Performances of lead-carbon electrode based on rice-husk-derived carbon under partial state of charge operation

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Lead carbon electrode
## Lead Acid Battery

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<th>Advantages</th>
<th>DisAdvantages</th>
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<tr>
<td>Mature Technology</td>
<td>Low specific energy</td>
</tr>
<tr>
<td>Low price</td>
<td>Low power density for long time</td>
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<tr>
<td>Good Safety</td>
<td>discharge</td>
</tr>
<tr>
<td>High recycle ratio</td>
<td>Low charge acceptance</td>
</tr>
<tr>
<td></td>
<td>Low cycle life at PSoC</td>
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- Low charge acceptance at PSoC
- Short life, especially VRLA: design VRLA with long life both at PSoC and deep charge-discharge

Great values lies in the research and development of LAB!
Failure mode of LAB under PSoC

Simplified discharge and charge profile for HEV applications [1].

IEC 61427 standard cycling test procedure for PV applications [2].


At PSoC condition, recrystallization occurs, large PbSO₄ crystals are formed, the charge acceptance then decreases, HER occurs at NAM and capacity of battery declines.

Lead carbon battery (electrode)
Advanced lead acid battery technology

- Lead Carbon electrode
- Ca. 1-2wt.% in NAM
- Long life under PSoC
- High charge acceptance
- Good cold cranking capability
Terminology of Lead Carbon Electrode

Lead carbon electrode is the mixed lead carbon composite electrode;
LAB with lead carbon electrode shows high charge acceptance and long cycle life under PSoC operation conditions.
Mechanism of Carbon
Mechanism of Carbon

Increase conductivity: Sulfation of NAM make hard to charge LAB, and the carbon can serves electron pathways in NAM between PbSO₄ particles.

Charge flows will be terminated by HER or the reduction of PbSO₄. hence great importance is the electrochemical reduction of PbSO₄ at carbon surface. HER as a side reaction, under some conditions, should be reduced.

Steric hindrance: The low surface area of NAM of LAB is the necessary condition of the sulfation of NAM, since it has a low SSA of 0.3-1.0 m² g⁻¹, great contrast to the high SSA of PAM (3-8 m² g⁻¹). Pore volume of NAM will be increased by the addition of carbon. Sulfation is thus prohibited.
**Capacitive contribution**: capacitive energy storage is greatly enhanced by the addition of high SSA carbon. So lead carbon electrode is a bi-functional electrode.

Capacitive capacity can increase the charge acceptance.

Electro-catalytic effect: Parallel reaction mechanism

Reduction of PbSO₄ will occur on two surfaces namely the lead surface and carbon surface. The current flow is higher than that of lead. So a heterogeneous electro-catalytic effect is considered to have a great importance in lead carbon electrode.

Surfaces of carbon will transformed into Pb electrochemical active surface area.

Mechanism of Carbon Materials:

1. Steric hindrance: separate PbSO₄;
2. Increase conductivity: electron pathways between PbSO₄ particles;
3. Electrochemical reaction at carbon surface: \( \text{PbSO}_4 + 2e^- \rightarrow \text{Pb} \);
4. Capacitive contribution

Summary:
Increase the Pb electrochemical active surface area during long-term operation

Lead Carbon electrode based on RHC
Peculiarities of Rice Husk Carbon

SEM images of (a, b, c,) RHC and (d, e, f) KAC

Formation of RHC electrode

Formation curve

SEM images after Formation
HER and EIS of RHC electrode

Current and Voltage Stepwise EIS results

EIS results
# Simulated EIS results of RHC electrode

## Table 6.4: Simulated values of each electrical element for three lead-carbon electrodes

<table>
<thead>
<tr>
<th></th>
<th>$R_s$</th>
<th>$Q_f$</th>
<th>$R_f$</th>
<th>$n_1$</th>
<th>$Q_{dl}$</th>
<th>$C_{dl}$</th>
<th>$R_{ct}$</th>
<th>$n_2$</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>0.01233</td>
<td>1.2270</td>
<td>0.0088</td>
<td>0.7446</td>
<td>1.321</td>
<td>1.265</td>
<td>0.3908</td>
<td>0.9385</td>
<td>$1.08 \times 10^{-3}$</td>
</tr>
<tr>
<td><strong>RHC</strong></td>
<td>0.01620</td>
<td>0.6948</td>
<td>0.0072</td>
<td>0.8180</td>
<td>1.527</td>
<td>1.368</td>
<td>0.2707</td>
<td>0.8798</td>
<td>$1.39 \times 10^{-3}$</td>
</tr>
<tr>
<td><strong>KAC</strong></td>
<td>0.01526</td>
<td>0.8716</td>
<td>0.0099</td>
<td>0.7737</td>
<td>9.401</td>
<td>16.01</td>
<td>0.4372</td>
<td>0.5408</td>
<td>$1.21 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Rate performance of RHC electrode

Capacity retention at various charge rate
PSoC performance of RHC electrode

Charge-discharge and Capacity retention at PSoC
SEM and capacity of RHC electrode after PSoC test

SEM images and capacity test after PSoC
Conclusion

Outlook

Lead Carbon Battery for Remote Area Power Supply
Outlook

10MW4h Energy Storage System

Container-Type 135kW4h Lead-Carbon Energy Storage System designed by Kaiyu EES
Outlook

1. Homogeneous mix of lead and carbon
2. Inhibition of the Negative effect of carbon: HER, impurities
3. Advance valve regulated lead carbon battery: advanced design of lead alloy grid for a long life LAB; grid/PAM interface
4. Applications; Severe operation conditions, Grid peak and frequency regulation
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Your comments and suggestions are appreciated