Lithium-ion cell safety improvement with reduced pressure

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Summary
- Preventing Li-ion cell fire and cell explosion with reduced pressure
- Increase of Li-ion cell safety

Motivation
- Enhancing the cell safety of Li-ion batteries
- Exploring the removal of highly flammable electrolyte solvent and gaseous products during thermal runaway
- Reducing fire hazard after cell accident
- Evaluation of the technique in terms of explosion prevention

State of the art

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<th>Before thermal runaway</th>
<th>During/after thermal runaway</th>
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<td>Use of electrolyte additives (redox shuttle, fire-inhibitors), liquid electrolyte solvents and gel polymer electrolytes</td>
<td>Pressure relief valve</td>
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<td>Solid-state electrolytes</td>
<td>Use of heat-absorbing material around the cell</td>
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<td>Use of safer separators (ceramic coated)</td>
<td>Cell and battery cooling system</td>
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<td>Electronic devices (battery management system)</td>
<td>Stable cell casing</td>
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Novel concept
- Adapting cell to reduced pressure unit
- Overcharging the Li-ion cell
- Overcharging the pouch bag cell
- Applying of reduced pressure at the crucial moment of thermal runaway (strong swelling of the cell)
- Remove of the hot gaseous products and solvents from the electrode material
- 88 mAh pouch bag cell (NMC, graphite, 850 µl EC/DMC + 1M LiPF₆ electrolyte, ceramic coated separator) is equipped with tube to vacuum pump or suction unit (manually connectable)
- Overcharging the Li-ion cell with current rate of 5C
- Applying of reduced pressure at the crucial moment of thermal runaway (strong swelling of the cell)
- Remove of the hot gaseous products and solvents from the electrode material

Pouch bag cells after thermal runaway (under reduced pressure)
- All cells remain tightly close and exhibit a cell voltage of 0 V in contrast to Li-ion reference cell without protection
- The electrode foils are dry and the electrode material can easily be detached from the current collector foils (Cu and Al)
- Electrolyte solvents and gaseous products are removed during thermal runaway experiments under reduced pressure
- Formation of gaseous products approx. 0.15 l due to the electrolyte amount
- Strong heat is produced in all cases, but without fire or explosion (see cells after thermal runaway below)
- The outer plastic coating of the pouch bag foil melts and becomes colored due to the heat formation
- Temperature of the outer pouch-bag foil (above electrode sheets) during overcharging increases to >150 °C
- Vacuum pump as well as suction unit both are appropriate to remove the gaseous products reliably
- Increase of cell safety due to the removal of highly combustible solvents and decomposition products inside of the cell
- Technique can be combined with other methods to improve the cell safety (electrolyte, separator, cell casing, etc.)

Possible adaption to larger cells
- Electrolyte amount in 20 Ah cell: approx. 80 ml
- This gives rise to ~120 dm³ gaseous products during thermal runaway
- Gaseous products could be removed via suction unit
- Cell opening pressure can be adjusted by aluminum sealing
- Several single pouch bag cells are enclosed inside a container equipped with a rupture disk which is connected to the suction unit
- In case of a thermal runaway accident, temperature sensors can be used to turn on the suction unit

Conclusions
- Prevention of cell explosion in 88 mAh pouch bag cells (cell remains close)
- Highly volatile and combustible electrolyte solvents are removed under reduced pressure
- Oxygen getting formed during thermal runaway is also removed from the cell
- Strong heat formation without explosion of fire

Outlook
- Quantification of the heat flow during thermal runaway
- Quantification of the mass reduction of highly volatile electrolyte
- Test of the findings in larger cells

References
- Hofmann et al., “Preventing Li-ion cell explosion during thermal runaway by reduced pressure”, Appl. Thermal Eng., under revision.

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