LiFePO$_4$ Testing

LiFePO$_4$ Batteries vs Lead Acid Batteries
- Charging cycles
- **Weight and Volume**
- Charging efficiency
- Charging complexity
- **Cost**
- **Cold temperature performance**

The PASSCAL Engineering group and Genasun have characterized the cold temperature performance of the LiFePO$_4$ batteries sold by Genasun:
- In-house cold temperature discharge testing
- Third part cold charging investigation
LiFePO₄ Testing

Cold Discharge Testing:

- **Test Phase 1** – High current discharge tests to verify batteries’ ability to operate at cold temperatures

- **Test Phase 2** – Constant current to constant voltage (CC/CV) discharge tests to characterize low discharge rate performance

- **Test Phase 3** – Long term low current discharge test

Third-party cell characterization:

- Effect of cold charging on LiFePO₄ cells, charging efficiency at low temperatures
<table>
<thead>
<tr>
<th>Temp</th>
<th>5A</th>
<th>2A</th>
<th>1A</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>103Ah</td>
<td>103Ah</td>
<td>104Ah</td>
</tr>
<tr>
<td>-20°C</td>
<td>57Ah</td>
<td>69Ah</td>
<td>85Ah</td>
</tr>
<tr>
<td>Capacity at -20°C</td>
<td>55%</td>
<td>67%</td>
<td>82%</td>
</tr>
</tbody>
</table>

- Clear loss of capacity at lower temperature
- Capacity loss lessens as discharge rate decreases (beneficial for Polar use)
Genasun ran CC/CV discharge tests to rapidly characterize performance at low discharge rates:

- Rapidly remove a significant portion of the battery’s capacity
- Can obtain a complete capacity vs. discharge rate curve after running a single test
- Run this test at different temperatures to obtain capacity vs temperature relationship
LiFePO₄ Test Phase 2

CC/CV discharge test results for a 3.3V 180Ah LiFePO₄ Cell

Plot courtesy of Genasun
LiFePO$_4$ Test Phase 2

Zoomed in view of results:

Nominal Capacity

Plot courtesy of Genasun
Comparison of constant discharge rate and temperature affects on the 180Ah LiFePO$_4$ Cell:

<table>
<thead>
<tr>
<th>Discharge Rate</th>
<th>-40°C</th>
<th>-30°C</th>
<th>-20°C</th>
<th>0°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>79Ah</td>
<td>132Ah</td>
<td>177Ah</td>
<td>206Ah</td>
</tr>
<tr>
<td>0.5A</td>
<td>100Ah</td>
<td>155Ah</td>
<td>192Ah</td>
<td>207Ah</td>
</tr>
<tr>
<td>0.25A</td>
<td>125Ah</td>
<td>175Ah</td>
<td>200Ah</td>
<td>207.75Ah</td>
</tr>
<tr>
<td>0.1A</td>
<td>157Ah</td>
<td>195Ah</td>
<td>205Ah</td>
<td>208.1Ah</td>
</tr>
<tr>
<td>0.05A</td>
<td>180Ah</td>
<td>203Ah</td>
<td>ND</td>
<td>208.3Ah</td>
</tr>
</tbody>
</table>

Low discharge rate allows the battery to deliver nameplate capacity even at very cold temperatures.
LiFePO$_4$ Test Phase 3

Two month discharge test to validate cold temperature performance

- Two identical 100Ah LiFePO$_4$ batteries were discharged at -20°C with a load sized to drain the batteries in two months (≈65mA current draw).

**Capacity Delivered:**

- Batt 1 = 97.7Ah
- Batt 2 = 97.5Ah

Essentially no de-rate from nameplate capacity!
LiFePO$_4$ Testing – Third Party

Third party – Exponent Engineering and Scientific Consulting contracted by Genasun

Key Points
• At low temperatures, cell resistance increases significantly which limits charge/discharge capacity
• No evidence of lithium plating in the cells when charged at low temperatures
  • i.e. cells are NOT damaged by cold temperature charging (within bounds)
  • Exponent charged cells with 39.5A at -10°C, -20°C, -30°C and -40°C
• Electrolyte NOT frozen at -40°C, but it is partially frozen at -60°C.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Charge Capacity (Ah)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>187.7</td>
</tr>
<tr>
<td>-20</td>
<td>159.8</td>
</tr>
<tr>
<td>-30</td>
<td>104.0</td>
</tr>
<tr>
<td>-40</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Plot, table courtesy of Genasun
Battery Testing

1. Long Term AGM Testing:
   - 108Ah SunExtender Battery discharged at -20°C and -30°C
   - Resistive load discharged battery at C/5840 rate
     - Same rate batteries deployed at year round AGM station in Antarctica experience
   - -20°C: 64% of nameplate capacity
   - -30°C: 56.5% of nameplate capacity

2. Long Term LTC Testing:
   - Test is currently running and should complete in two months
   - -30°C test to verify battery performance for two year deployment station design and verify manufacturer’s data.

3. Air cell cold testing
   - Planned test to characterize the performance of air cell batteries at cold temperatures (0°C to -30°C).
   - Materials are purchased and test is scheduled to begin immediately

4. Rechargeable LiFePO4 battery testing
   - No testing updates from last PTC. A written report of results is available, e-mail polar@passcal.nmt.edu for a copy
   - Results of in field testing from the TA-Alaska project are expected soon
Battery Testing

Capacity versus Temperature

- C/1
- C/2
- C/4
- C/8
- C/24
- C/5840

Percent of 25°C Capacity

Temperature (°C)

Concorde Battery Corporation, 2009 San Bernardino Rd., West Covina, CA 91790   www.concordebattery.com   Phone 626-813-1234
POLAR Group