Polymer-Filled Expanded Graphite: An Advanced Bipolar Plate Material for Redox Flow Batteries

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Redox Flow Battery
SGL Group – The Carbon Company

Introduction

Carbon and Graphites for Energy Storage Systems

Carbon and Graphites for Redox Flow Batteries
Introduction
SGL Group – The Carbon Company

• One of the world’s largest manufacturers of carbon-based products with a comprehensive portfolio ranging from carbon and graphite products to carbon fibers and composites

• More than 40 production sites worldwide

• Service network covering more than 100 countries

• Sales of ~€ 1.2 bn in 2009

• Head office in Wiesbaden/Germany

• Approx. 6,000 employees worldwide

• Listed on MDAX
Introduction

Energy vs Power

SGL contributes to all of the above Energy Storage and Conversion Systems

Introduction

Material overview within SGL Group

Graphitic
- Synthetic graphite
- Natural graphite

Non-graphitic / amorphous
- “Soft carbons”
- “Hard carbons”

Specialties
- Carbon black
- Expanded graphite
- Carbon fibers
- Carbon Nanotubes
- Fullerenes

Activated Carbons
- Activated carbon powders
- Activated carbon felts and cloths

Introduction

Carbon and Graphites for Energy Storage Systems

Carbon and Graphites for Redox Flow Batteries
Electric Double Layer Capacitor (EDLC)

Materials: activated carbons
- For anode and cathode
- Electrostatic charge storage
- Excellent cycle life
- Fast self-discharge
- High rate / high power
- Aqueous or organic electrolyte
- Low / mid voltage

Li-ion Battery (LIB)

Materials: graphites, hard carbons
- For anode
- Faradaic charge storage
- Good cycle life
- Low self-discharge
- Mid rate / mid power
- Organic electrolyte
- High voltage
Gas diffusion layers (GDL) for Fuel Cells

Carbon and Graphites for Energy Storage Systems

Gas Diffusion Layer (GDL)
Carbon and Graphites for Energy Storage Systems

High Temperature Batteries

Sodium Sulfur Batteries (NaS)

Sodium Metal Halide Batteries (e.g. NaNiCl₂, NaZnCl₂)

SGL is prepared to produce high quality battery felt at competitive prices with the installation of the world's most modern carbon and graphite soft felt line.
Carbon and Graphites for Energy Storage Systems

Expanded Graphite – High Potential Material

Graphite/PCM Composites for Thermal Energy Storage

- Tap density: 600…700 g/l
- Tap density: 2…7 g/l
- Density: 100…200 g/l
- Density: 700…1800 g/l

Conductive Additive for Battery Application

Expansion
Thermal shock: 1000 °C

Milling
Compaction
Energy is a top priority topic for SGL Group

Solutions for electrochemical energy storage and conversion

- **ANODE** material for Li-ion batteries
- **PEAC®** activated carbons for Supercapacitors
- **CONDUCTOGRAPH®** expanded graphite as conductive additive for different batteries
- **SIGRAFLEX®** graphite foil or compound sheets as bipolar plates for redox flow batteries
- **Sigratherm®** carbon felts for Na-S, Na-MH, and redox flow batteries
- **SIGRACET®** gas diffusion layers for PEM fuel cells
- **ECOPHIT®** graphite/PCM composites for heat/cold storage
Redox Flow Battery
SGL Group – The Carbon Company

Introduction

Carbon and Graphites for Energy Storage Systems

Carbon and Graphites for Redox Flow Batteries
Redox Flow Battery

Working Principle (Vanadium – Vanadium)

V\textsuperscript{5+} / V\textsuperscript{4+} electrolyte tank + Sulfuric acid

V\textsuperscript{2+} / V\textsuperscript{3+} electrolyte tank + Sulfuric acid

AC / DC Generator

Charging

Discharging

Load

Pump

Membrane

Graphite based electrode design

Carbon Soft Felt

Graphite Plates

\text{charged} \rightarrow \text{discharged}

\text{charged} \rightarrow \text{discharged}

\text{charged} \rightarrow \text{discharged}

\text{charged} \rightarrow \text{discharged}
Redox Flow Battery

Material requirements

- High electrical conductivity (reduce electrical losses)
- Chemical inertness (acidic electrolyte)
- Large surface to increase current density and power
- High liquid permeability to reduce pressure drop and efficiency losses

Major Target = Cost reduction through
- Improved mat. performance
- Innov. production processes

Electrolyte separation
High tightness at low resistivity

Carbon Soft Felt
Graphite Plates
Redox Flow Battery

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Carbon Soft Felt

Graphite Plates

Electrolyte separation
High tightness at low resistivity
## Redox Flow Battery

Comparison of Graphite Foil with New Polymer-Filled Expanded Graphite

<table>
<thead>
<tr>
<th></th>
<th>SIGRAFLEX Graphite Foil</th>
<th>New Expanded Graphite Based BPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.00</td>
<td>1.70</td>
</tr>
<tr>
<td>Thicknesses</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Therm. Conduct. in plane</td>
<td>≥ 200</td>
<td>≥ 250</td>
</tr>
<tr>
<td>Therm. Conduct. through plane</td>
<td>4 - 6</td>
<td>3 - 5</td>
</tr>
<tr>
<td>Spec. Electrical. Resistance through plane(^1)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Permeability(^2) through plane</td>
<td>≤ 1 * 10E-01</td>
<td>≤ 1 * 10E-03</td>
</tr>
</tbody>
</table>

1) Parameters: 50 mm (Area), 50 N (Load)
2) Area pressure 20 N/mm²; 1 bar helium over pressure
# Redox Flow Battery

Comparison of Compound Plates with New Polymer-Filled Expanded Graphite

<table>
<thead>
<tr>
<th></th>
<th>Typical Compound Plate</th>
<th>New Expanded Graphite Based BPP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturing process</strong></td>
<td>Batch process with compound (Injection or compression moulding)</td>
<td>Continuous production of material possible (low cost)</td>
</tr>
<tr>
<td><strong>Thickness (typical)</strong></td>
<td>1 – 3 mm</td>
<td>0,5 - 1 mm</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td>Limited (toolsize)</td>
<td>Length: 1 m (endless)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Width: 1 m</td>
</tr>
<tr>
<td><strong>Specific electrical resistivity (contact and material)</strong></td>
<td>High at small contact pressures (as in cell stacks)</td>
<td>Low at small contact pressures (as in cell stacks)</td>
</tr>
</tbody>
</table>
Material requirements

**Carbon Soft Felt**

- Large surface to increase current density and power
- High liquid permeability to reduce pressure drop and efficiency losses

**Graphite Plates**

- High electrical conductivity (reduce electrical losses)
- Chemical inertness (acidic electrolyte)

Major Target = Cost reduction through
- Improved mat. performance
- Innov. production processes

Electrolyte separation
- High tightness at low resistivity
## Redox Flow Battery

**Material properties of different carbon soft felts**

<table>
<thead>
<tr>
<th></th>
<th>Rayon based felts</th>
<th>PAN based felts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KFA (carbonized)</td>
<td>GFA (graphitized)</td>
</tr>
<tr>
<td>Currently delivered qualities</td>
<td>none</td>
<td>GFA 5</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>–</td>
<td>o</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Purity</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Surface activity</td>
<td>+</td>
<td>o</td>
</tr>
<tr>
<td>Wettability (as processed)</td>
<td>o ... +</td>
<td>–</td>
</tr>
<tr>
<td>Wettability (post-treated)</td>
<td>not possible</td>
<td>o ... +</td>
</tr>
<tr>
<td>Resulting battery efficiency (as processed)</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Resulting battery efficiency (post-treated)</td>
<td>not possible</td>
<td>+</td>
</tr>
<tr>
<td>Resulting power density (as processed)</td>
<td>o</td>
<td>+</td>
</tr>
<tr>
<td>Resulting power density (post-treated)</td>
<td>not possible</td>
<td>+</td>
</tr>
</tbody>
</table>
Redox Flow Battery
Battery specific felt properties

Enhance battery specific felt properties:

- Homogeneity in thickness and area weight
- Density homogeneity
- Electrical conductivity (Adaption of electrical resistivity measurement equipment)
- Liquid permeability / wettability measurements
- Specific surface area (BET)
- Electrochemical activity (Redox Flow laboratory test cell)
- Electrochemical purity
Redox Flow Battery

Summary on Redox Flow Battery

**General requirement**

Need for cost efficient materials with increased performance characteristics for fully implementing redox flow technology in energy storage market

**New expanded graphite based BPP (®SIGRAFLEX BPP)**

- Large sizes and low thicknesses available
- Inertness and tightness at low resistivity (especially at low contact pressures)

**Carbon and graphite felts (®SIGRATHERM KFA, GFA, KFD, GFD)**

- Several material types available
- Further enhancement of battery specific properties
Innovative Carbon Solutions for Energy Technology.

With carbon and graphite components, the future of energy technology starts today. That is why SGL Group develops innovative products, such as ultracapacitor materials derived from seaweeds.

Our materials stand for maximum performance: PEAC™ porous carbon powders for ultracapacitors, SIGRACET® gas diffusion layers for fuel cells, CONDUCTOGRAPH® expanded graphite as conductive additive, SIGRACET® graphite foils as bipolar plates/current collectors and SIGRATHERM® carbon felts as electrodes, carbon and graphite materials for thermal management.

Find out more about the potential of carbon and graphite, and about how we can use these materials to develop customized solutions for you.

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Thank you for your attention!

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