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# Optimization of Paste Formulation for Lead–Acid Batteries Used for Parking Air-Conditioners in Heavy Duty Trucks

04/11/2021

CUI Pengfei

19th Asian Battery
Conference & exhibition

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# 01 Jinkeli & R&D Profile

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# History

**1982**

- Establishment

**1992**

- Collaboration with ICCCAS

**2007**

- Jinkeli Battery Engineering Lab

**2012-2016**

- Strategic partner with Borregaard, Cabot and joint labs

**2017**

- R&D center recognized as provincial level lab

**2018**

- National standard of battery additives drfter

**2019**

- Jinkeli (Vietnam) Co., Ltd

**2020**

- Jinkeli New Energy Technology Co. Ltd

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# Company Structure

**Jinkeli**

- **Battery Testing Center**
- **Battery R&D Center**
- Vietnam Plant

- Zichuan HQ

- Hubei Plant

- Gaoqing Plant

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# Product Solution


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# R&D Center

- **Built in 2007**
- **20+ battery engineers and 10 experts as consultant**
- **7 labs and 5 shared R&D platforms, dedicated to R&D of advancd materials, formulation as well as battery new processing and technology to provide turn-key solution to customers**
- **Featured with pre-blended expander, all-round technical support covering applications for SLI, Start-stop, Parking AC, Motive, ESS and Backup.**

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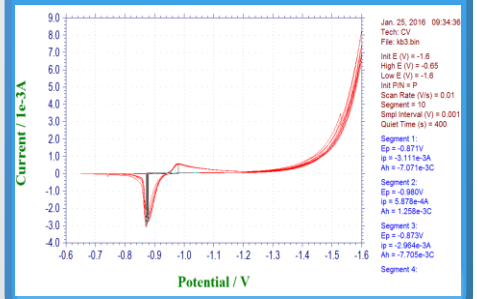
# Paste Formulation Optimization Process

**1**

**Material electrochemical performance selection**




**2**

**Cells validation**

**3**

**Battery testing**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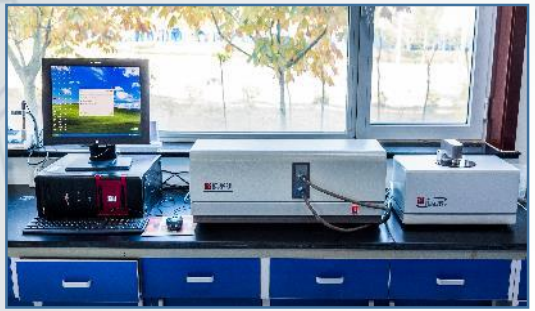
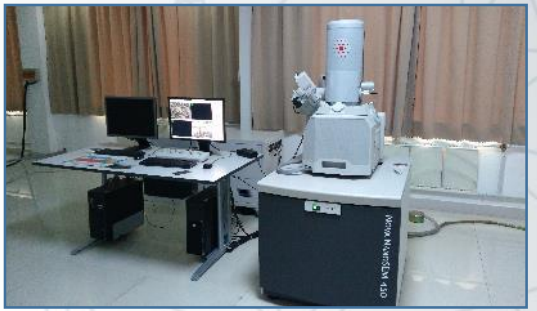
# Materials Selection



Laser particle size analyzer


DSC/TGA



SEM


Ultraviolet Spectrophotometer

AAS

XRD

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# Cells Validation

Paste mixing

Pasting

Curing

COS

Assemble


Formation

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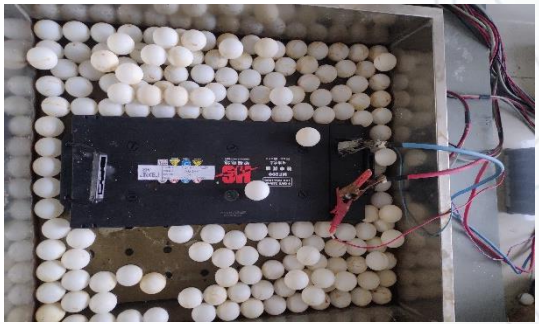
# Battery Performance Testing



- **Testing circuits：500+**
- **Tests: 30+**

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# 02 Parking AC Batteries

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# Market Situation

- Original AC's fuel cost is higher during traffic, parking and rest etc, with risk of engine wear and CO poisoning.
- Battery powered AC can reduce fuel consumption and carbon emission.

| Air conditioner solution | Advantage | Weakness |
|---|---|---|
| Generator | Stable Power supply | 1.Cost higher<br>2.Noise<br>3.Maintenance |
| Battery | 1.No additional position<br>2.Quiet<br>3.Cheap | 1.Short Cycle life<br>2.Difficult cranking after deep discharge |


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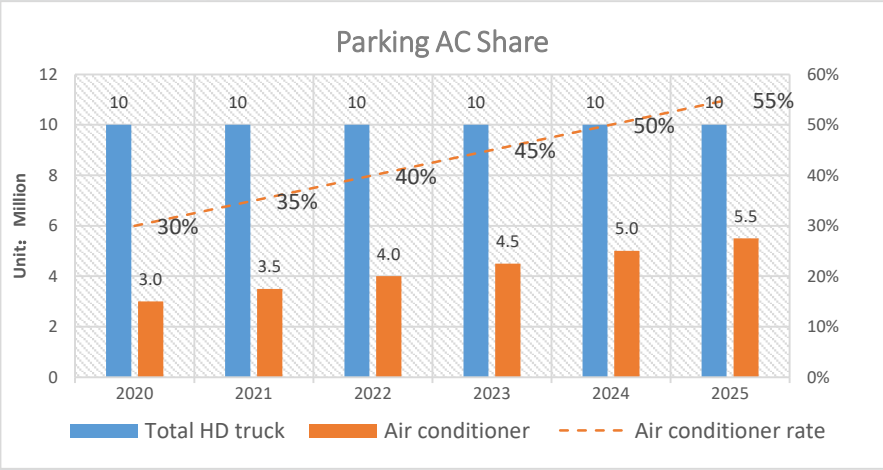
# Market Survey

- Parking AC is powered by batteries when parking and taking rest without the engine's on.
- Originally from the drivers'needs for a better and comfortable driving life
- 30% market share by battery powered and keep increasing
- 2 batteries parallel and replace traditional SLI batteries




Market Survey (Source from HV)

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# Operation Conditon of Parking AC Battery

- **AC：**

Top installation: better colling, power 750W around, long period use but high cost

Double mode: power 1000W~1400W，short period use, lower cost

- **Charging：**

Voltage：14.0V~14.2V，risk of insufficient charge of low voltage

Time：12h+ for long distance，4h~6h for short distance

- **Discharging：**

Voltage：10.5V~11.4V per battery (self-modified)，risk of over-dischage

11.5V~11.75V per battery(original equipped), limit the AC using time

Time：3h~4h Day time，average currnet 27A

6h~8h Night time，average currnet 5A

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# Parking AC Battery Performance Requirement

Unlike traditional SLI batteries, they operate under partial state-of-charge (PSoC) conditions and a high deep-discharge cycle performance and low-voltage charging and discharging are required. At present, the products on the China market suffer a rapid drop in capacity and a short life.

| Application | Requirements for battery | Design solution |
|---|---|---|
| Overnight stay with integrated parking cooler:<br>Approx.5 overnight stays/week; battery lifetime 24+ month | 1.Excellent deep cycle robustness<br>2.Excellent cranking performance at low SOC<br>3.Excellent cycling capability | 1. Formulation for deep cycle<br>2. Expander grid and increase AC wt.<br>3. Alloy optimization and adjustment<br>4. Compound seperator<br>5. AGM batteries |
| Less than 9 hours charging with low charging voltage | 1.Excellent dynamic charge acceptance<br>2.No acid stratification | 1. Improvement of charge acceptance<br>2. Anti stratification<br>3. Gel addition |
| Long charing time | Overcharging endurance and water loss | 1. Paste formulation adjustment<br>2. Acid circulation or VRLA type |
| End of frame installation | Good vibration endurance | 1. Plate group fixed struction or use glue<br>2. Tight assemble |

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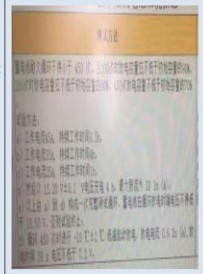
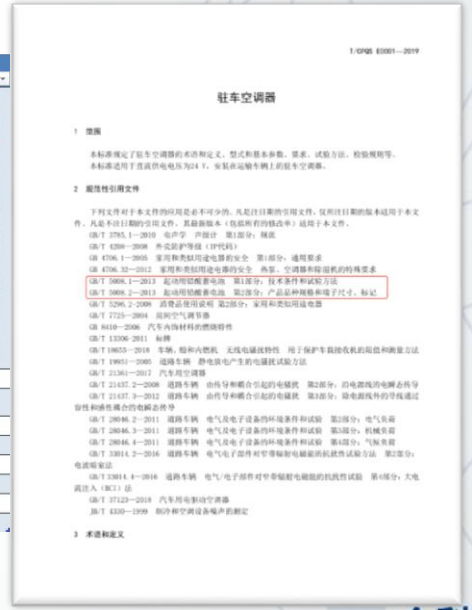
# Battery Testing Standard

《T/CPQS E0001 —2019驻车空调器Parking vehicle air conditioner》standard drafted

Based on SLI battery , not suitable for AC battery operation condition

OEM has no standard for deep-cycle performance, battery makers standard varies a lot

| 测试 | 北汽++奥克莱 | 客户1 | 客户2++凌云 | 风帆+凌云 | 一汽解放 |
|---|---|---|---|---|---|
| 试验方法 |  | 工况：客户1<br>充放电模式：1、以30A放电2小时（日天空调使用）<br>2、然后以14V稳压充电6小时（车载充电）<br>3、以14.5A放电6小时（晚上空调使用）<br>4、以14V稳压充电6小时（车载充电）<br>注：放电电压低于11.75V（整车保护电压），终止。<br>客户要求：180次循环（6个月）<br>初步分析：一个循环放电容量：147Ah；如果选用目前最大容量的启动铅酸电池（220Ah），放电深度为：147/220=66.8% | 客户2<br>1、以电流30A放电30min，然后再以电流16A放电5h30min后结束放电；<br>2、每次结束放电后，进行常温起动测试，400A放电5S，记录测试相应试验数据；<br>3、再恒压14.25V限流5I20充电8h；<br>注：放电电压低于11.75V（整车保护电压），终止。<br>180次循环（6个月）<br>一个循环放电容量：103Ah<br>如果选用目前最大容量的启动铅酸电池（220Ah），放电深度为：103/220=46.8% | GBT 5008 循环耐久II<br>a、5In*2h<br>b、恒压<br>15.2V*4.75h, 2.5In*0.25h |  |
| 类型 | 富液 | 富液 | 富液 | 富液 | AGM |
| 温度 | 25℃ | 25℃ | 25℃ | 25℃ | 25℃ |
| 循环电流 | 50 | 30 | 30 | 55 | 45 |
| 功率 | 1200 | 720 | 720 | 1320 | 1080 |
| 放电深度 | 78.64% | 66.82% | 46.82% | 50.00% | 54% |
| 循环次数 | 无 | 180 | 180 | 180 | 450次 |
| 终止电压 | | 11.75 | 11.75\|7.2 | 10 | 10.5 |
| 验证起动 | 常温 600A | 无 | 常温 400A | 低温 720A | 低温 720A |


T/CPQS E0001—2019

驻车空调器

1 范围

本标准规定了驻车空调器的术语和定义、型式和基本参数、要求、试验方法、检验规则等。
本标准适用于直流供电电压为24 V，安装在运输车辆上的驻车空调器。

2 规范性引用文件

下列文件对于本文件的应用是必不可少的。凡是注日期的引用文件，仅所注日期的版本适用于本文件。凡是不注日期的引用文件，其最新版本（包括所有的修改单）适用于本文件。

GB/T 3785.1—2010 电声学 声级计 第1部分：规范

GB/T 4208—2008 外壳防护等级（IP代码）

GB 4706.1—2005 家用和类似用途电器的安全 第1部分：通用要求

GB 4706.32—2012 家用和类似用途电器的安全 热泵、空调器和除湿机的特殊要求

GB/T 5008.1—2013 起动用铅酸蓄电池 第1部分：技术条件和试验方法

GB/T 5008.2—2013 起动用铅酸蓄电池 第2部分：产品品种规格和端子尺寸、标记

GB/T 5296.2—2008 消费品使用说明 第2部分：家用和类似用途电器

GB/T 7725—2004 房间空气调节器

GB 8410—2006 汽车内饰材料的燃烧特性

GB/T 13306—2011 标牌

GB/T 18655—2018 车辆、船和内燃机 无线电骚扰特性 用于保护车载接收机的限值和测量方法

GB/T 19951—2005 道路车辆 静电放电产生的电骚扰试验方法

GB/T 21361—2017 汽车用空调器

GB/T 21437.2—2008 道路车辆 由传导和耦合引起的电骚扰 第2部分：沿电源线的电瞬态传导

GB/T 21437.3—2012 道路车辆 由传导和耦合引起的电骚扰 第3部分：除电源线外的导线通过容性和感性耦合的电瞬态传导

GB/T 28046.2—2011 道路车辆 电气及电子设备的环境条件和试验 第2部分：电气负荷

GB/T 28046.3—2011 道路车辆 电气及电子设备的环境条件和试验 第3部分：机械负荷

GB/T 28046.4—2011 道路车辆 电气及电子设备的环境条件和试验 第4部分：气候负荷

GB/T 33014.2—2016 道路车辆 电气电子部件对窄带辐射电磁能的抗扰性试验方法 第2部分：电波暗室法

GB/T 33014.4—2016 道路车辆 电气/电子部件对窄带辐射电磁能的抗扰性试验 第4部分：大电流注入（BCI）法

GB/T 37123—2018 汽车用电制动空调器

JB/T 4330—1999 制冷和空调设备噪声的测定

3 术语和定义

After calculations, DOD is 47%~80%.

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# Battery Testing Standard

Consideration of DOD and Cycling Teperature

- **Flooded:** Operation cycle, Low-vol. char& dis. Cycling, Cycling test Ⅱ, Deep discharge cycling, 50%DOD cycling
- **AGM:** Low-vol. char& dis. Cycling, operation cycling, 50%DOD cycling, 80%DOD cycling

## Operation Cycle

After fully charged, put battery in the water bath setting 25℃ for 24h. Then perform below cycle.
a. Discharge with 4A constant current for 6h;
b. Charging with constant voltage of 14V and limited current of 70A for 6h;
c. Discharge with 27A constant current for 3h;
d. Then charge with a constant voltage of 14V and a current limit of 70A for 6 hours.
The above steps a-d are one cycle. Cycle terminated till terminal voltage below 11V.
After the test terminated, undertake CCA -18℃ test , and the 30s voltage ≥ 7.2V.

## Low-vol. Cycle

After fully charged, put battery in the 25℃ water bath for 24h. Then perform below cycle.
a. Discharge with 25A current to 11V, then suspend for 10min;
b. Charging with constant voltage of 14V and limited current of 50A for 12h, then suspend for 10min;
The above steps a-b are one cycle. Cycle terminated till discharge capacity ＜ 40%$C_e$
After the test terminated, undertake Cold Cranking -18℃ test , and the 30s voltage ≥ 7.2V.

## 80%DOD Cycle

After fully charged, put battery in the 25℃ water bath for 24h. Then perform below cycle.
a. Discharge with 5In constant current for 2h;
b. Charging with constant voltage(Flooded 15.6V, VRLA 14.4V) and limited current of 5In for 8h.
The above steps a-b are one cycle. Cycle terminated till terminal voltage below 10V.
After the test terminated, undertake Cold Cranking -18℃ test , and the 30s voltage ≥ 7.2V.

**Cycling test** （IEC 60095-1:2006 Term 9.6.3） **50%DOD cycling**（IEC 60095-6:2019 Term 9.6.2）

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# 03 Materials Selection

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# Cells design


**Table 1 Container Size**

| Size | L/mm | W/mm | H/mm |
|---|---|---|---|
| Overall | 66.0 | 30.4 | 107.5 |
| Inner cavity | 56.0 | 20.5 | 100.0 |

**Table 2 Grid & AM**

| Grid Size | W/mm | H/mm | T/mm | AM Wt./g | Qty/PCS |
|---|---|---|---|---|---|
| POS. | 44.5 | 72.0 | 2.8 | 27 | 3 |
| NEG. | 44.5 | 72.0 | 1.9 | 19 | 2 |

**Testing Standard：**

**GB/T 5008.1-2013、GB/T 22199.1-2017**

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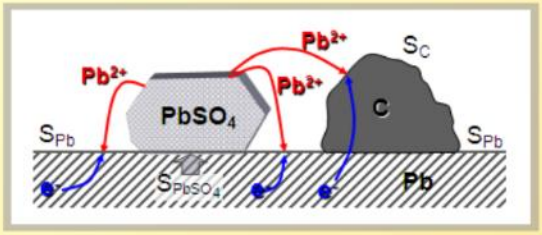
# Carbon Black

**Carbon black can increase the effective specific surface area of the negative paste and optimize the micro morphology of the negative electrode. Therefore, carbon material can improve the dynamic charge acceptance and cycle life of the battery**




$S_C$ - Carbon contact surface area with solution

$S_{NAM} = S_{Pb} - S_{PbSO_4} + S_C$

$I$ - charge/given constant current

Tafel equation: $\Delta\varphi = a + b.lg\frac{I}{S_{Pb} - S_{PbSO_4} + S_C}$

Carbon black with different BET and particle size Comparision

Dosage: 0.25%, 0.4%,0.5%, 0.6%, 0.7%

Formulation: 0.2%lignin+0.25%humic acid+1.0%barium sulfate

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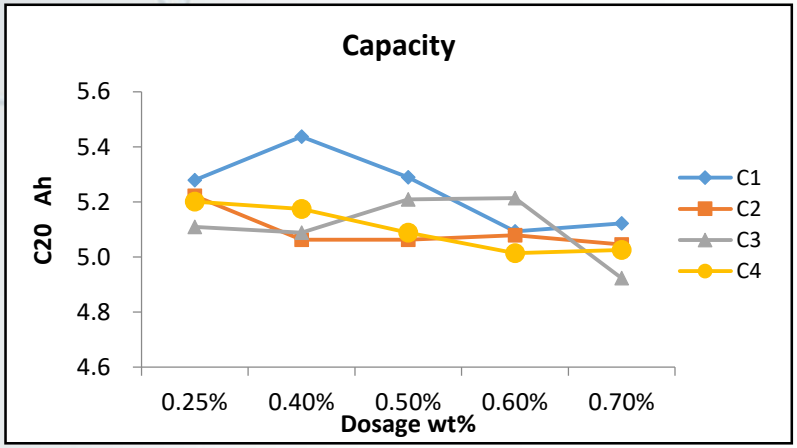
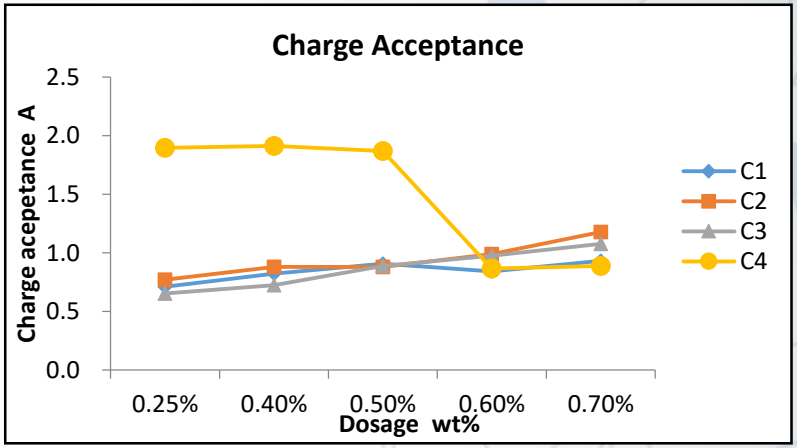
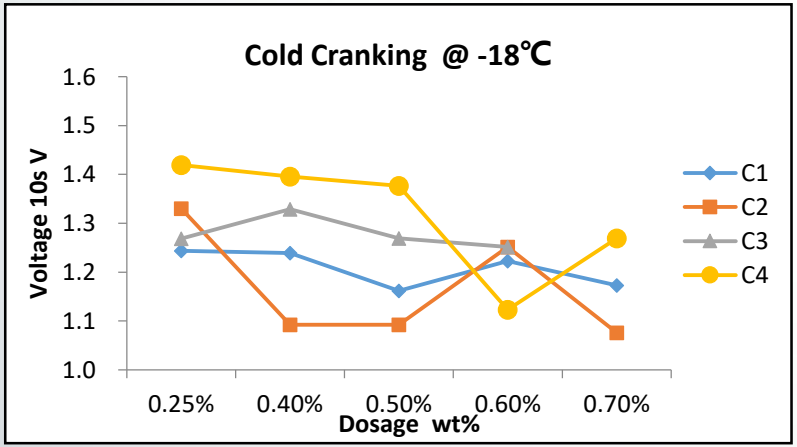
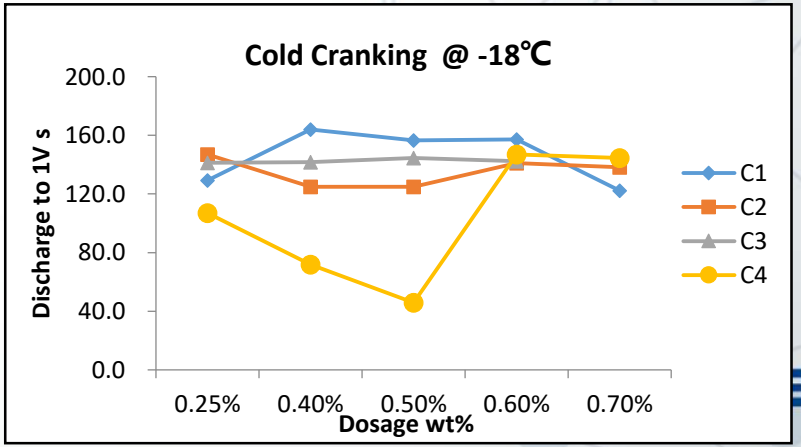
# Carbon Black Effect on Battery Performance

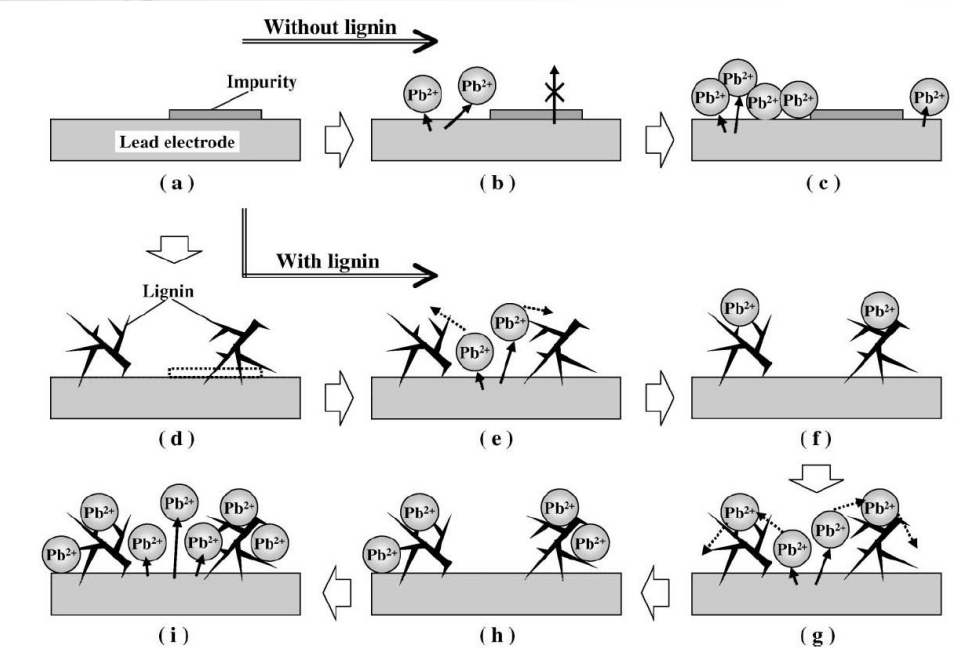


# Lignin




Lignin effect on plate
(Source: Ref. J. Power Sources 107(2) 167–172)

**Lead ions are arranged in disorder on the plate (a-c) without lignin. After adding lignin, the lignin effectively prevents the plate from being completely covered by lead sulfate crystals (d-g), thereby imprvoing performance at low temperature.**

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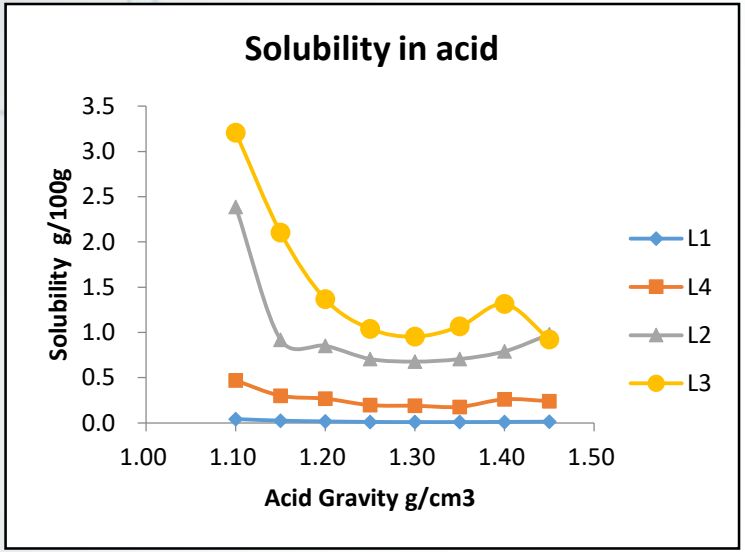
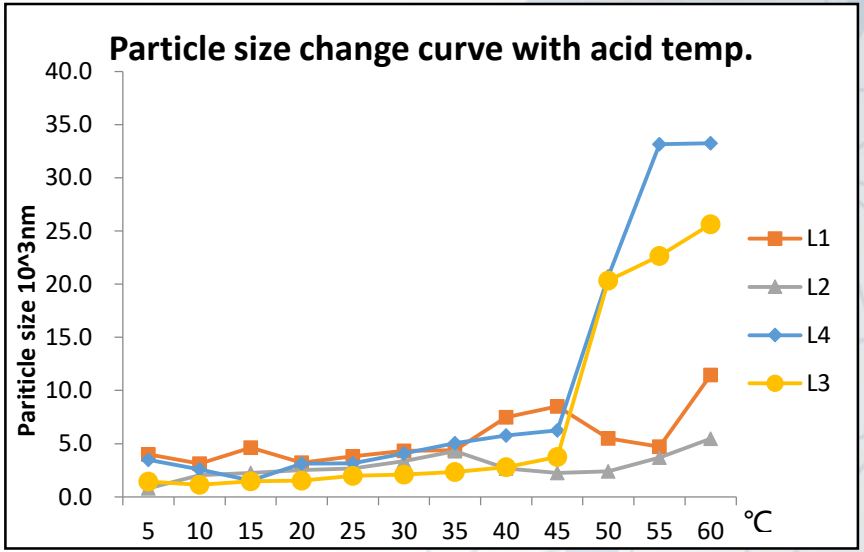
# Lignin




Different lignin comparision

Formulation: 0.25% carbon black + 1.0% barium sulfate

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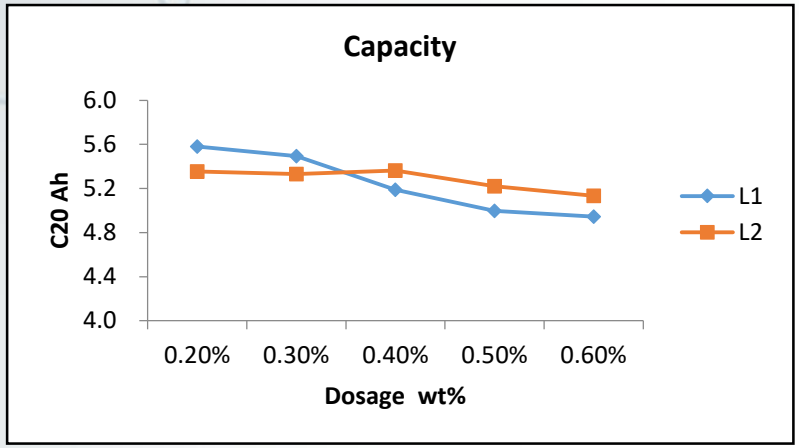
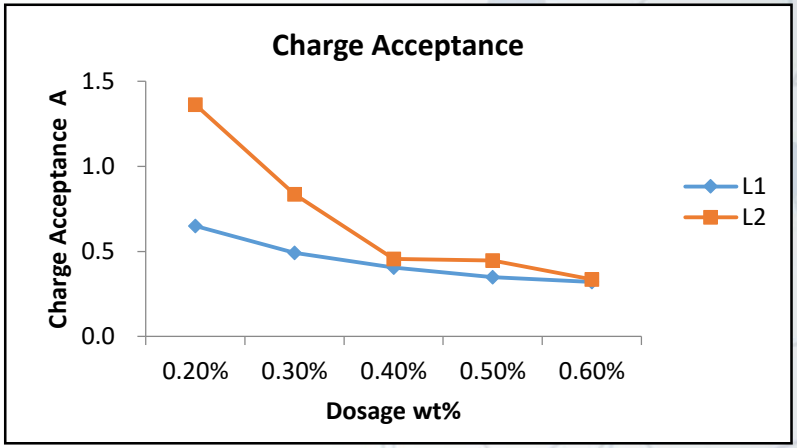
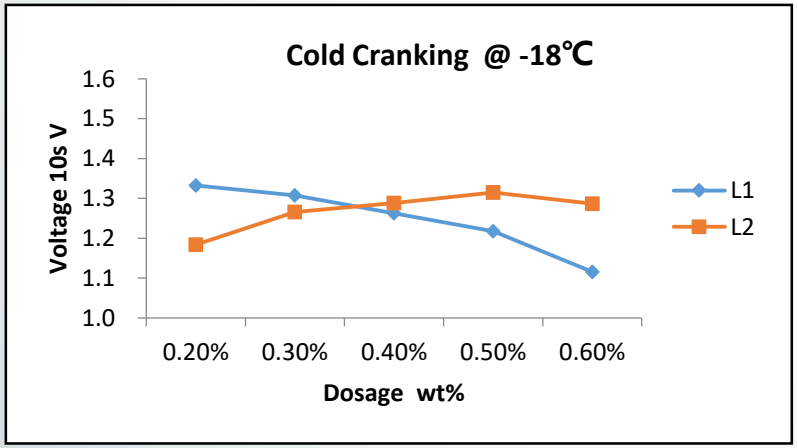
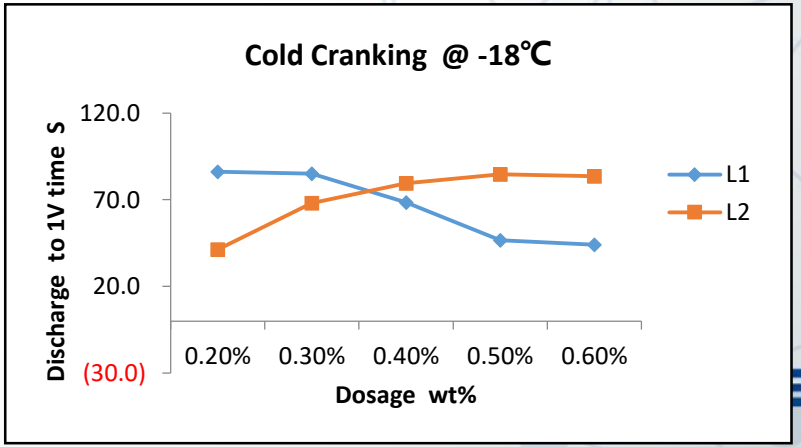
# Lignin Effect on Battery Performance

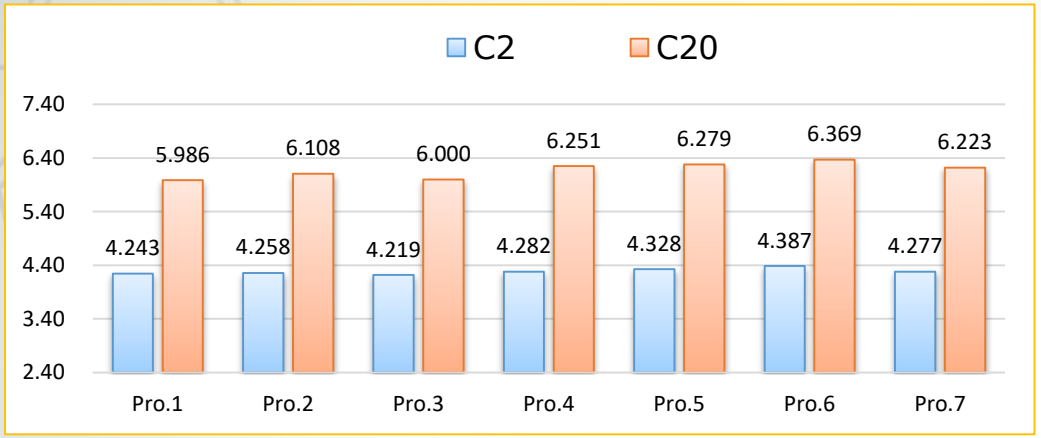


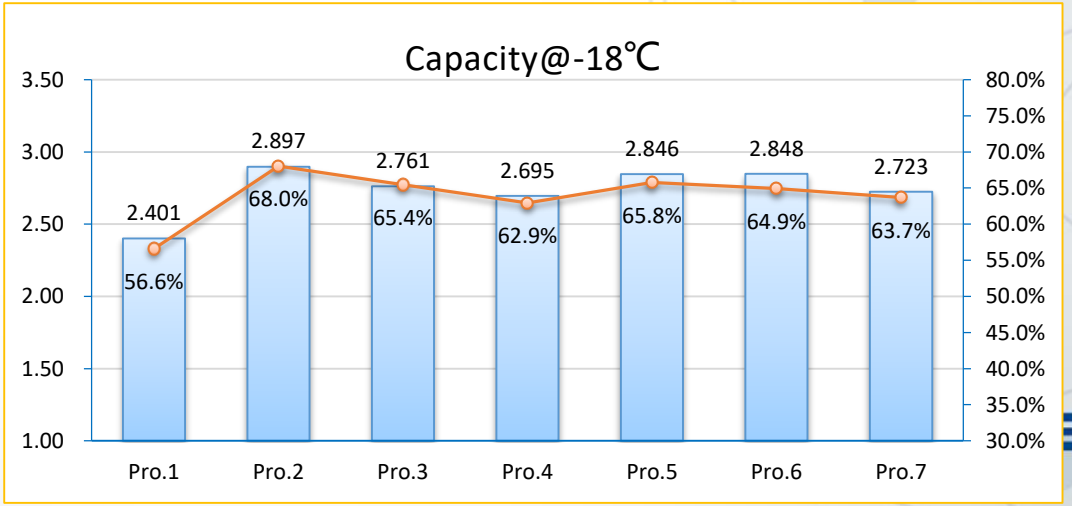



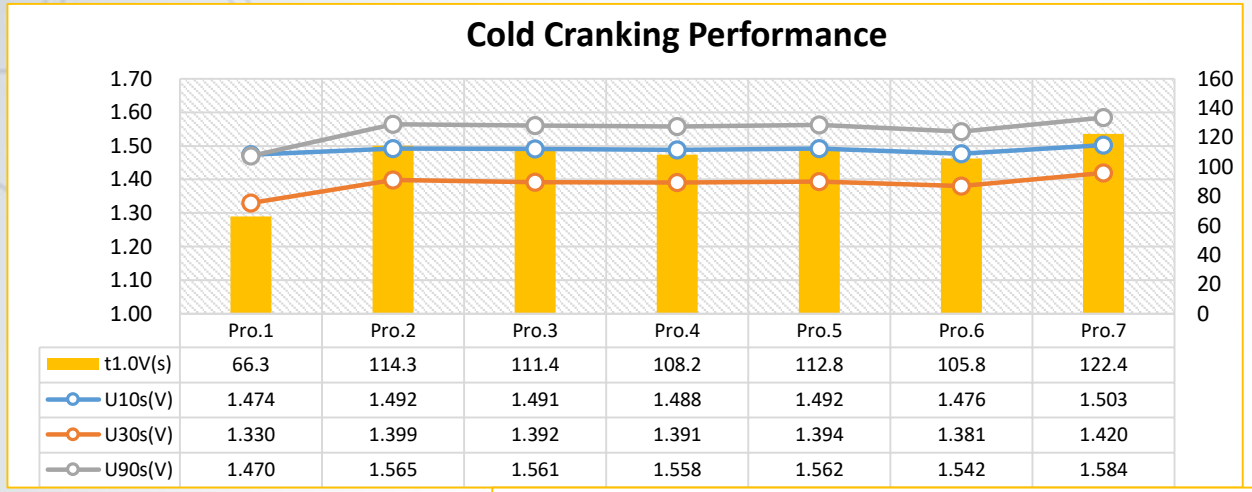



# Cell Testing Data （Negative formulation ）

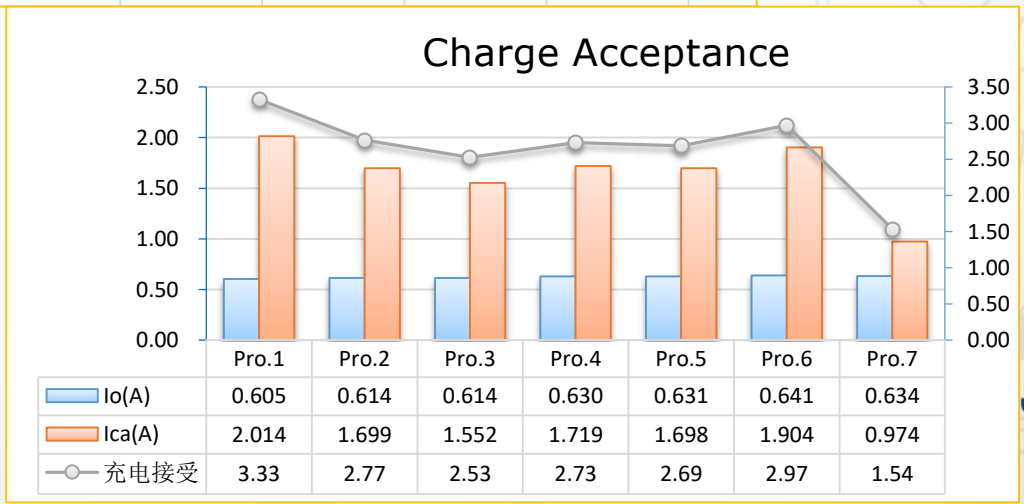


# Cell Testing Data （Negative formulation ）




| | Pro.1 | Pro.2 | Pro.3 | Pro.4 | Pro.5 | Pro.6 | Pro.7 |
|---|---|---|---|---|---|---|---|
| t1.0V(s) | 66.3 | 114.3 | 111.4 | 108.2 | 112.8 | 105.8 | 122.4 |
| U10s(V) | 1.474 | 1.492 | 1.491 | 1.488 | 1.492 | 1.476 | 1.503 |
| U30s(V) | 1.330 | 1.399 | 1.392 | 1.391 | 1.394 | 1.381 | 1.420 |
| U90s(V) | 1.470 | 1.565 | 1.561 | 1.558 | 1.562 | 1.542 | 1.584 |




| | Pro.1 | Pro.2 | Pro.3 | Pro.4 | Pro.5 | Pro.6 | Pro.7 |
|---|---|---|---|---|---|---|---|
| Io(A) | 0.605 | 0.614 | 0.614 | 0.630 | 0.631 | 0.641 | 0.634 |
| Ica(A) | 2.014 | 1.699 | 1.552 | 1.719 | 1.698 | 1.904 | 0.974 |
| 充电接受 | 3.33 | 2.77 | 2.53 | 2.73 | 2.69 | 2.97 | 1.54 |

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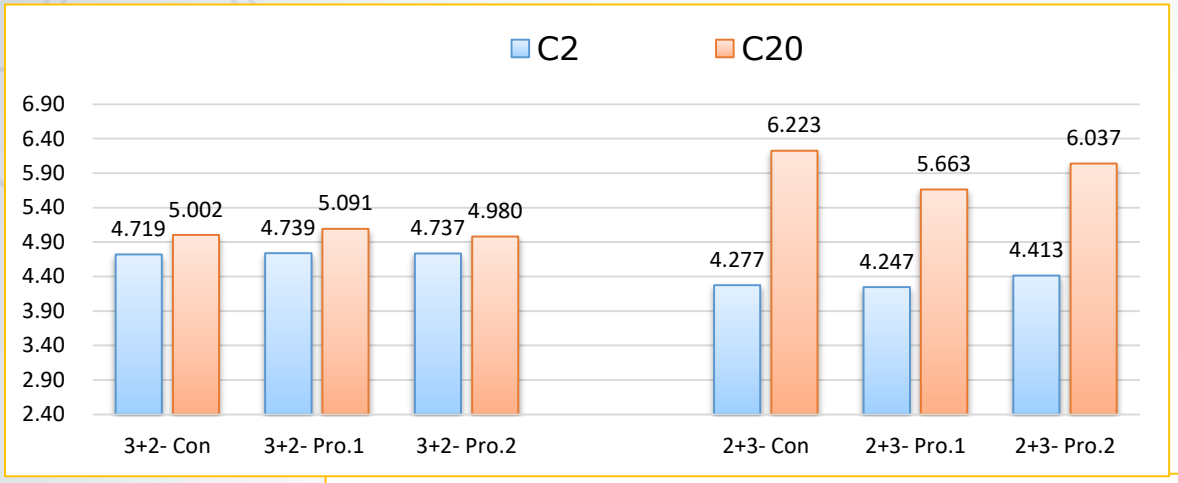
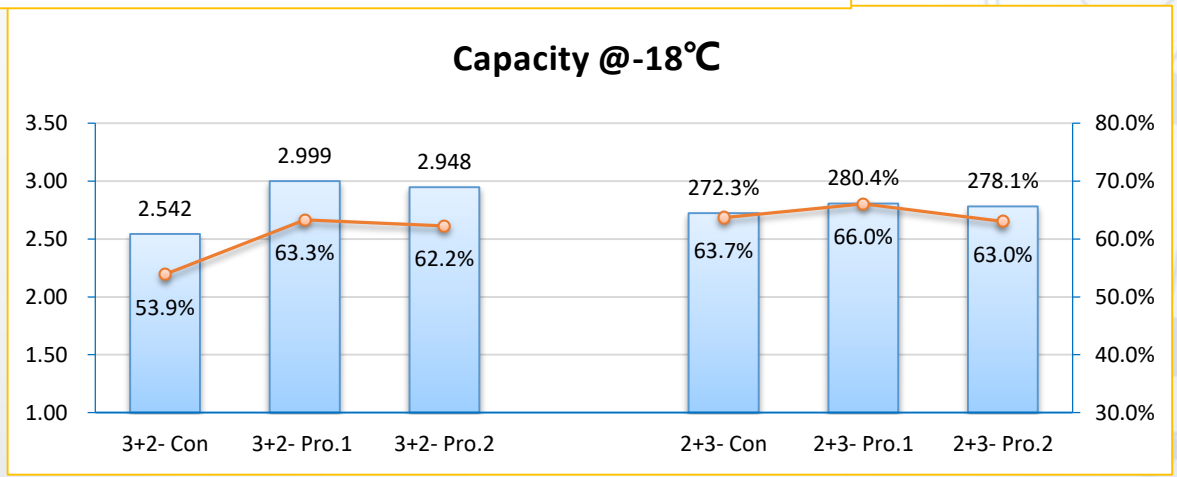
# Cell Testing Data（Positive ）

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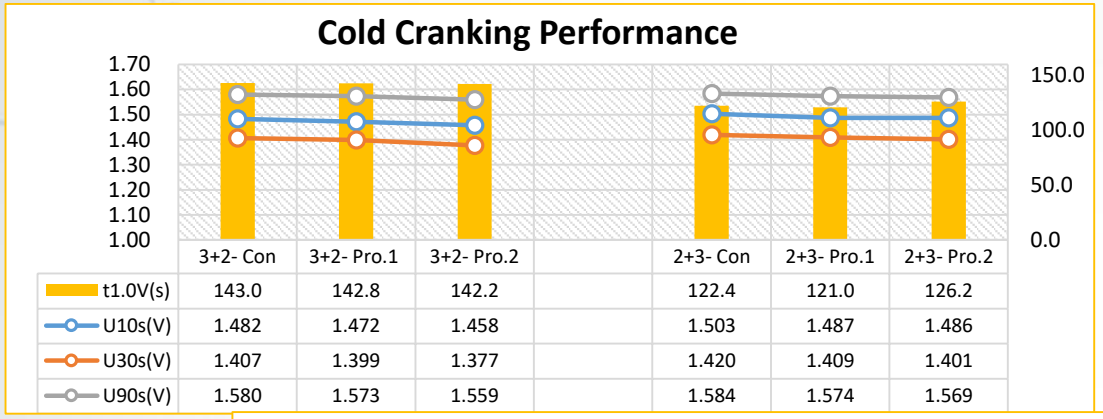
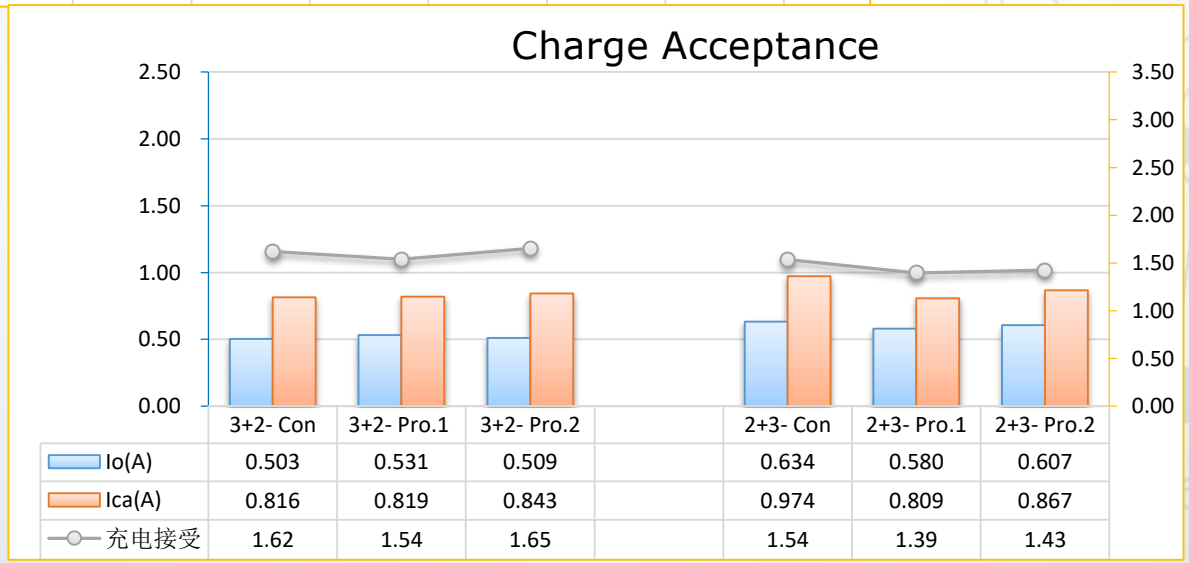
# Cell Testing Data （Positive ）




| | 3+2- Con | 3+2- Pro.1 | 3+2- Pro.2 | 2+3- Con | 2+3- Pro.1 | 2+3- Pro.2 |
|---|---|---|---|---|---|---|
| t1.0V(s) | 143.0 | 142.8 | 142.2 | 122.4 | 121.0 | 126.2 |
| U10s(V) | 1.482 | 1.472 | 1.458 | 1.503 | 1.487 | 1.486 |
| U30s(V) | 1.407 | 1.399 | 1.377 | 1.420 | 1.409 | 1.401 |
| U90s(V) | 1.580 | 1.573 | 1.559 | 1.584 | 1.574 | 1.569 |




| | 3+2- Con | 3+2- Pro.1 | 3+2- Pro.2 | 2+3- Con | 2+3- Pro.1 | 2+3- Pro.2 |
|---|---|---|---|---|---|---|
| Io(A) | 0.503 | 0.531 | 0.509 | 0.634 | 0.580 | 0.607 |
| Ica(A) | 0.816 | 0.819 | 0.843 | 0.974 | 0.809 | 0.867 |
| 充电接受 | 1.62 | 1.54 | 1.65 | 1.54 | 1.39 | 1.43 |

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# 04 Battery Testing

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# Sample Battery


| Testing Date | MFR. | Capacity | Type | Plate | Plate Group |
|---|---|---|---|---|---|
| **2020.9** | Y | 230Ah | Flooded | Neg. &Pos. same casting 130mm | +17/-18 |
| **2021.5** | H | 180Ah | Flooded | Neg. & Pos. casting 124.5mm | +13/-14 +11/-12 |
| **2021.6** | K | 180Ah | Flooded | Neg. & Pos. casting 115mm | +14/-15 |
| **2021.7** | R | 200Ah | AGM | Neg. & Pos. casting 154mm | +13/-14 |

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# Sample Battery Initial Performance

| Type | Sample | Spec. | OCV (V) | IR (mΩ) | Weight (kg) | C20 (Ah) | Cold Cranking @ -18℃(1000A, IEC) | | | CA |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $U_{10S}$ (V) | $U_{30S}$ (V) | $U_{90S}$ (V) | |
| Flooded | Y | 12V 230Ah | 12.90 | 2.00 | 58.12 | 234.87 | 8.785 | 8.622 | 9.766 | 3.02 |
| | Y | 12V 230Ah | 12.91 | 2.00 | 59.12 | 246.15 | 8.812 | 8.652 | 9.789 | 3.16 |
| | H | 12V 180Ah | 12.68 | 2.34 | 46.50 | 181.49 | 8.545 | 8.258 | 9.557 | 3.25 |
| | H | 12V 180Ah | 12.68 | 2.37 | 46.45 | 182.08 | 8.543 | 8.291 | 9.547 | 2.88 |
| | H | 12V 180Ah | 12.62 | 2.70 | 45.13 | 180.38 | 7.701 | 7.306 | 8.964 | 2.39 |
| | H | 12V 180Ah | 12.65 | 2.57 | 46.23 | 185.26 | 7.738 | 7.374 | 9.007 | 2.53 |
| | MFR:C | 12V 220Ah | 12.71 | 2.01 | 60.00 | 250.16 | 9.156 | 9.036 | 10.060 | 2.92 |
| | MFR:B | 12V 200Ah | 12.71 | 2.49 | 51.87 | 166.31 | 8.389 | 7.944 | 9.137 | 2.78 |
| | MFR:A | 12V 200Ah | 12.80 | 2.60 | 47.07 | 176.94 | 8.449 | 8.106 | 9.349 | / |
| | MFR:A | 12V 180Ah | 12.74 | 2.33 | 45.14 | 153.81 | 8.434 | 8.165 | 9.350 | 3.18 |
| AGM | MFR:C | 12V 330Ah | 12.77 | 1.90 | 87.00 | 332.68 | 8.302 | 8.064 | 9.485 | 2.08 |
| | MFR:B | 12V 330Ah | 12.88 | 2.80 | 81.00 | 307.15 | 7.643 | 7.132 | 8.815 | 2.14 |
| | R | 12V 200Ah | 13.01 | 2.17 | 63.42 | 240.52 | / | / | / | / |
| | R | 12V 200Ah | 12.98 | 2.18 | 63.34 | 237.56 | / | / | / | / |

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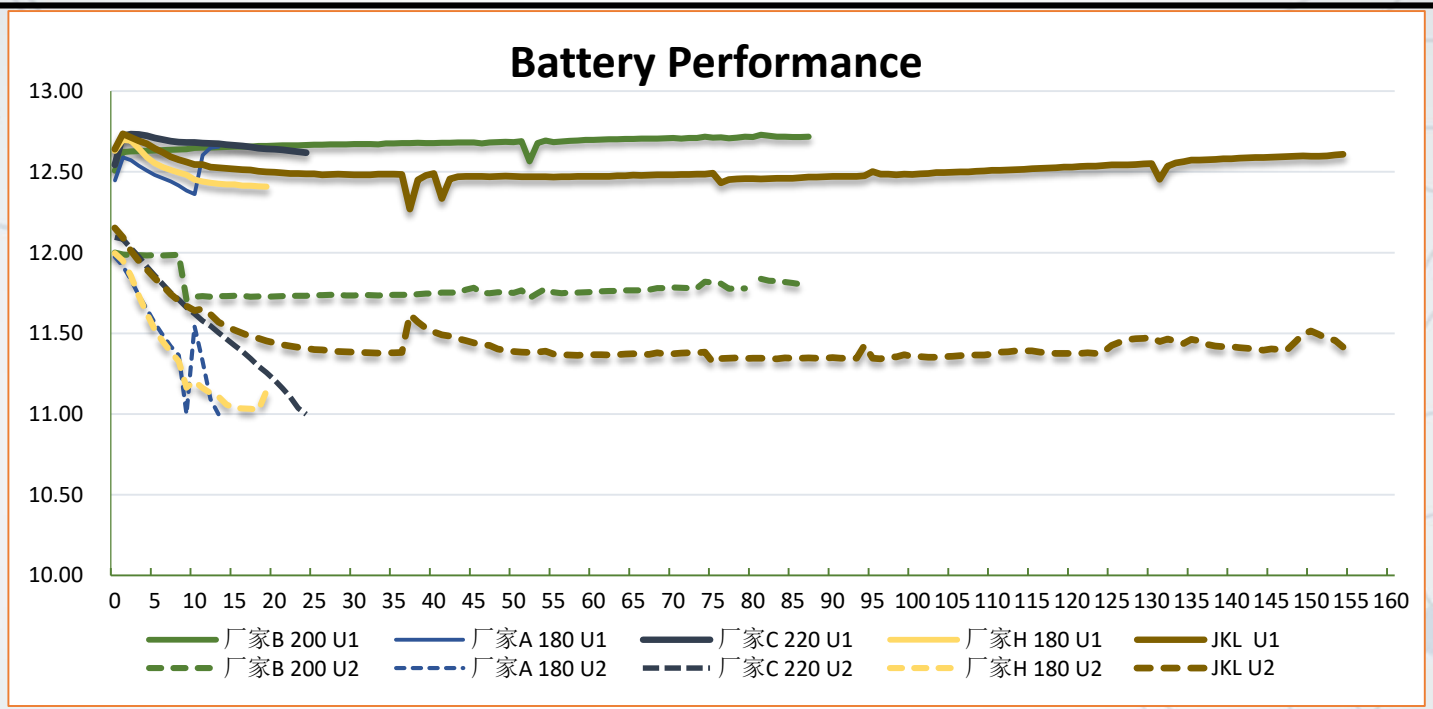
# Flooded Battery under Simulated Operation Condition




After fully charged, put battery in the 25℃ water bath for 24h. Then perform below cycle.

a. Discharge with 4A constant current for 6h;
b. Charging with constant voltage of 14V and limited current of 70A for 6h;
c. Discharge with 27A constant current for 3h;
d. Then charge with a constant voltage of 14V and a current limit of 70A for 6 hours.

The above steps a-d are one cycle. Cycle terminated till terminal voltage below 11V.
After the test terminated, undertake CCA -18℃ test , and the 30s voltage ≥ 7.2V.

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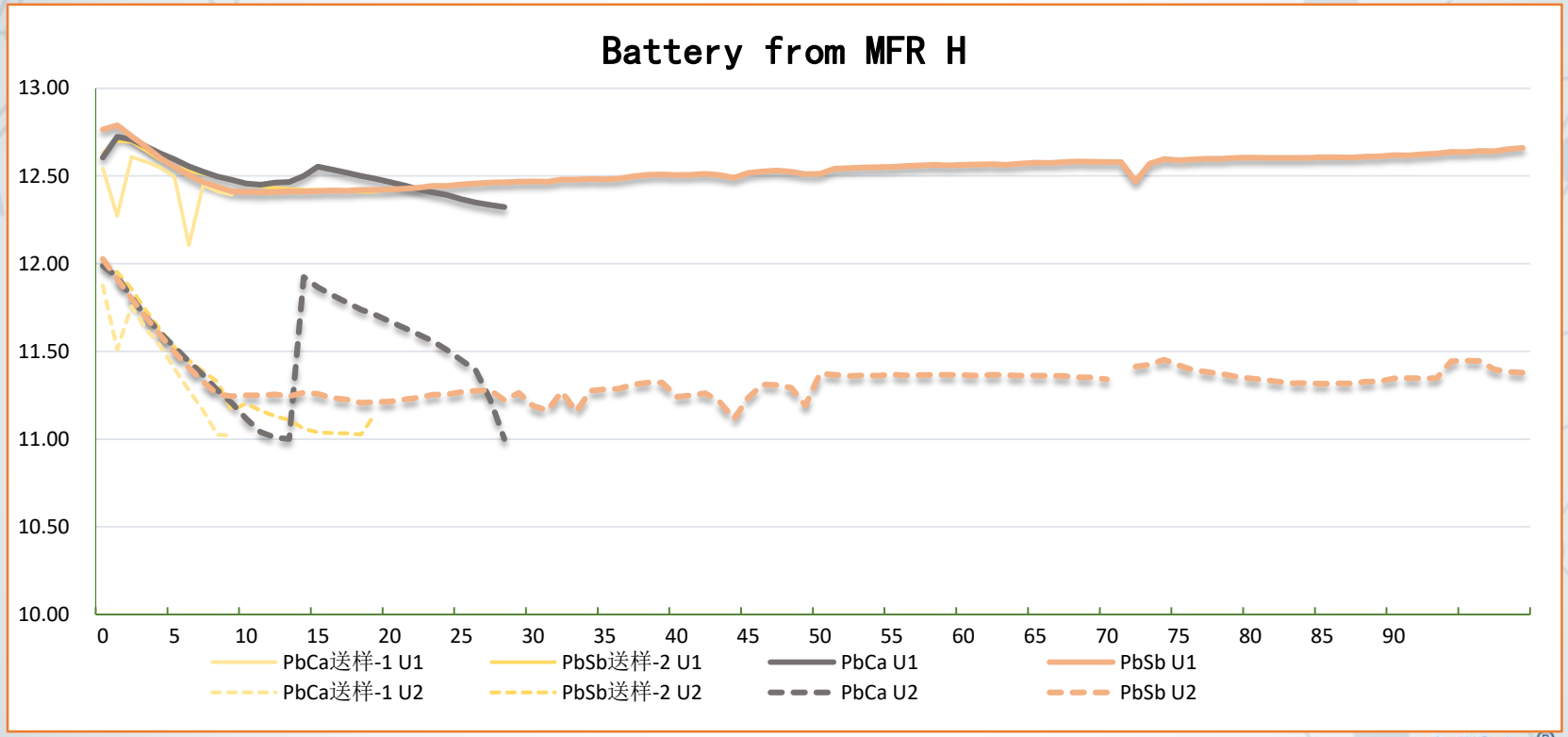
# Flooded Battery under Simulated Operation Condition

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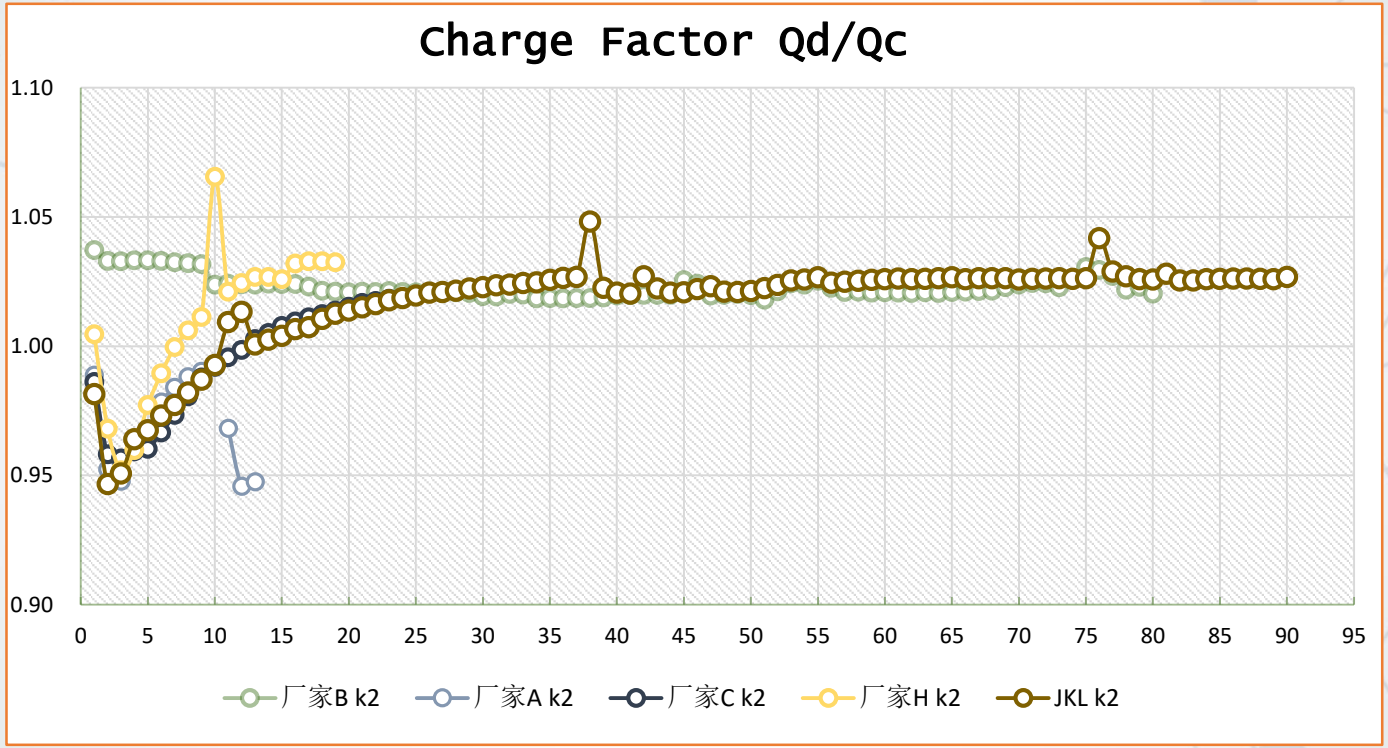
# Flooded Battery under Simulated Operation Condition

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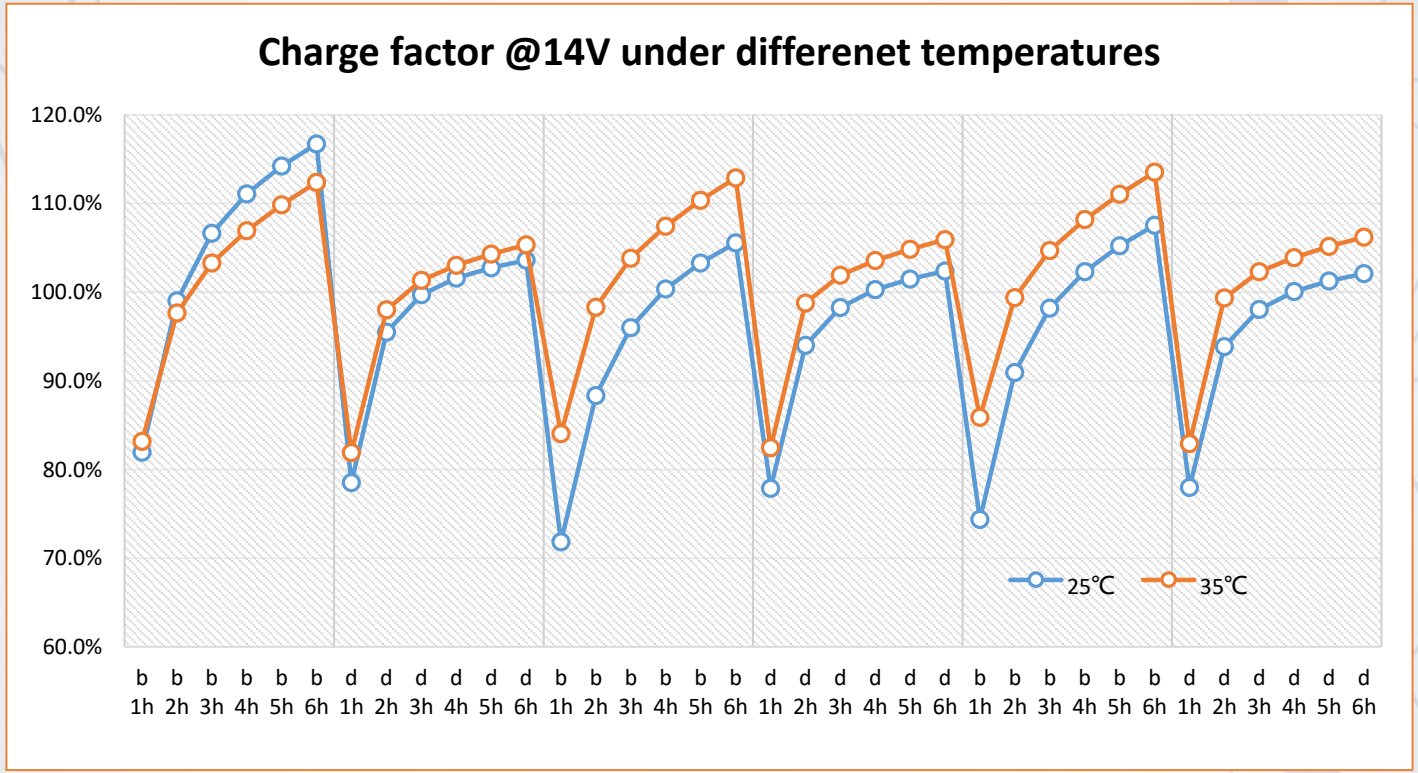
# Flooded Battery Operation 1

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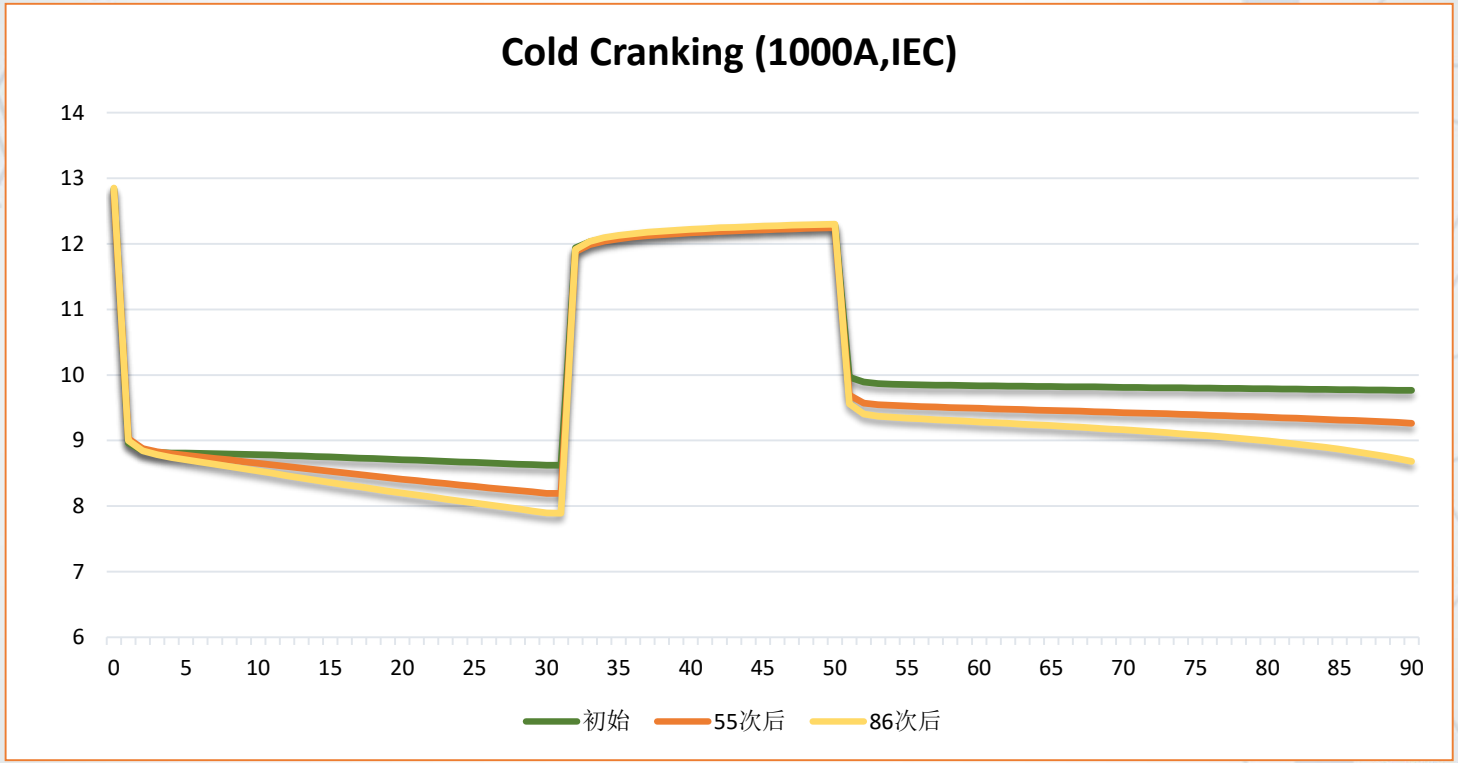
# Flooded Battery under Simulated Operation Condition

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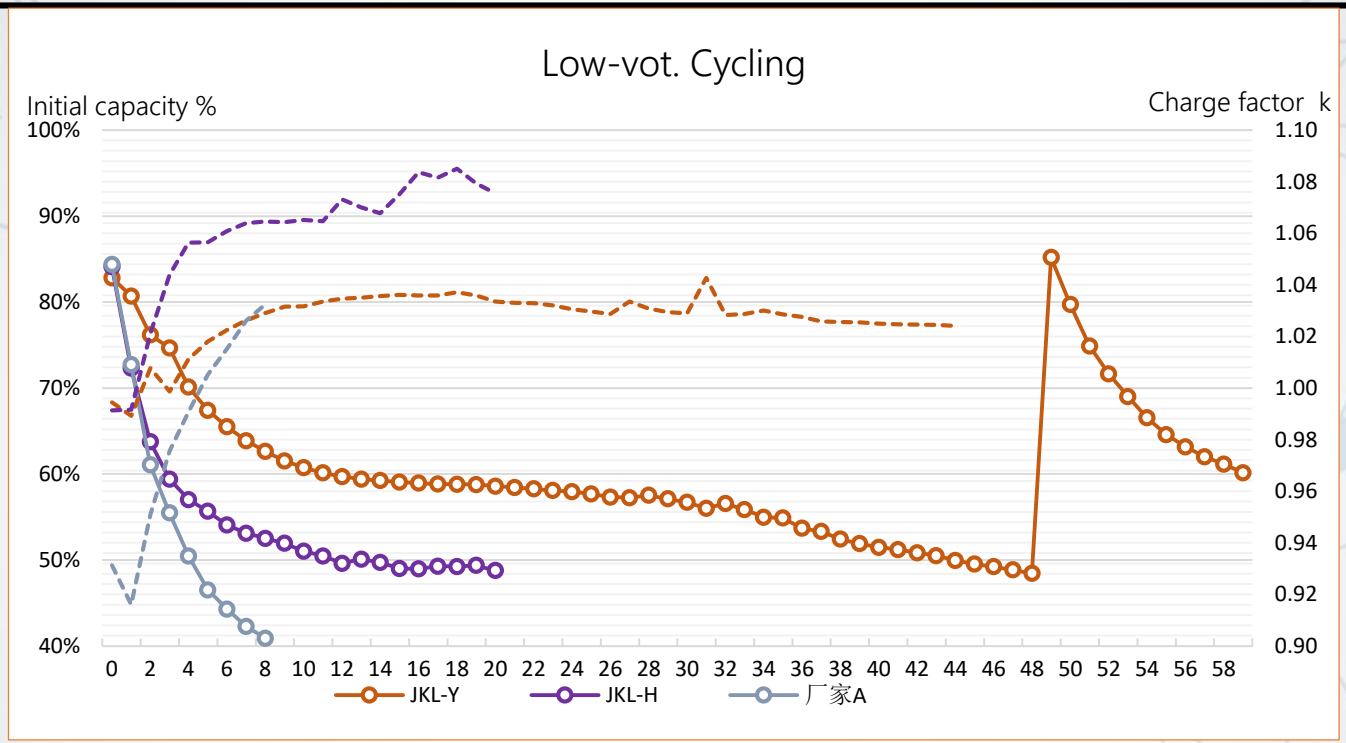
# Flooded Battery Low-voltage Cycle




After fully charged, put battery in the 25℃ water bath for 24h. Then perform below cycle.

a. Discharge with 25A current to 11V, then suspend for 10min;

b. Charging with constant voltage of 14V and limited current of 50A for 12h, then suspend for 10min;

The above steps a-b are one cycle. Cycle terminated till discharge capacity ＜ 40%$C_e$

After the test terminated, undertake Cold Cranking -18℃ test , and the 30s voltage ≥ 7.2V.

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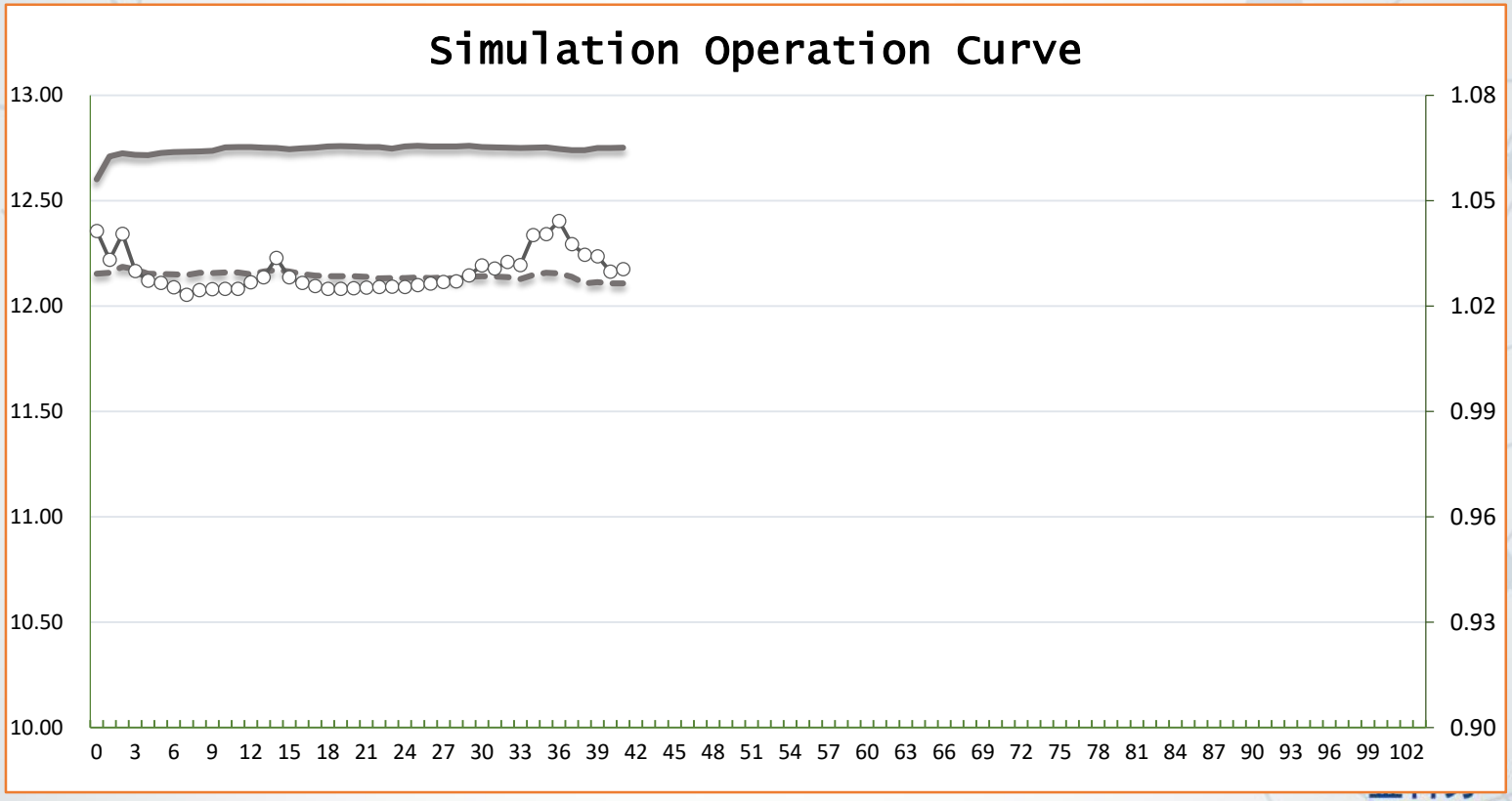
# AGM Battery under Simulated Operation Condition

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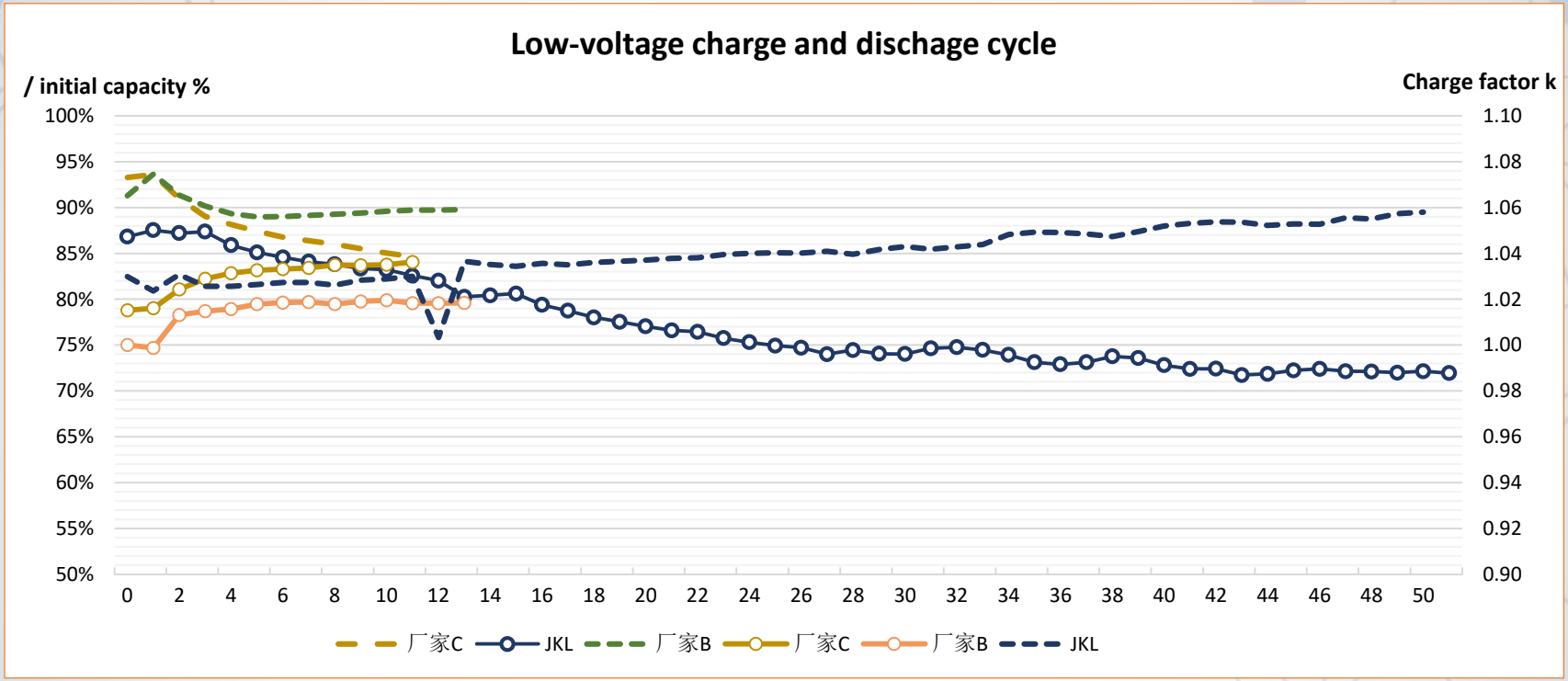
# AGM Battery Low-voltage Cycle

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# Summary of Life Testing

| Item | Capacity | Type | Battery on market | Jinkeli | Standard | Testing Data |
|---|---|---|---|---|---|---|
| Operation Cycle | 230Ah | Flooded | | Y | ≥90 | 155，terminate |
| | 180Ah | Flooded | | H | ≥45 | 104，ing |
| | 200Ah | AGM | | R | ≥120 | 25，ing |
| | 180AH | Flooded | MNF: A | | ≥45 | 11，failed |
| | 200Ah | Flooded | MNF: B | | ≥60 | 83，ok |
| | 220Ah | Flooded | MNF: C | | ≥90 | 22，failed |
| Low-vol. Cycle | 180Ah | Flooded | | Y | / | 72，ing |
| | 180AH | Flooded | | H | / | 35，ing |
| | 200Ah | Flooded | MNF: A | | / | 9，failed |
| | 200Ah | AGM | | R | / | 52，ing |
| | 330Ah | AGM | MNF: B | | / | 14，ing |
| | 330Ah | AGM | MNF: C | | / | 12，ing |

# Conclusion

- Parking ac battery will gradully expand on market. In addition to capacity and cold cranking performance, a higher cycle life is required. New design of large capacity flooded battery is needed, even a AGM battery.
- Unlike the charging and discharing condition of traditional SLI battery, a paste formulation optimization is required to meet deep-discharge and fast charging requirement along with structure and active material wt. adjustment.
- Flooded and AGM battery should use different paste formulation for both positive and negative plates.
- We suggest setup a uniform testing standard for parking ac battery to evaluate the life of batteries.

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# Thanks for your attention.

http: www.jinkeli.com
E-mail: jkl@jinkeli.com

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