Coating Solutions for Li-Ion Batteries
Lab to Fab concept

Thomas Kolbusch, Vice President
Dr. Klaus Peter Crone, Director of R&D
Summary

Battery basics

Coating systems

Drying & curing

Todays equipment

Battery production lines

The Battery Fab

Proof of Concept
Battery basics
## Battery basics

### Overview

<table>
<thead>
<tr>
<th>Storage-Systems</th>
<th>Energy-carrier</th>
<th>Energy-density</th>
<th>Power-density</th>
<th>Lifetime / Cycles no.</th>
<th>Self-Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wh/kg</td>
<td>Wh/l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitor</td>
<td>e- Super Cap</td>
<td>4</td>
<td>5</td>
<td>++</td>
<td>+ / ++</td>
</tr>
<tr>
<td>Primary-cells</td>
<td>Zn-C</td>
<td>60-100</td>
<td>100-150</td>
<td>--</td>
<td>0 / --</td>
</tr>
<tr>
<td></td>
<td>Zn-MnO₂</td>
<td>100-150</td>
<td>200-300</td>
<td>0</td>
<td>+ / --</td>
</tr>
<tr>
<td></td>
<td>Zn-O₂</td>
<td>Ca. 300</td>
<td>Ca. 450</td>
<td>+</td>
<td>0 / --</td>
</tr>
<tr>
<td>Secondary-cells</td>
<td>Pb-PbO₂</td>
<td>20 - 40</td>
<td>50-100</td>
<td>0</td>
<td>0 / 0</td>
</tr>
<tr>
<td></td>
<td>Ni-Cd</td>
<td>40 - 60</td>
<td>100-150</td>
<td>+</td>
<td>++ / ++</td>
</tr>
<tr>
<td></td>
<td>Ni-MeH</td>
<td>60 - 90</td>
<td>150-250</td>
<td>+</td>
<td>++ / ++</td>
</tr>
<tr>
<td></td>
<td>Ag-Zn</td>
<td>80-120</td>
<td>150-250</td>
<td>++</td>
<td>- / -</td>
</tr>
<tr>
<td></td>
<td>Li-Ion</td>
<td>100-200</td>
<td>150-500</td>
<td>+</td>
<td>+ / +</td>
</tr>
<tr>
<td>Fuel cells</td>
<td>H₂ (300 Bar)</td>
<td>33.000</td>
<td>2400</td>
<td>o</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>H₂ (liquid)</td>
<td>33.000</td>
<td>750</td>
<td>o</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>H₂ (MeH)</td>
<td>600</td>
<td>3200</td>
<td>o</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Methanol</td>
<td>5600</td>
<td>4400</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Combustion-engines</td>
<td>Petrol</td>
<td>12700</td>
<td>8800</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Diesel Fuel</td>
<td>11600</td>
<td>9700</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>
Battery basics

Overview

- **Cathode**
  - LiCoO$_2$
  - Co, Li, O

- **Electrolyte**
  - Charge Li$^+$
  - Discharge Li$^+$
  - LiPF$_6$ + O + RO-C-OR

- **Anode**
  - Graphite
  - Typical Species in SEI:
    - Li$_2$CO$_3$
    - ROCO$_2$Li
    - ROLi
    - (CH$_2$OCO$_2$Li)$_2$, etc.

- **Solid Electrolyte Interphase (SEI)**

- Reversible Li Ion
- Irreversible Li Ion
Battery basics

Overview

Source: IEEE 1725 - 2009
Technologies & Processes

Coating Systems

- Knife
- Double Side
- Commabar
- Case Knife
- Hotmelt Slot Die
- Engraved Roller
- 3 Roller Combi
- Micro Roller
- 5 Roller
- Reverse Roll
- Slot Die
- Curtain Coating
- 2 Roller Combi
- Powder Scattering
- Dipping
- Rotary Screen
# Coating Systems

## Coating Parameters

### Coating Chemistry
- Rheology
- Viscosity
- Viscoleasticity
- Type of solvents
- Amount of solids
- Van der Waals force
- Sheer ratio
- Adhesion/Cohesion

### Coating Processes
- Coating systems
- Single or Multilayer coatings
- Direct coatings
- Transfer (indirect) coatings
- Substrate speed
- Layer Thickness
- Coating accuracy

### Process control
- Process layout
- Tension control system
- Material guiding system
- Inline parameter control
- Quality control

### Drying
- Convection drying
- Contact drying
- Infrared drying
- Sintering
- NIR
- High Frequency
- UV crosslinking systems

### Substrate
- Surface tension
- Dimension stability
- Surface structure
- Contact angle

### Pretreatment
- Corona
- Plasma
- Cleaning

### Environment
- Humidity
- Temperature
- Inert Conditions

### Finishing
- Calendaring
- Embossing
- Slitting
Drying, curing & crosslinking
Drying Topics

Drying Technologies

Drying with hot air technology
Drying Topics

Drying Technologies
1.) transfer the drying energy into solids and solvent to achieve the drying temperature

2.) evaporate the solvent

3.) remove the solvent vapor
Drying Topics

Drying systems: hot air technology

- combined functions of heating and vapor transport
- bulk heating by heat transfer from the surface
- overheating easily avoided by limited air temperature

simple slot dryer

wing shaped slot dryer

wing shaped nozzle dryer with different nozzles
Drying Topics

Drying systems: hot air technology

Floating dryer

single nozzle
Drying Topics

Drying Technologies

Exhaust air → Fresh air supply → Dirt filter with radiator → Circulation air fan
Drying Topics

Drying Technologies
Drying Topics

Drying Technologies
Drying Topics

Drying systems: IR technology

- separate functions of heating and vapor transport
- full bulk heating by IR-absorption
- absorption dependant on wavelength
- overheating to be avoided by surface temperature sensor control
- problem: temperature homogeneity
Drying systems: IR technology

\[ I_1 = I_0 e^{-ax} \]

\( I_0 \) intensity in
\( I_1 \) intensity out
\( a \) absorption coefficient
\( x \) layer thickness
Drying Topics

Drying Technologies

IR-Sinter unit
Drying Topics

Infrared dryers

Combined hot air / IR dryer
Drying Topics

Microwave dryers

- same pros and cons as IR, but even exaggerated
- complex system
- advantages for very thick layers only
Drying Topics

Comparison solvent- vs. waterbased adhesives

<table>
<thead>
<tr>
<th>Solvent-based solution</th>
<th>Waterbased dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. high vapor pressure at low temperature, drying sometimes possible without dryer</td>
<td>1. low vapor pressure at low temperature makes dryers always necessary</td>
</tr>
<tr>
<td>2. solved polymers are activated, green tack (tacky even if wet) (Anfangsklebrigkeit, Nasshaftung)</td>
<td>2. dispersed polymers first have to film, then are activated by heat. No green tack. Tacky only after complete drying</td>
</tr>
<tr>
<td>3. Dilution simply by adding solvent</td>
<td>3. Dilution more difficult. Precipitation possible</td>
</tr>
<tr>
<td>4. Skinning and particle creation can be prevented and removed by solvent</td>
<td>4. Skinning and particle creation are more severe. Both cannot be removed by water after filming</td>
</tr>
<tr>
<td>5. Sensitive to freezing</td>
<td></td>
</tr>
</tbody>
</table>

A good replacement is PU-dispersion:
- a) dry to filming
- b) activate by heat and pressure

So very different processes may be necessary
# Drying Topics

## Comparison of data

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Molar mass (g/mol)</th>
<th>Boiling point (°C)</th>
<th>Vapor pressure at 20°C (mbar)</th>
<th>Vapor pressure at 50°C (mbar)</th>
<th>Evaporation energy (kJ/kg)</th>
<th>Heat capacity (kJ/kgK)</th>
<th>Surface energy at 20°C (mN/m=dyn/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>18</td>
<td>100</td>
<td>23</td>
<td>123</td>
<td>2256</td>
<td>4.18</td>
<td>71.9</td>
</tr>
<tr>
<td>Methanol</td>
<td>32</td>
<td>65</td>
<td>129</td>
<td>535</td>
<td>1100</td>
<td>2.47</td>
<td>22.5</td>
</tr>
<tr>
<td>Ethanol</td>
<td>46</td>
<td>78</td>
<td>59</td>
<td>280</td>
<td>840</td>
<td>2.43</td>
<td>21.6</td>
</tr>
<tr>
<td>Propanol-1</td>
<td>60</td>
<td>97</td>
<td>20</td>
<td>112</td>
<td>750</td>
<td>2.77</td>
<td>23</td>
</tr>
<tr>
<td>Propanol-2</td>
<td>60</td>
<td>82</td>
<td>43</td>
<td>225</td>
<td>650</td>
<td>2.69</td>
<td>21</td>
</tr>
<tr>
<td>Acetone</td>
<td>58</td>
<td>56</td>
<td>246</td>
<td>830</td>
<td>525</td>
<td>2.16</td>
<td>22.8</td>
</tr>
<tr>
<td>MEK</td>
<td>72</td>
<td>80</td>
<td>105</td>
<td>373</td>
<td>447</td>
<td>2.2</td>
<td>24.6</td>
</tr>
<tr>
<td>NMP</td>
<td>99</td>
<td>203</td>
<td>0.32</td>
<td>2.9</td>
<td>511</td>
<td>2.1</td>
<td>40.9</td>
</tr>
<tr>
<td>Ethylacetate</td>
<td>88</td>
<td>77</td>
<td>98</td>
<td>360</td>
<td>362</td>
<td>1.92</td>
<td>23</td>
</tr>
<tr>
<td>Toluene</td>
<td>92</td>
<td>111</td>
<td>29</td>
<td>124</td>
<td>414</td>
<td>1.7</td>
<td>28.5</td>
</tr>
</tbody>
</table>

The table summarizes relevant data of water and solvents. The data originate from different sources. No guarantee for correctness.
Drying Topics

Water vs. Organic solvents: Energy

heat capacity

kJ / kg\(^\circ\)K

- water
- methanol
- ethanol
- propanol-1
- propanol-2
- acetone
- MEK
- NMP
- ethylacetate
- toluene
Drying Topics

Water vs. Organic solvents: Energy

**evaporation energy**

<table>
<thead>
<tr>
<th>Solvent</th>
<th>kJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>2500</td>
</tr>
<tr>
<td>methanol</td>
<td>1700</td>
</tr>
<tr>
<td>ethanol</td>
<td>1100</td>
</tr>
<tr>
<td>propanol-1</td>
<td>700</td>
</tr>
<tr>
<td>propanol-2</td>
<td>600</td>
</tr>
<tr>
<td>acetone</td>
<td>500</td>
</tr>
<tr>
<td>MEK</td>
<td>500</td>
</tr>
<tr>
<td>NMP</td>
<td>500</td>
</tr>
<tr>
<td>ethylacetate</td>
<td>500</td>
</tr>
<tr>
<td>toluene</td>
<td>500</td>
</tr>
</tbody>
</table>
Drying Topics

Water vs. Organic solvents: Time

vapor pressure at 50 °C

No disadvantage of water, if drying temperature is near boiling point. Otherwise water will dry slower in most cases.
Drying Topics

Water vs. Organic solvents: Time

Diffusion limit andSkinning

• drying is limited by diffusion

• if the internal diffusion is slower than the evaporation from the surface, a skin may be created

• the remaining diffusion through the skin may be slower than the wet diffusion by many orders of magnitude

• so the initial evaporation must be limited
  - by low temperature and/or
  - by partially saturated atmosphere
Drying Topics

How to design a dryer?

1. Choose the basic technology (hot air, IR, µ-wave)

2. Choose the temperature and the number of temperature zones

3. Determine the average evaporation speed \( R \) (g/m²s)

4. \( R \) and grammature → drying time

5. Drying time and web speed → dryer length

6. Grammature, heat capacity, evaporation energy → total energy

7. Start building the dryer.
Todays equipment
Todays equipment

The Easycoater
Todays equipment

**The Easycoater**

<table>
<thead>
<tr>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knife System</td>
</tr>
<tr>
<td>Slot Die System</td>
</tr>
<tr>
<td>Screen System</td>
</tr>
<tr>
<td>Heated vacuum table</td>
</tr>
<tr>
<td>Integrated Air Heating</td>
</tr>
</tbody>
</table>

Today's equipment
Todays equipment

The Thin Film Coater & Printer
The Thin Film Coater & Printer

**Facts**

- Printing systems: Flexo, Engraved Roller, Rotary Screen
- Coating system: slot die
- Precision vacuum table
- High precision motoric gap adjustment
- Camera detection system for registration control
- Can operate with solvent based materials
- Clean room compatible
Todays equipment

The Basecoater 3rd Generation
Todays equipment

The Basecoater 3rd Generation

Facts

- Cantilever Rollers
- Delamination / Lamination
- Contact cleaning
- Corona station
- Slot Die System
- Rotary Screen System
- 2 Roller System
- Hot Air Dryer
- IR Dryer
- UV unit
- Edge sealing & glue application
- Cross-directional cutting system
Todays equipment

The Click&Coat
Todays equipment

The Click&Coat
Todays equipment

The Click&Coat
Today's equipment

The Verticoater
Todays equipment

The Linecoater
The Linecoater
Battery production lines
Battery production lines

Production line for Batteries
Battery production lines

Flotation dryer in Pilotcoater concept
Battery production lines

Flotation dryer in Pilotcoater concept
Battery production lines

Production line
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Production line
The Battery Fab
The Battery Fab

Overview
The Battery Fab

Coatema Battery Fab concept
# Lithium Battery Markets

## The Battery Fab

<table>
<thead>
<tr>
<th>Transportation</th>
<th>Electric Grid Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEV / PHEV / EV</td>
<td>Grid Stabilization</td>
</tr>
<tr>
<td>Heavy-Duty Hybrids</td>
<td>Uninterrupted Power Supply</td>
</tr>
</tbody>
</table>

- **Fuel Economy**
- **Reduced Emissions**
- **Energy Independence**
- **Increase Plant Efficiency**
- **Increase Grid Reliability**
- **Energy Independence**
The Battery Fab

Production Process Li-Ion Batteries

![Flowchart of the battery production process]

- **Anode**
  - Material Preparation
  - Mixing
  - Coating
  - Pressing
  - Slitting, Notching
  - Drying

- **Cathode**
  - Material Preparation
  - Mixing
  - Coating
  - Pressing
  - Slitting, Notching
  - Drying

- **Cell Stages**
  - Second Drying
  - Sealing
  - Canning / Packaging
  - Cell-stack Assembly
  - Winding / Lamination
  - Tab Alignment and Welding

- **Preparation Stages**
  - X-Ray
  - Electrolyte Injection
  - Rest
  - Pre-Formation

- **Formation Stages**
  - Formation
  - Degassing
  - Aging
  - X-Ray

- **Final Storage**
The Battery Fab

Factory Concept: Master Site Plan
Factory Concept: Buildings & Facilities

- Energy Center
- powder delivery & slurry mixing area
- solvent storage
- fire fighting facilities
- office
- explosion-proof wall elements
- transport corridor
- electrical formation, testing & shipment
- electrode production and cell assembly
- central utility building
The Battery Fab

Concept – Phase II: Capacity 1200-1800 MWh/a
The Battery Fab

Concept – Phase I

- Cathode Production
- Anode Production
- Drying
- Assembly
- Electrolyte Filling
- CUB
- Final Storage
- Degassing
- Formation
- Aging
- Pre-Formation
- Resting
The Battery Fab

Most Relevant Energy Flows

- **Coating**
  - Solvents Evaporation (~ 100 °C)

- **Drying**
  - Heating
  - Air Condition

- **Assembly**
  - Air Condition

- **Formation**
  - Charging
  - Discharging (~ 60 °C)

- **Rest**
  - Heating
Proof of Concept
Proof of concept

Basecoater for batteries
Proof of concept

Basecoater for batteries
Proof of concept

Linecoater for batteries

[Images of linecoaters for batteries]
Proof of concept

Custom made solution
COATEMA Coating Machinery GmbH

Roseller Str. 4
D-41539 Dormagen
021 33 / 97 84 – 0
tkolbusch@coatema.de

THANK YOU