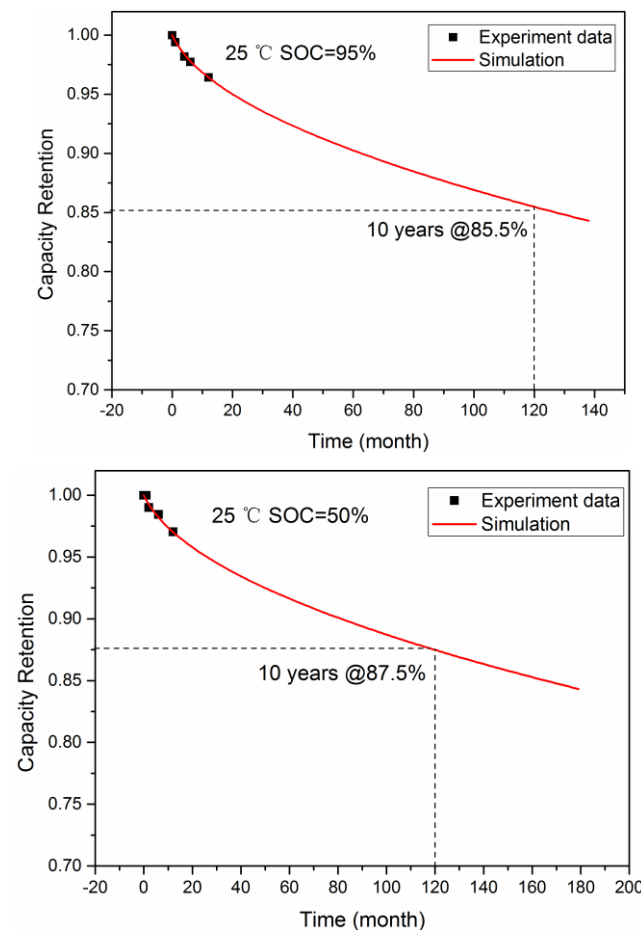
|        |                      | Discharge Power   cell   BOL, 10s |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|--------|----------------------|-----------------------------------|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|        |                      | 0%                                | 5%  | 10% | 15%  | 20%  | 25%  | 30%  | 35%  | 40%  | 45%  | 50%  | 55%  | 60%  | 65%  | 70%  | 75%  | 80%  | 85%  | 90%  | 95%  | 100% |
| 60° C  | Power Req [W]        | 0                                 | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 55° C  | Power Req [W]        |                                   | 74  | 74  | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 50° C  | Power Req [W]        |                                   | 74  | 74  | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 40° C  | Power Req [W]        |                                   | 887 | 887 | 887  | 887  | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 |
|        | Power Comm. [W]      |                                   | 424 | 764 | 1012 | 1035 | 1053 | 1075 | 1085 | 1098 | 1111 | 1123 | 1138 | 1156 | 1176 | 1196 | 1214 | 1232 | 1249 | 1262 | 1272 | 1286 |
|        | I <sub>max</sub> [A] |                                   | 150 | 250 | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  |
| 35° C  | Power Req [W]        |                                   | 887 | 887 | 887  | 887  | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 |
|        | Power Comm. [W]      |                                   | 396 | 731 | 1004 | 1028 | 1047 | 1065 | 1079 | 1093 | 1107 | 1117 | 1132 | 1150 | 1170 | 1190 | 1208 | 1226 | 1244 | 1257 | 1267 | 1280 |
|        | I <sub>max</sub> [A] |                                   | 140 | 240 | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  |
| 25° C  | Power Req [W]        |                                   | 887 | 887 | 887  | 887  | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 |
|        | Power Comm. [W]      |                                   | 383 | 685 | 960  | 1016 | 1036 | 1061 | 1074 | 1091 | 1105 | 1101 | 1116 | 1134 | 1154 | 1174 | 1192 | 1210 | 1228 | 1241 | 1251 | 1264 |
|        | I <sub>max</sub> [A] |                                   | 140 | 220 | 310  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  |
| 15° C  | Power Req [W]        |                                   | 887 | 887 | 887  | 887  | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 |
|        | Power Comm. [W]      |                                   | 325 | 590 | 875  | 977  | 999  | 1019 | 1035 | 1050 | 1063 | 1076 | 1090 | 1108 | 1128 | 1148 | 1167 | 1185 | 1203 | 1217 | 1226 | 1238 |
|        | I <sub>max</sub> [A] |                                   | 120 | 200 | 300  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  | 330  |
| 10° C  | Power Req [W]        |                                   | 887 | 887 | 887  | 887  | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 | 1073 |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 0° C   | Power Req [W]        |                                   | 454 | 454 | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| -7° C  | Power Req [W]        |                                   | 74  | 74  | 454  | 454  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  | 887  |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| -15° C | Power Req [W]        |                                   | 74  | 74  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| -25° C | Power Req [W]        |                                   | 74  | 74  | 74   | 74   | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  | 454  |
|        | Power Comm. [W]      |                                   | 71  | 104 | 130  | 144  | 158  | 172  | 183  | 196  | 200  | 208  | 218  | 227  | 237  | 242  | 245  | 249  | 249  | 246  | 241  | 231  |
|        | I <sub>max</sub> [A] |                                   | 30  | 40  | 50   | 55   | 60   | 65   | 68   | 72   | 73   | 75   | 78   | 80   | 82   | 82   | 82   | 82   | 80   | 78   | 75   | 70   |
| -35° C | Power Req [W]        |                                   | 74  | 74  | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   | 74   |
|        | Power Comm. [W]      |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|        | I <sub>max</sub> [A] |                                   |     |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |

# Autolion电池仿真分析

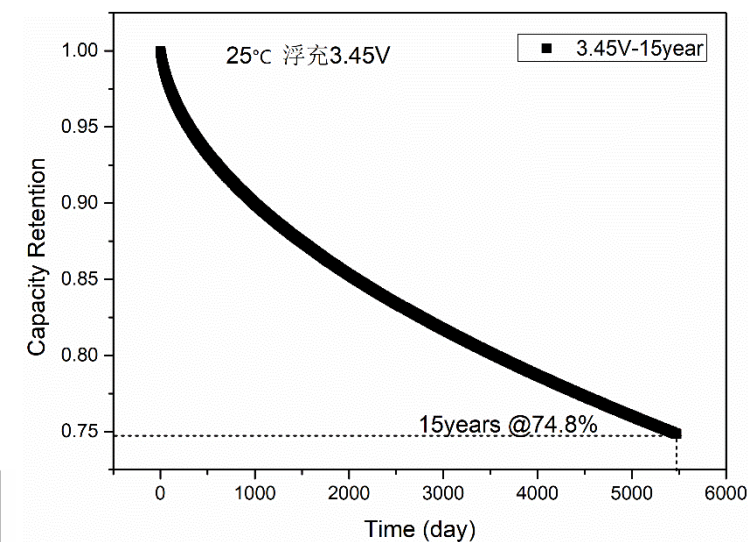
## 循环寿命



## 存储寿命

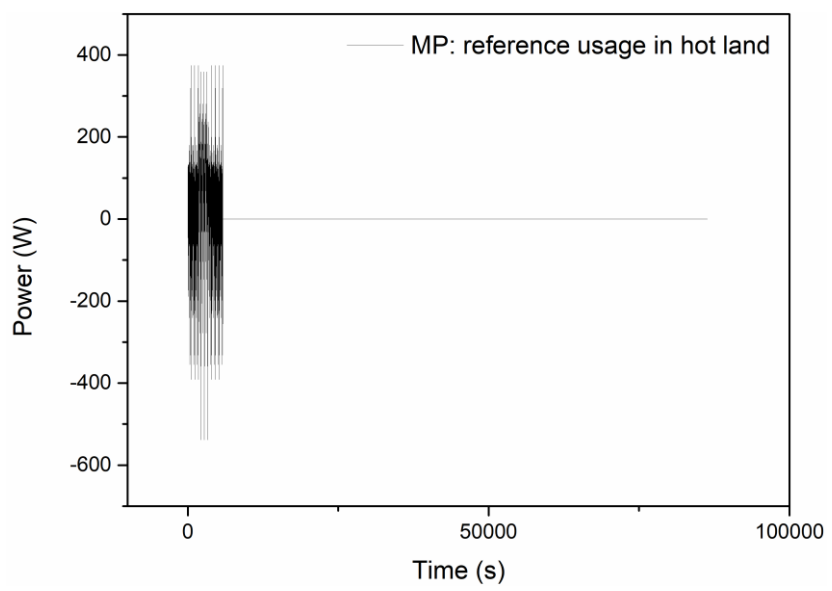


## 浮充寿命

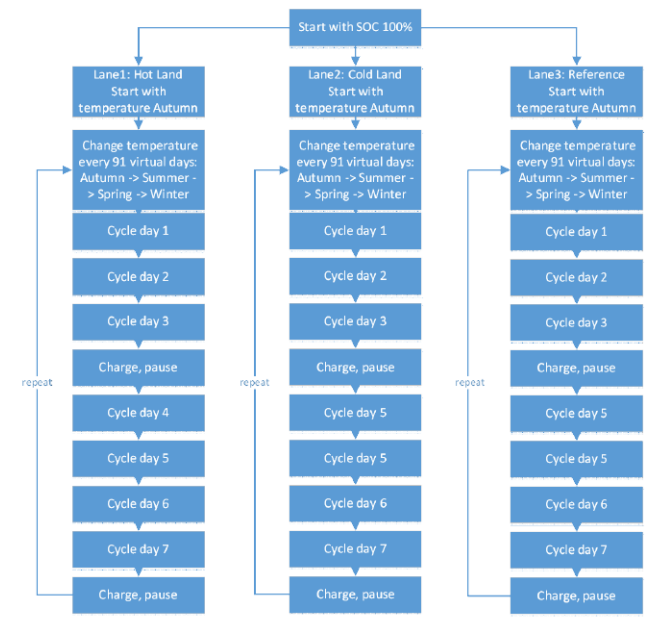


Autolion电池仿真分析

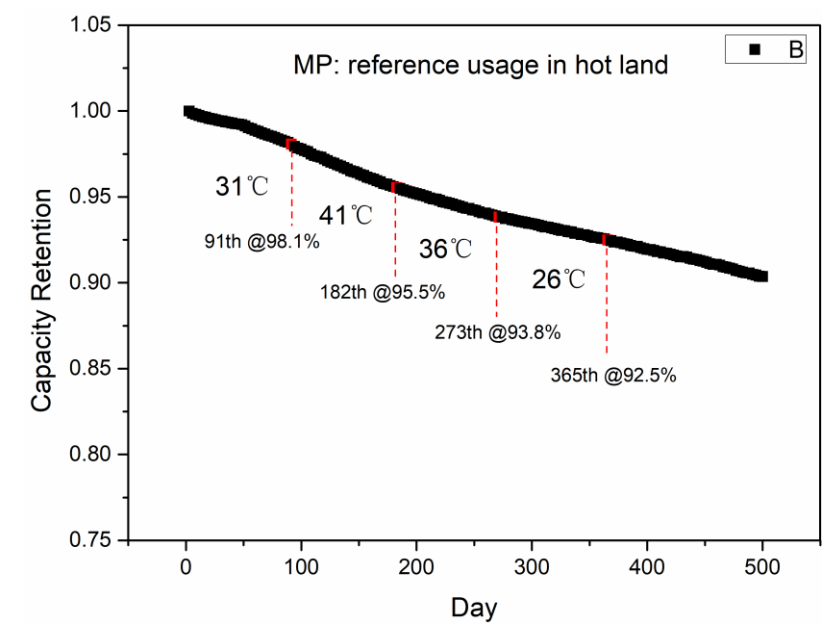
工况循环寿命



MP: reference usage流程

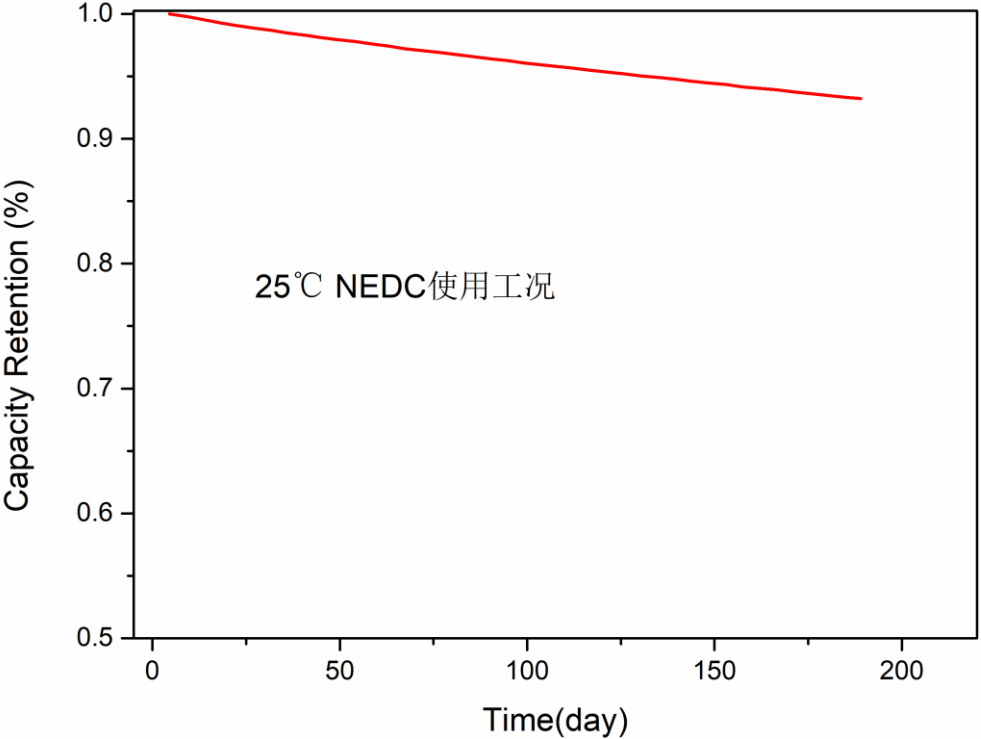
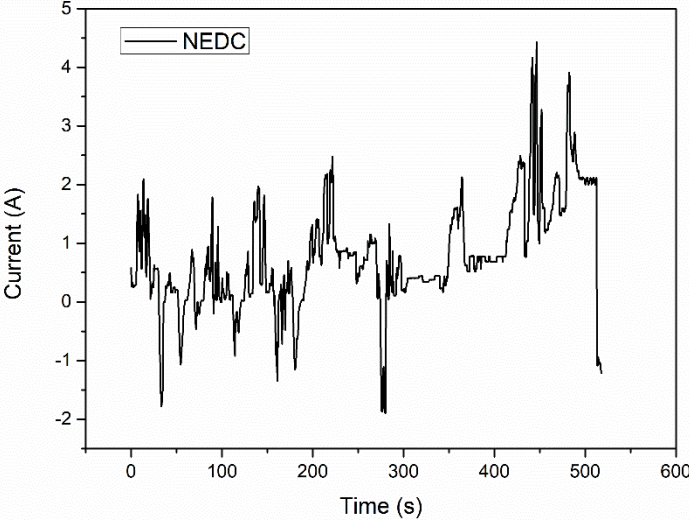


MP: reference usage工况寿命



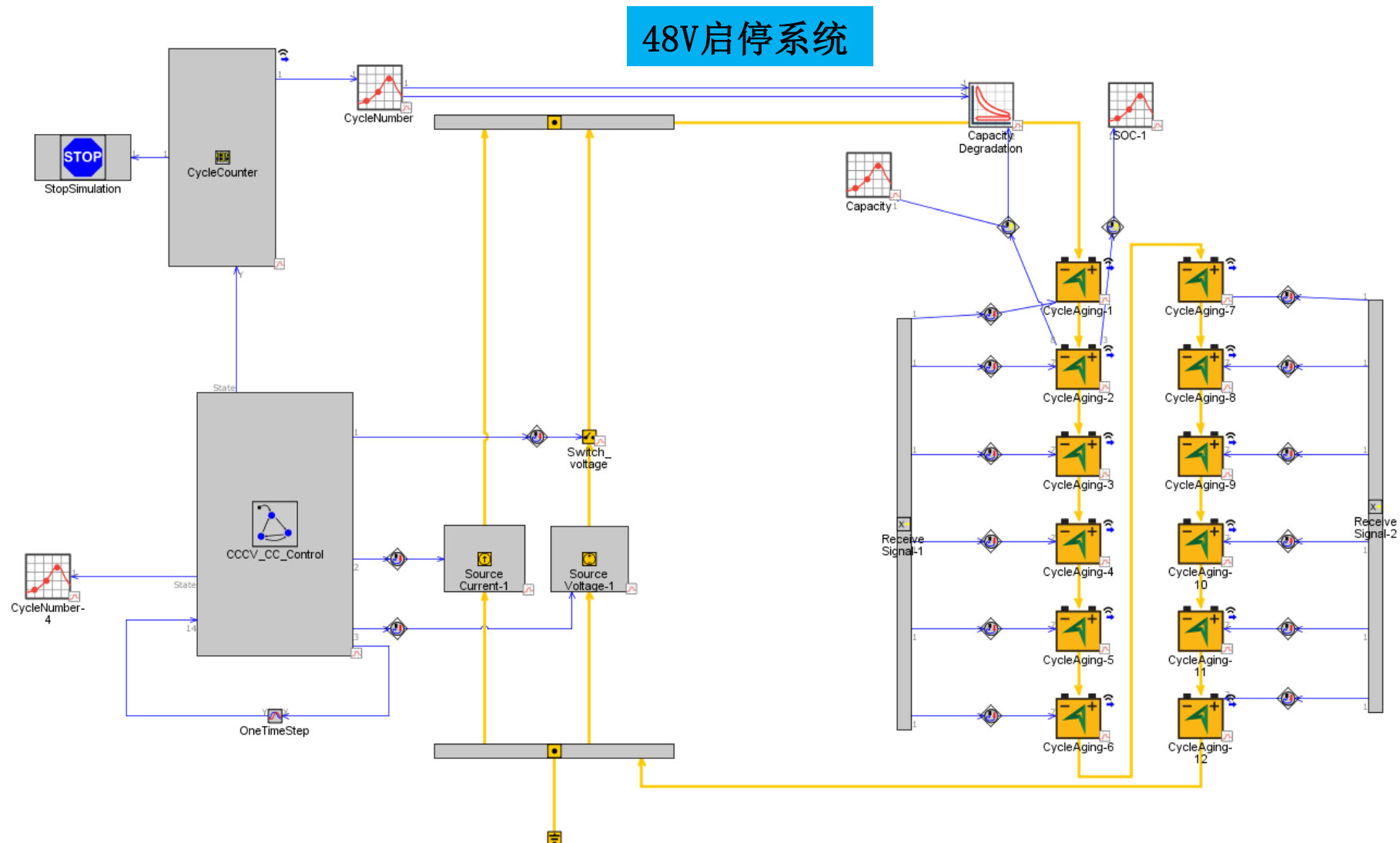
Autolion电池仿真分析

工况循环寿命 NEDC



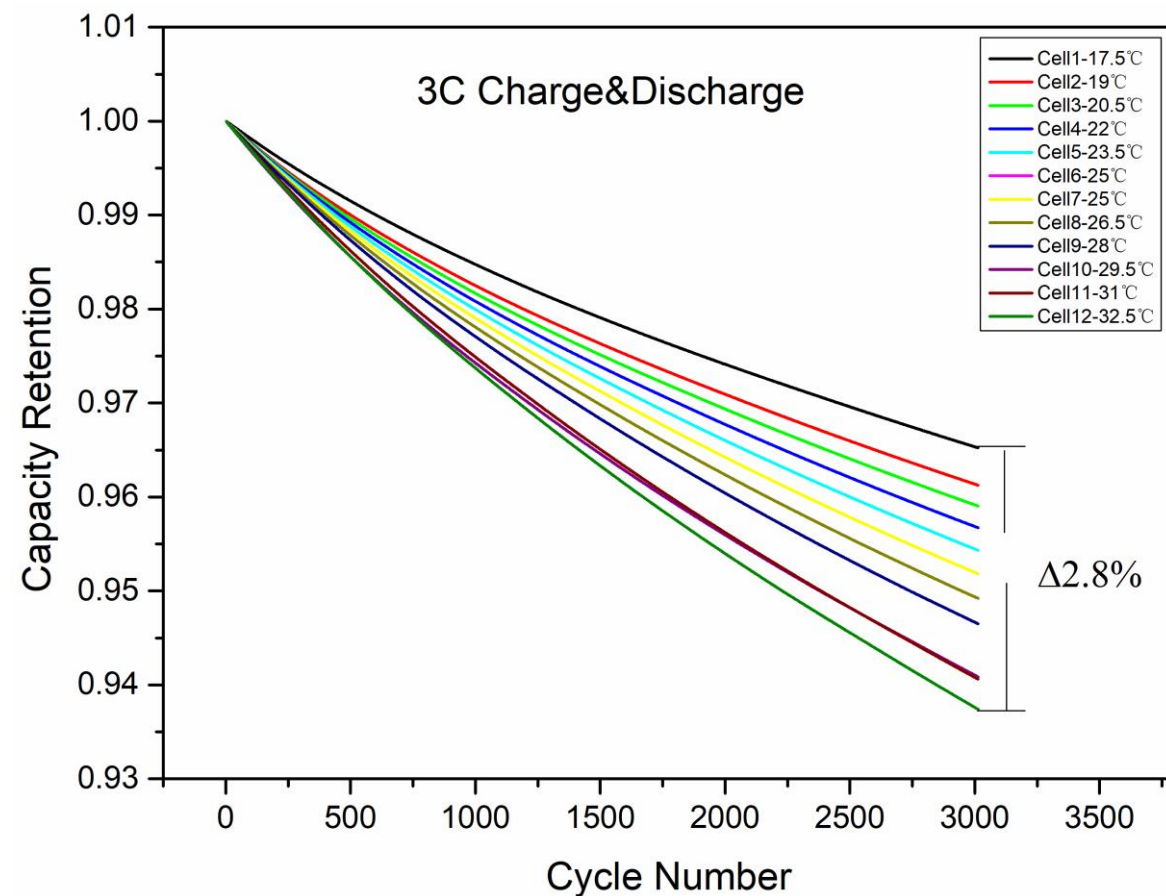
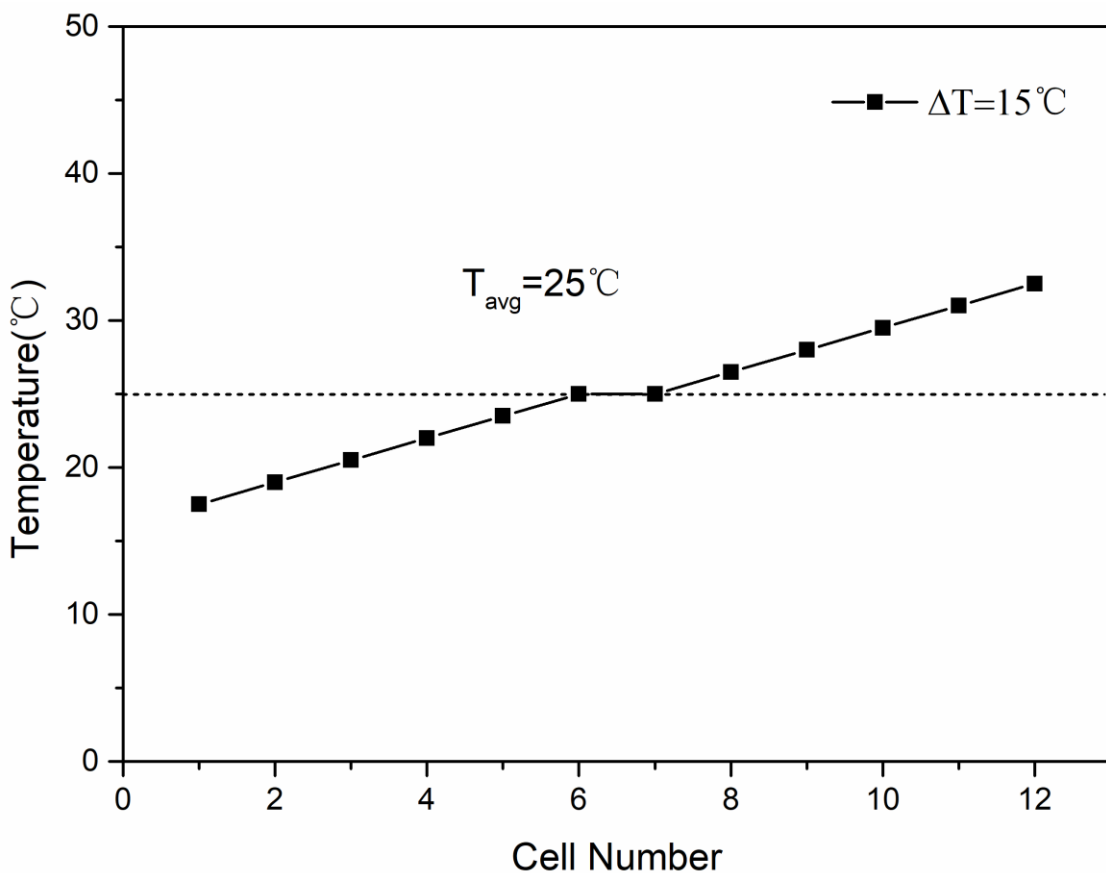
|                    |              |    |                    |              |    |                      |              |     |
|--------------------|--------------|----|--------------------|--------------|----|----------------------|--------------|-----|
| NEDC工况循环3次         |              | 1天 | NEDC工况循环3次         |              | 5天 | NEDC工况循环3次           |              | 9天  |
| 静置10h              | SOC90%状态下存储  |    | 静置10h              | SOC90%状态下存储  |    | 静置10h                | SOC90%状态下存储  |     |
| NEDC工况循环4次         |              | 2天 | NEDC工况循环4次         |              | 6天 | NEDC工况循环4次           |              | 10天 |
| 静置10h              | SOC80%状态下存储  |    | 静置10h              | SOC80%状态下存储  |    | 静置10h                | SOC80%状态下存储  |     |
| NEDC工况循环3次         |              | 3天 | NEDC工况循环3次         |              | 7天 | NEDC工况循环3次           |              | 11天 |
| 静置10h              | SOC70%状态下存储  |    | 静置10h              | SOC70%状态下存储  |    | 静置10h                | SOC70%状态下存储  |     |
| NEDC工况循环4次         |              | 4天 | NEDC工况循环4次         |              | 8天 | NEDC工况循环4次           |              | 12天 |
| 静置10h              | SOC60%状态下存储  |    | 静置10h              | SOC60%状态下存储  |    | 静置10h                | SOC60%状态下存储  |     |
| NEDC工况循环3次         |              |    | NEDC工况循环3次         |              |    | NEDC工况循环3次           |              |     |
| 静置10h              | SOC50%状态下存储  |    | 静置10h              | SOC50%状态下存储  |    | 静置10h                | SOC50%状态下存储  |     |
| NEDC工况循环4次         |              |    | NEDC工况循环4次         |              |    | NEDC工况循环4次           |              |     |
| 静置10h              | SOC40%状态下存储  |    | 静置10h              | SOC40%状态下存储  |    | 静置10h                | SOC40%状态下存储  |     |
| NEDC工况循环3次         |              |    | NEDC工况循环3次         |              |    | NEDC工况循环3次           |              |     |
| 静置10h              | SOC30%状态下存储  |    | 静置10h              | SOC30%状态下存储  |    | 静置10h                | SOC30%状态下存储  |     |
| NEDC工况循环4次         |              |    | NEDC工况循环4次         |              |    | NEDC工况循环4次           |              |     |
| 慢充至SOC100%<br>静置2h | SOC100%状态下存储 |    | 慢充至SOC100%<br>静置2h | SOC100%状态下存储 |    | 快充至SOC100%<br>静置8.5h | SOC100%状态下存储 |     |

# Autolion电池系统仿真分析



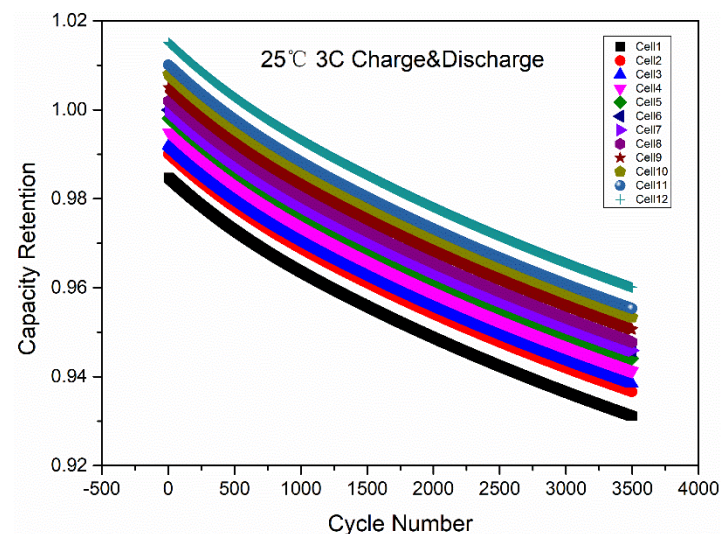
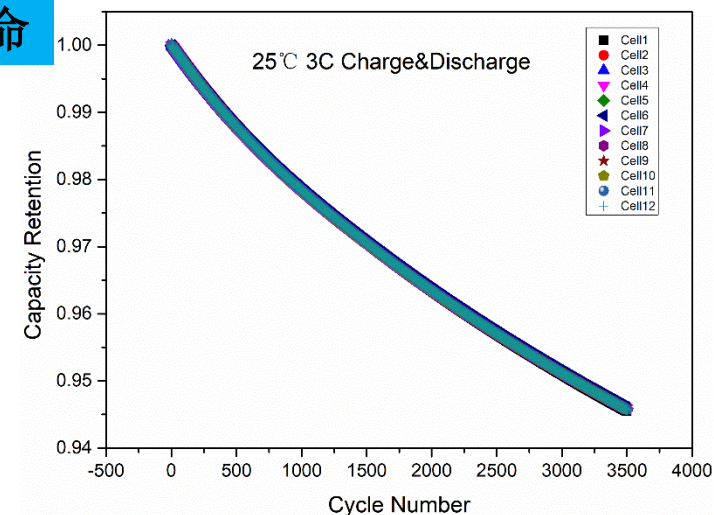
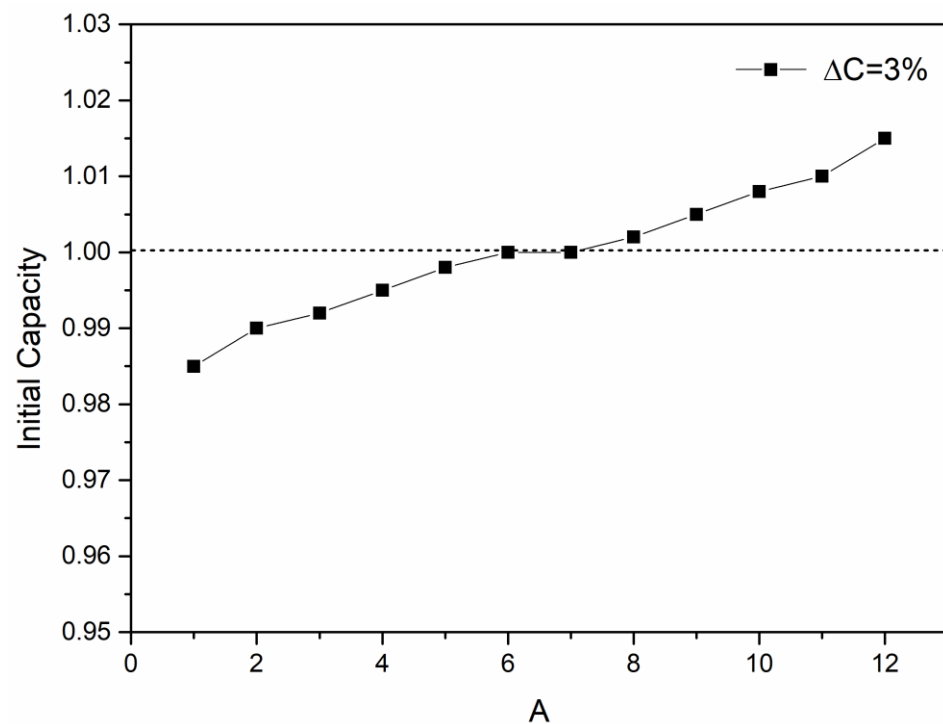
# Autolion电池系统仿真分析

## 不同环境温度电池系统寿命



# Autolion电池系统仿真分析

## 不同初始容量电池系统寿命



感谢您的聆听！