PREVENTING THERMAL PROPAGATION – APPROACHES & EFFORT TO IMPLEMENT THEM IN A BATTERY SYSTEM

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MARIO HARWAR // STEFAN MORGENSTERN // PETER KRITZER
FREUDENBERG SEALING TECHNOLOGIES
D-69465 WEINHEIM
peter.kritzer@fst.com // +49 6201 80 4003
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Key Facts Freudenberg GROUP

> 8.6bn EUR Sales 2016

> 1bn EUR consolidated Profit before income tax

Global presence in more than 55 countries worldwide

100% Family Ownership

Stable Outlook

> 46.000 employees

2.4bn EUR Sales with NEW products (< 4 years since SOP)

Established 1849

4.3 % R&D Ratio
**Freudenberg – Organization // Battery Activities since 1950ies**

<table>
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<th>STRATEGIC MANAGEMENT PARENT COMPANY: FREUDENBERG &amp; CO. KOMMANDITGESELLSCHAFT</th>
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- **World-wide leader of sealing components** to e.g. Automotive industry
- **Many serial LiB projects since 2000**

- **Longtime supplier to the battery industry (since 1950ies)**
- **Separator supplier for Lead-acid, NiCd & NiMH systems**
- **Li-ion Separator activities since 2002**
Lithium Batteries – Outlook

Trends & Requirements for Battery Systems (some…)

- Increased energy density on Cell level
- Increased energy density on System level
- Ultra-fast charging capability
- Shorter battery development cycles vs. long-term reliability

Main Challenges (also some…)

- Effective thermal management
- Fulfilling future safety aspects

There is a need for
- reliable components (“carefree solution”)
- new approaches strongly improving system performance
Freudenberg’s Portfolio for Lithium Batteries

- Cell Seals
- Heat Shields
- Cooling Cycle Tubes
- Pouch Cell Fixation
- Connector Seals for Cooling Cycles
- Advanced Connectors
- Housing gaskets
- Plug Seals & Cable Bushings
- Thermal Gap Fillers
- Cooling Modules
- Pressure Compensation Elements
- Safety Concept
- Cell Separators
- Safety Relevant

Pressure regulating DIAvent

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Pressure Compensation Elements

Safety Concept

Cell Separators

Safety Relevant
Battery Safety Approaches
Lithium Batteries – Safe and Not-so-safe Operation States

Cell Operation  Cell Abuse  Cell Thermal Runaway  Heat Propagation System Thermal Runaway

Reliable Operation  Avoidance of Cell Runaway  Combating Cell Runaway  Avoiding Heat Propagation

Freudenberg’s activities

Safe Separator  Emergency Cooling  Heat Shields
Overpressure Valves  Pressure Compensation
Separators
Safety on Cell Level

Contact:
Freudenberg Performance Materials
Margarita Messerle
Phone +(49) 6201 80 3615
Mail margarita.messerle@freudenberg-pm.com
Freudenberg’s Flexible Ceramic Separator

- **Polyester Support Nonwoven**
  - Ultrathin < 20µm
  - Homogenous porosity

- **Innovative Impregnation Technology**
  - Paste with inorganic particles
  - Al-Oxide bonded reliably to the substrate

- **Novel Separator for Li Ion Battery**
  - Ceramic particles fill the cross section
  - Highly flexible, porous Ceramic/Polyester structure

True ceramic separator with fiber reinforcement
Flexible, free standing ceramic structure
Freudenberg’s Separator - Key Benefits

- No thermal shrinkage (175 °C / 1 h)
- No local meltdown (420 °C)
- Faster electrolyte filling
- Excellent charge/discharge acceptance
- Excellent cycle life performance
  [also at high C rates]

- Thickness down to 23 µm (19 µm under development)

More information? Visit us here at our Booth (21)
Freudenberg’s Separator - Comparison to Coated Membrane

Find the nail test video on our homepage:
https://separators.freudenberg-pm.com/Benefits/Safety
Heat Shields
Blocking Thermal Propagation
The Need For Heat Shields

Situation without Heat Shield

- Thermal runaway of a cell
- Thermal energy can be transferred to neighbored cells
- Fatal „chain reaction“; sudden release of energy from all cells in a module

=> Battery explosion possible!
The Need For Heat Shields

Situation with Heat Shield

- In case of thermal runaway of a cell
- Thermal energy *cannot* be transferred to neighbored cells
- **No** fatal „chain reaction“;
  problem keeps limited on one cell
Heat Shields for Lithium Batteries – Key Questions

- What is the surface temperature of a „Thermal Runaway Cell“?
- How long will the surface stay hot?

- What is the maximum acceptable surface temperature of the neighbored cell? 
  [-> heat transfer cell housing -> “cell chemistry”]

- Which influence has the cell form (prismatic; pouch) for the above mentioned statements?
Heat Shields for Lithium Batteries – a Basic Assumption

If this cell thermally ran away...

... a 1 mm thick heat shield had to make sure...

... that the neighbored cell will not be overheated

600 °C for 30 sec -> below 200 °C after 30 sec
The “Ideal” Heat Shield

- Efficiently blocks the heat transfer through the plane [at T-level >> 200 °C]
- It is neither brittle nor too rigid
- It is compressible (supporting dimensional changes of the cell)
- Stays in shape also when exposed to high temperatures
- Is not contributing to the decomposition reaction (e.g. fulfilling UL94 V0) => it does not contain organic matter
- Low additional volume & weight
Heat Shields – FST’s Approach

● Sheet material consisting basically of a thermally stable silicone-based rubber

● Material can resist 600 °C for short time waffle-structure for thermal insulation
  -> low contact area heat sheet to cell surface
  -> air pockets on cell surface

● Compressibility in order to compensate cell thickness variations

● Special material composition withstanding & absorbing the thermal load

“Waffle” structure to generate an insulating “air space” between cell surface & heat shield
Heat Shields – Test Bench

- Heat shields for **e-mobility batteries**
- Different silicone-based materials and geometries
- Heating plate temperature: 600 °C
- Three thermocouples on back side
- Monitor temperature vs. time
- Postmortem analysis of heat shield (600 °C / 3 min)

**Place sample**

**Place measuring unit**

**Test duration: 3 min**

**Evaluation**
Heat Shields – Test Results – Material Influence

- Original target could be fulfilled
- Samples are still elastic after test, not brittle and do not break under mechanical stress

Design AND material development know-how necessary to obtain a suitable product!
Heat Shields – Test Results vs. Thickness

Reduction of thickness increases the backside temperature

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Temperature in °C

Time in s

Heat Shields

Test Results vs. Thickness

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- Heat Shields
- Test Results vs. Thickness
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Safety Approach
Emergency Cooling Concept
Emergency Cooling Concept

Basic Idea:

- Use pressurized CO$_2$ – the medium of future mobile air conditioning systems – for emergency cooling
- When a cell becomes overheated, CO$_2$ can expand through a nozzle to rapidly cool-down the cell
- Prevention of a thermal runaway
- Concept has been proven in lab scale [cooperation with ZSW, Ulm*]

Details see:
H. Döring, B. Emmermacher, P. Kritzer
Advances in Chemical Engineering and Science, 2014, 4, 197-207
Emergency Cooling Concept

Stack of 4 Pouch Cells
4 Ah per cell
3 cells charged to 50%
1 cell charged to 100%
Module charged with 16 A

CO₂ dozing nozzle
Reduction & Avoidance of Oxygen
Avoid Oxygen in the Battery System!

Luftzutritt erhöht die Wärmefreisetzung um einen Faktor zwischen 3 und 4.

- FST’s DIAvent integrates pressure regulating and overpressure release (> 40 l/sec @ 50 mbar)

- Battery System overpressure vent with a reversible valve function – no bursting disk

- Valve closes after release of thermal runaway exhaust gas

- Entrance of air from outside occurs only slowly
  (-> through the pressure regulating section)

Fast removal of the exhaust gases
Limited re-entrance of oxygen from outside

Details see:
C. Schäfer, C. Kleinke, P. Kritzer
eMobilityTec 04/2017; 48-5
And How about an *Inert Gas Battery System*?

- No gas exchange between battery and environment
- But:
  Sealed battery housings would require thick walls -> No option!
Pressure Compensation Element / Basic Idea

- Approach of a compensation element creating a **variable isolated volume**
- Battery housing and the variable volume to contain an inert gas (e.g. N$_2$, CO$_2$)

![Diagram of pressure compensation element with labeled parts: INERT GAS, Variable volume, Spring activation, Low-friction sealed piston.](image-url)
Pressure *Compensation Element / Implementation Concept*

- Inert Gas
  => No additional oxidation after thermal runaway

- No contamination / water vapour can enter battery during normal operation

- Thus, no condensate formation inside the housing

- Enabler for a maintenance-free solution

- Integration of overpressure function possible
Pressure *Compensation* Element / Implementation Concept

- The element could be implemented in the battery housing structure
- Thus, intelligent usage of existing dead volumes
## Freudenberg’s Safety Components for Lithium Batteries - Summary

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**Freudenberg SEALING TECHNOLOGIES**

**FREUDENBERG INNOVATING TOGETHER**
Summary

- Freudenberg is a world-wide key supplier of sealing components both for automotive and industrial industries
- With our long-term battery experience, we have the system know-how to actively support our customers & partners
- Regarding battery safety, we offer a variety of components
- Thereby, different mode of actions in the battery system are considered
- We are looking for a close cooperation with our partners!

Thanks a lot & keep your SoH!