THT UK
Thermal Hazard Technology
1 North House, Bond Avenue
Bletchley, Milton Keynes MK1 1SW
United Kingdom
Phone: +44 1908 646800 Fax: +44 1908 645209

THT INC
Thermal Hazard Technology
49 Boone Village # 130
Zionsville, IN 46077
USA
Phone: 001 317 222 1904 Fax: 001 317 660 2092

THT CHINA
Thermal Hazard Technology
Rm 1115, 775 Long, No 1 Si Ping Road
Shanghai 200092
P.R. China
Phone: 0086 21 58362582 Fax:0086 21 58362581

THT INDIA
Thermal Hazard Technology
I-2/100,SECTOR-16, Rohini
DELHI-110085
India
Phone: 0091 9560655656

E-mail: info@thermalhazardtechnology.com Web: www.thermalhazardtechnology.com

Papers citing use of THT ARC

Battery Papers

2017

Preventing Li-ion cell explosion during thermal runaway with reduced pressure
Applied Thermal Engineering 124 (2017) 539–544

Andreas Hofmann, Nils Uhlmann , Carlos Ziebert, Olivia Wiegand, Alexander Schmidt,Thomas Hanemann
Karlsruher Institut für Technologie (KIT), Institut für Angewandte Materialien – Werkstoffkunde (IAM-WK), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Abstract
Concerning Li-ion cells it is demonstrated by overcharging tests both on the shelf in a fume-hood and in an accelerating rate calorimeter that the application of reduced pressure in the moment of a thermal runaway accident can prevent a fire and in particular a cell explosion, caused by the electrolyte. Within the experiment, pouch-bag Li-ion cells (88 mAh and 264 mAh) composed of graphite and NMC (LiNi1/3Mn1/3Co1/3O2) were overcharged by 10 C in order to induce a thermal runaway. In spite of a strong temperature increase, the cell remains tightly close during the thermal runaway without any fire or explosion in case of vacuum application.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S1359431116333609

Roles of positive or negative electrodes in the thermal runaway of lithium-ion batteries: Accelerating rate calorimetry analyses with an all-inclusive microcell
Electrochemistry Communications: In Press, Accepted Manuscript

Takao Inoue, Kazuhiko Mukai
Toyota Central Research & Development Laboratories, Inc., 41-1 Yokomichi, Nagakute, Aichi 480-1192, Japan

Abstract
To improve the thermal stability of lithium-ion batteries (LIBs) at elevated temperatures, the roles of positive or negative electrode materials in thermal runaway should be clarified. In this paper, we performed accelerating rare calorimetry analyses on two types of LIBs by using an all-inclusive microcell (AIM) method, where the AIM consists of all LIB components. We found that the thermal runaway in LiNi0.8Co0.15Al0.05O2 (NCA)|LiPF6 dissolved in ethylene carbonate (EC)/diethyl carbonate solution (DEC) (EC/DEC = 1/1 by volume); LiPF6(EC/DEC)|artificial graphite (AG) and LiNi1/3Co1/3Mn1/3O2 (NCM)|LiPF6(EC/DEC)|AG cells is brought about by different electrodes, i.e., NCA for the former, and AG for the latter. The above difference is attributed to the different oxidation temperature of the EC/DEC solvents, indicating that we first pay attention which electrodes govern the thermal runaway. Trials for improving the thermal stability of NCA are also reported.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S1388248117300401

Correlation of aging and thermal stability of commercial 18650-type lithium ion batteries
Journal of Power Sources: 342 (2017) 382-392

M. Börnera, A. Friesena, M. Grützkea, Y.P. Stenzela, G. Brunklausa, J. Haetgea, S. Nowaka, F.M. Schappachera, , , M. Wintera, b, c
a University of Münster, MEET Battery Research Center, 48149 Münster, Germany
b University of Münster, Institute of Physical Chemistry, 48149 Münster, Germany
c Helmholtz Institute Münster, Forschungszentrum Jülich GmbH, 48149 Münster, Germany

Abstract
Established safety of lithium ion batteries is key for the vast diversity of applications. The influence of aging on the thermal stability of individual cell components and complete cells is of particular interest. Commercial 18650-type lithium ion batteries

based on $LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$/C are investigated after cycling at different temperatures. The variations in the electrochemical performance are mainly attributed to aging effects on the anode side considering the formation of an effective solid-electrolyte interphase (SEI) during cycling at 45 °C and a thick decomposition layer on the anode surface at 20 °C. The thermal stability of the anodes is investigated including the analysis of the evolving gases which confirmed the severe degradation of the electrolyte and active material during cycling at 20 °C. In addition, the presence of metallic lithium deposits could strongly affect the thermal stability. Thermal safety tests using quasi-adiabatic conditions show variations in the cells response to elevated temperatures according to the state-of-charge, i.e. a reduced reactivity in the discharged state. Furthermore, it is revealed that the onset of exothermic reactions correlates with the thermal stability of the SEI, while the thermal runaway is mainly attributed to the decomposition of the cathode and the subsequent reactions with the electrolyte.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775316317347

Effects of rest time after Li plating on safety behavior—ARC tests with commercial high-energy 18650 Li-ion cells
Electrochimica Acta 230 (2017) 454-460
Thomas Waldmann, , Margret Wohlfahrt-Mehrens
ZSW – Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Helmholtzstrasse 8, D-89081 Ulm, Germany
Abstract
During charging at low temperatures, metallic Lithium can be deposited on the surface of graphite anodes of Li-ion cells. This Li plating does not only lead to fast capacity fade, it can also impair the safety behavior. The present study observes the effect of rest periods between Li plating and subsequent accelerated rate calorimetry (ARC) tests. As an example, commercial 3.25 Ah 18650-type cells with graphite anodes and NCA cathodes are cycled at 0 °C to provoke Li plating. It is found that the rest period at 25 °C between Li plating and the ARC tests has a significant influence on the onset temperature of exothermic reactions (T_{SH}), the onset temperature of thermal runaway (T_{TR}), the maximum temperature, the self-heating rate, and on damage patterns of 18650 cells. The results are discussed in terms of chemical intercalation of Li plating into adjacent graphite particles during the rest period. The exponential increase of capacity recovery and T_{SH} as a function of time suggests a reaction of 1st order for the relaxation process.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0013468617302979

2016

Impact of cycling at low temperatures on the safety behavior of 18650-type lithium ion cells: Combined study of mechanical and thermal abuse testing accompanied by post-mortem analysis
Journal of Power Sources 334 (2016) 1–11
Alex Friesen , Fabian Horsthemke, Xaver Mönnighoff, Gunther Brunklaus,
Roman Krafft , Markus Börner , Tim Risthaus , Martin Winter, Falko M. Schappacher
MEET Battery Research Center, University of Muenster, Corrensstraße 46, 48149 Muenster, Germany
Abstract
The impact of cycling at low temperatures on the thermal and mechanical abuse behavior of commercial 18650-type lithium ion cells was compared to fresh cells. Post-mortem analyses revealed a deposition of high surface area lithium (HSAL) metal on the graphite surface accompanied by severe electrolyte decomposition. Heat wait search (HWS) tests in an accelerating rate calorimeter (ARC) were performed to investigate the thermal abuse behavior of aged and fresh cells under quasi-adiabatic conditions, showing a strong shift of the onset temperature for exothermic reactions. HSAL deposition promotes the reduction of the carbonate based electrolyte due to the high reactivity of lithium metal with high surface area, leading to a thermally induced decomposition of the electrolyte to produce volatile gaseous products. Nail penetration tests showed a change in the thermal runaway (TR) behavior affected by the decomposition reaction. This study indicates a greater thermal hazard for LIB cells at higher SOC and experiencing aging at low temperature.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775316313106

Thermal behavior and failure mechanism of lithium ion cells during overcharge under adiabatic conditions

Applied Energy 182 (2016) 464–474
Jiana Ye [a,d], Haodong Chen [a], Qingsong Wanga,[b,c] , Peifeng Huang [a], Jinhua Sun [a,b], Siuming Lo [d]
[a] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230026, PR China
[b] Collaborative Innovation Center for Urban Public Safety, Hefei 230026, Anhui Province, PR China
[c] CAS Key Laboratory of Materials for Energy Conversion, University of Science and Technology of China, Hefei 230026, PR China
[d] Department of Architecture and Civil Engineering, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, China
Abstract
Cells in battery packs are easily overcharged when battery management system (BMS) is out of order, causing thermal runaway. However, the traditional calorimetry could not estimate dynamic overcharging heat release. In this study, commercial LiCoO2 + Li(Ni0.5Co0.2Mn0.3)O2/C + SiOx cells are employed to investigate the dynamic thermal behaviors during overcharge under adiabatic condition by combining a multichannel battery cycler with an accelerating rate calorimeter. The results indicate that overcharging with galvanostatic - potentiostatic - galvanostatic regime is more dangerous than that with galvanostatic way. Side reactions contribute 80% heat to thermal runaway in cases below 1.0 C charging rate. To prevent the thermal runaway, the effective methods should be taken within 2 min to cool down the batteries as soon as the cells pass inflection point voltage. Hereinto, the inflection and maximum voltages increase linearly with the increasing current rates. By scanning electron microscope and energy dispersive spectrometer, the decomposed products of cathode materials are suspected to be soluble with SiOx. The overcharge induced decomposition reaction of Li(Ni0.5Co0.2Mn0.3)O2 is also proposed. These results can provide support for the safety designs of lithium ion batteries and BMS.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0306261916312247

Heat loss distribution: Impedance and thermal loss analyses in LiFePO4/graphite 18650 electrochemical cell

Journal of Power Sources 328 (2016) 413–42
Manikandan Balasundaram, Vishwanathan Ramar, Christopher Yap, Lu Li, Andrew A.O. Tay, Palani Balaya,
Department of Mechanical Engineering, National University of Singapore, 117576, Singapore
We report here thermal behaviour and various components of heat loss of 18650-type LiFePO4/graphite cell at different testing conditions. In this regard, the total heat generated during charging and discharging processes at various current rates (C) has been quantified in an Accelerating Rate Calorimeter experiment. Irreversible heat generation, which depends on applied current and internal cell resistance, is measured under corresponding charge/discharge conditions using intermittent pulse techniques. On the other hand, reversible heat generation which depends on entropy changes of the electrode materials during the cell reaction is measured from the determination of entropic coefficient at various states of charge/discharge. The contributions of irreversible and reversible heat generation to the total heat generation at both high and low current rates are evaluated. At every state of charge/discharge, the nature of the cell reaction is found to be either exothermic or endothermic which is especially evident at low C rates. In addition, electrochemical impedance spectroscopy measurements are performed on above 18650 cells at various states of charge to determine the components of internal resistance. The findings from the impedance and thermal loss analysis are helpful for understanding the favourable states of charge/discharge for battery operation, and designing better thermal management systems.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775316310448

Energy distributions exhibited during thermal runaway of commercial lithium ion batteries used for human spaceflight applications

Journal of Power Sources Volume 329 (2016) 197–206
Sandeep Yayathia, William Walker [a, b], Daniel Doughty[c], Haleh Ardebili[b]
a NASA Johnson Space Center, 2101 NASA Road 1, Houston, TX 77058, USA
b University of Houston, 4800 Calhoun Road, Houston, TX 77004, USA
c Battery Safety Consulting Inc., 139 Big Horn Ridge Drive NE, Albuquerque, NM 87122, USA
Lithium ion (Li-ion) batteries provide low mass and energy dense solutions necessary for space exploration, but thermal related safety concerns impede the utilization of Li-ion technology for human applications. Experimental characterization of thermal runaway energy release with accelerated rate calorimetry supports safer thermal management systems. 'Standard' accelerated rate calorimetry setup provides means to measure the addition of energy exhibited through the body of a Li-ion cell. This study considers the total energy generated during thermal runaway as distributions between cell body and hot gases via inclusion of a unique secondary enclosure inside the calorimeter; this closed system not only contains the cell body and gaseous species, but also captures energy release associated with rapid heat transfer to the system unobserved by measurements taken on the cell

body. Experiments include Boston Power Swing 5300, Samsung 18650-26F and MoliCel 18650-J Li-ion cells at varied states-of-charge. An inverse relationship between state-of-charge and onset temperature is observed. Energy contained in the cell body and gaseous species are successfully characterized; gaseous energy is minimal. Significant additional energy is measured with the heating of the secondary enclosure. Improved calorimeter apparatus including a secondary enclosure provides essential capability to measuring total energy release distributions during thermal runaway.
Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775316310874

Computational fluid dynamic and thermal analysis of Lithium-ion battery pack with air cooling

Applied Energy 177 (2016) 783–792

Lip Huat Saw a, Yonghuang Ye c,⇑, Andrew A.O. Tay b, Wen Tong Chong d, Seng How Kuan a, Ming Chian Yewa
a Lee Kong Chian Faculty of Engineering and Science, UTAR, Kajang 43000, Malaysia
b Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, 117576, Singapore
c Electric Vehicle Cell, Contemporary Amperex Techology Co. Limited, Fujian 352106, China
d Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603, Malaysia
A battery pack is produced by connecting the cells in series and/or in parallel to provide the necessary power for electric vehicles (EVs). Those parameters affecting cost and reliability of the EVs, including cycle life, capacity, durability and warranty are highly dependent on the thermal management system. In this work, computational fluid dynamic analysis is performed to investigate the air cooling system for a 38,120 cell battery pack. The battery pack contained 24 pieces of 38,120 cells, copper bus bars, intake and exhaust plenum and holding plates with venting holes. Heat generated by the cell during charging is measured using an accelerating rate calorimeter. Thermal performances of the battery pack were analyzed with various mass flow rates of cooling air using steady state simulation. The correlation between Nu number and Re number were deduced from the numerical modeling results and compared with literature. Additionally, an experimental testing of the battery pack at different charging rates is conducted to validate the correlation. This method provides a simple way to estimate thermal performance of the battery pack when the battery pack is large and full transient simulation is not viable.
Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0306261916307279

Performance assessment and optimization of a heat pipe thermal management system for fast charging lithium ion battery packs

International Journal of Heat and Mass Transfer 92 (2016) 893–903

Yonghuang Ye a, Yixiang Shi b, Lip Huat Saw a,c, Andrew A.O. Tay a,⇑
a Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore
b Key Laboratory for Thermal Science and Power Engineering of Ministry of Education, Department of Thermal Engineering, Tsinghua University, Beijing 100084, China
c Department of Mechanical and Materials Engineering, University Tunku Abdul Rahman, Kajang 43000, Malaysia
Thermal management system is critical for the electric vehicles and hybrid electric vehicles. This is due to the narrow operating temperature range for lithium ion batteries to achieve a good balance between performance and life. In this study, heat pipes are incorporated into a thermal management system for prismatic or pouch cells. Design optimizations focusing on increasing the cooling capacity and improving temperature uniformity of the system are undertaken through sensitivity studies. Subsequently, empirical study is carried out to assess the thermal performance of the optimized design integrated with prismatic cells at the unit level and the battery pack level. The results confirm that the optimized heat pipe thermal management system is feasible and effective for fast charging lithium ion battery packs. A delay quench cooling strategy is also proposed to enhance the performance of the thermal management system.
Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0017931015009825

The simulation on thermal stability of LiNi0.5Mn1.5O4/C electrochemical systems

Journal of Power Sources 302 (2016) 1-6

Kai Yang, Xuesheng Liu*, Lili Lu, Songrui Wang, Pan Liu
National Key Laboratory of Science and Technology on Power Sources, Tianjin Institute of Power Sources, Tianjin, 300384, China
A thermal model of LiNi0.5Mn1.5O4/C electrochemical system has been developed. The thermal model is based on the thermal characteristic and related calculation for full charged LiNi0.5Mn1.5O4 and full discharged carbon materials, respectively. According to simulations on the thermal stability of LiNi0.5Mn1.5O4/C electrochemical system, there is one exothermic process for the full charged LiNi0.5Mn1.5O4 and two for the full discharged carbon. The first exothermic reaction for carbon material should be the best explanation for the initially self-heating of LiNi0.5Mn1.5O4/C electrochemical system. It is the reactions between LiNi0.5Mn1.5O4 and the electrolyte that make the LiNi0.5Mn1.5O4/C cell going into thermal runway. The simulated

result shows a good consistency with the testing result, so this simulation method can provide a significant basis for the thermal and safety design of batteries.
Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S037877531530433X

Thermal hazards and kinetic analysis of salicyl hydroxamic acid under isothermal and adiabatic conditions Thermochimica Acta 623 (2016) 43–49

Gui-bin Lu, Cai-xing Zhang, Wang-hua Chen∗, Li-ping Chen, Yi-shan ZhouDepartment of Safety Engineering, School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing 210094 Jiangsu, Chinaa
Kinetic study and thermal hazards analysis on the thermal decomposition of salicyl hydroxamic acid(SHA) was carried out using differential scanning calorimetry (DSC). The isothermal and dynamic dif-ferential scanning calorimetric curves were recorded, respectively. The temperature dependence ofthe observed induction periods suggests an autocatalytic decomposition mechanism, which was sup-ported by the conversion-reduced time plots. The differential and integral isoconversional methodswere used to obtain the kinetic parameters. The decomposition mechanism model of the first peak wasf(˛) = ˛1.49(1 − ˛)1.59. Moreover, the isothermal temperature induction period were studied to obtain theactivation energy, which was close to that obtained by the isoconversional integral method. The adia-batic accelerating calorimetry (ARC) was also employed to evaluate the thermal hazards. The adiabaticactivation parameters were also obtained based on the autocatalytic reaction model
Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0040603115004384

2015

Novel Ethylene Carbonate Based Electrolyte Mixtures for Li-Ion Batteries with Improved Safety Characteristics
ChemSusChem 8 (2015) 1892-1900

A. Hofmann[*], M. Migeot, E. Thißen, M. Schulz, R. Heinzmann, S. Indris, Th. Bergfeldt, B. Lei, C. Ziebert, Th. Hanemann

In this study, novel electrolyte mixtures for Li-ion cells are presented with highly improved safety features. The electrolyte formulations are composed of ethylene carbonate/dimethyl sulfone (80:20 wt/wt) as the solvent mixture and $LiBF_4$, lithium bis(trifluoromethanesulfonyl)azanide, and lithiumbis(oxalato)-borate as the conducting salts. Initially, the electrolytes are characterized with regard to their physical properties, their lithium transport properties, and their electrochemical stability. The key advantages of the electrolytes are high flash points of > 140 °C, which enhance significantly the intrinsic safety of Li-ion cells containing these electrolytes. This has been quantified by measurements in an accelerating rate calorimeter. By using the newly developed electrolytes, which are liquid down to T = -10 °C, it is possible to achieve C-rates of up to 1.5 C with > 80% of the initial specific capacity. During 100 cycles in cell tests (graphite||$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$), it is proven that the retention of the specific capacity is > 98% of the third discharge cycle with dependence on the conducting salt. The best electrolyte mixture yields a capacity retention of > 96% after 200 cycles in coin cells.

Link to purchase paper: http://onlinelibrary.wiley.com/doi/10.1002/cssc.201500263/epdf

Thermal runaway propagation model for designing a safer battery pack with 25 Ah LiNixCoyMnzO2 large format lithium ion battery

Xuning Feng a, Xiangming He b, Minggao Ouyang a,⇑, Languang Lu a, Peng Wuc, Christian Kulp c,
Stefan Prasser c
a State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
b Institute of Nuclear and New Energy Technology, Tsinghua
c BMW China Services Ltd., Beijing 100027, China
Abstract
Thermal runaway (TR) propagation in a large format lithium ion battery pack can cause disastrous consequences and thus deserves study on preventing it. A lumped thermal model that can predict and help prevent TR propagation in a battery module using 25 Ah LiNixCoyMnzO2 large format lithium ion batteries has been built in this paper. The TR propagation model consists of 6 fully-charged single batteries connected through thermal resistances and can fit experiment data well. The modeling analysis focuses on discussing the influences on the TR propagation process caused by changes in different critical modelling parameters. The modeling analysis suggests possible solutions to postpone and prevent TR propagation. The simulation shows that it might be better to choose proper parameters that help prevent TR propagation rather than just postpone it, because a delay in the TR

propagation process leads to a higher level of heat gathering which may cause severer thermal hazards. To prevent TR propagation, the model provides some substantial quantified solutions: (1) raise the TR triggering temperature to higher than 469 _C; (2) reduce the total electric energy released during massive internal short circuit to 75% or less of its original value; (3) enhance the heat dissipation by increasing the heat dissipation coefficient to higher than 70Wm_2 K_1; (4) add extra thermal resistant layers between adjacent batteries with a thickness of 1 mm and a thermal conductivity less than 0.2Wm_1 K_1. One implementation, which is verified by experiment, is to insert thermal resistant layer between adjacent batteries to prevent TR propagation in the battery module.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0306261915005814

Interaction of cyclic ageing at high-rate and low temperatures and safety in lithium-ion batteries
Journal of Power Sources 274 (2015)

Meike Fleischhammer*, Thomas Waldmann, Gunther Bisle, Bjeorn-Ingo Hogg, Margret Wohlfahrt-Mehrens
ZSW Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Helmholtzstrasse 8, D-89081 Ulm, Germany

Abstract
The differences in the safety behaviour between un-aged and aged high-power 18650 lithium-ion cells were investigated at the cell and material level by Accelerating Rate Calorimetry (ARC) and Simultaneous Thermal Analysis (STA). Commercial cells containing a $Li_xNi_{1/3}Mn_{1/3}Co_{1/3}O_2/Li_yMn_2O_4$ blend cathode, a carbon/graphite anode and a PP/PE/PP trilayer separator were aged by high-rate and low temperature cycling, leading to (i) mechanical deformation of the jelly roll and (ii) lithium plating on the anode. The results show a strong influence of the ageing history on the safety behaviour. While cycling at high current does not have a strong influence on the cell safety, lithium plating leads to a significant increase of heat formation during thermal runaway and thus to a higher hazard of safety.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S037877531401489X

2014

Heat evolution and temperature increase in lithium ion cells studied by combined electrochemical-calorimetric measurements on lithium ion cells
CEEES Conference Environmental Testing and Safety of Batteries and Fuel Cells, Pfinztal, Germany, 18-09-2014

Magnus Rohde*, Boxia Lei, Carlos Ziebert, Andreas Melcher, Hans Jürgen Seifert
Karlsruhe Institute of Technology, Institute for Applied Materials - IAM-AWP, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

The performance of a lithium ion cell is strongly related to the temperature. Therefore it is important to understand the process of heat generation and dissipation inside a single cell but also in battery packs since this is also closely coupled to safety issues. In this study, commercial 18650 lithium ion cells with $LiMn_2O_4$ cathodes as well as 20 Ah pouch cells with $LiFePO_4$ cathodes were tested under isoperibolic and adiabatic conditions in an accelerating rate calorimeter (THT Company) to investigate the heat effects during cycling. Isoperibolic investigations in the range from 25 to 60°C show that the applied environmental temperature does not largely influence the battery thermal behavior. At 1C rate the maximum temperature increase over three cycles was 4°C almost independent of the environmental temperature. Additionally, the heat capacity and calorimeter constant were measured after calibration using cylindrical dummy cells made of $AlMgSi_{0.5}$ with the cell dimensions. By integrating over the heat dissipation rate and the enthalpy accumulation rate the total generated heat was determined in dependence of discharge C-rate. Tests under adiabatic conditions, i.e. under negligible heat loss, more accurately simulate a battery pack where several cells are closely packed and the neighboring cells prevent the heat transfer to the ambient. The cell temperature was largely increasing at 1C rate over three cycles by more than 40°C rate before reaching the safety limit temperature of 75°C. This work presents also a short overview of some ECMs followed by a first implementation of an extended ECM with a simplified thermal model in Matlab®/Simulink®/Simscape™. The identification problem of the structure and the parameters of an ECM are discussed in terms of the Current Interruption Technique (CIT). In addition to the calorimetric measurements the distribution of the surface temperature was determined on the pouch cell during charging and discharging using a thermographic camera system (FLIR, X6540sc) which allows temperature measurements with spatial resolution. The resulting information from the IR images could be correlated to the results of measurements with the calorimeter. It could be also used to identify temperature gradients and "hot spots" on the surface of the cell.

Link to view paper:
https://www.researchgate.net/publication/272021037_Heat_evolution_and_temperature_increase_in_lithium_ion_cells_studied_by_combined_electrochemical-_calorimetric_measurements_on_lithium_ion_cells

Electro-thermal analysis and integration issues of lithium ion battery for electric vehicles
Applied Energy 131 (2014) 97–107

L.H. Saw, Y. Ye, A.A.O. Tay
Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, 117576 Singapore, Singapore

Abstract
Electrical and thermal characteristics of lithium-ion battery packs in electric vehicles in different operating conditions are important in order to design the battery pack thermal management system. In this work, electrical and thermal behaviors of different size of $LiFePO_4$ cylindrical cells are investigated under various operating conditions. The simulation results show good agreement with the experimental data under various operating modes. Due to the large thermal resistance of layered active material in a Li-ion cell, the temperature difference in the radial direction is significantly correlated with a diameter of cell and It-rates. Compared with natural convection, strong forced convection will reduce the temperature uniformity in the cell and accelerate the thermal aging rate. Lastly, integration issues of the cells into a battery pack are discussed from mechanical, electrical, thermal, control and monitoring, manufacturing and maintenance aspects. These issues could impact the performance, cost, driving range and life cycle of the battery pack in electric vehicles.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0306261914005984

Thermal and overcharge abuse analysis of a redox shuttle for overcharge protection of LiFePO4
Journal of Power Sources 247 (2014)

Joshua Lamb [a],*, Christopher J. Orendorff [a], Khalil Amine [b], Gregory Krumdick [b], Zhengcheng Zhang [b], Lu Zhang [b], Antoni S. Gozdz [c]
[a] Sandia National Laboratories, Albuquerque, NM, USA
[b] Argonne National Laboratory, Argonne, IL, USA
[c] A123 Systems, LLC, Waltham, MA, USA

Abstract
This work investigated the performance and abuse tolerance of cells protected using the redox shuttle 1,4-bis(2-methoxyethoxy)-2,5-di-tert-butylbenzene. The thermal efficiencies were evaluated using isothermal battery calorimetry. Cells containing the overcharge shuttle were observed to reach a steady state value of approximately 3.8 V, with a small variance in direct proportion to the applied current. In all cases the heat output from the cells was measured to reach ∼90% of the total input power. The heat output was also measured using isothermal calorimetry. At higher rates of overcharge, the data shows that the cell containing the shuttle rapidly reaches a steady state voltage, while the temperature increases until a moderately high steady state temperature is reached. The control cell meanwhile rapidly increases in both applied voltage and cell temperature until cell failure. Two cells in series were taken deliberately out of balance individually, then charged as a single pack to observe the time needed to bring the cells into balance with one another.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S037877531301392X

Thermal runaway features of large format prismatic lithium ion battery using extended volume accelerating rate Calorimetry
Journal of Power Sources 255 (2014)

Xuning Feng [a], Mou Fang [b], Xiangming He [a,b], Minggao Ouyang [a], Languang Lu [a],Hao Wang [b], Mingxuan Zhang [a]
[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China

Abstract
In this paper, the thermal runaway features of a 25 Ah large format prismatic lithium ion battery with $Li(Ni_xCo_yMn_z)O_2$ (NCM) cathode are evaluated using the extended volume-accelerating rate calorimetry (EV-ARC). 4 thermocouples are set at different positions of the battery. The temperature inside the battery is 870 °C or so, much higher than that outside the battery. The temperature difference is calculated from the recorded data. The temperature difference within the battery stays lower than 1 °C for 97% of the test period, while it rises to its highest, approximately 520 °C, when thermal runaway happens. The voltage of the battery is also measured during the test. It takes 15–40 s from the sharp drop of voltage to the instantaneous rise of temperature. Such a time interval is beneficial for early warning of the thermal runaway. Using a pulse charge/discharge profile, the internal resistance is derived from the quotient of the pulse voltage and the current during the ARC test. The internal resistance of the battery increases slowly from 20 mΩ to 60 mΩ before thermal runaway, while it rises to 370 mΩ when thermal runaway happens indicating the loss of the integrity of the separator or the battery swell.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775314000159

Simultaneous estimation of thermal parameters for large-format laminated lithium-ion batteries

Journal of Power Sources 259 (2014)

Jianbo Zhang, Bin Wu, Zhe Li*, Jun Huang
State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China

Abstract
In-situ determination of the battery thermal parameters is important to provide accurate inputs for battery thermal models. This paper develops a method to estimate the multiple thermal parameters of large-format laminated lithium-ion batteries both simultaneously and in-situ. The central area of one battery surface is heated with a circular planar heater, while the temperature responses on the opposite surface at multiple strategically-chosen locations are recorded with the attached thermocouples. This thermal system is modeled in COMSOL v4.2 using a two-dimensional axially-symmetric thermal conduction equation containing thermal parameters such as the thermal capacity, anisotropic thermal conductivities, and thermal interfacial conductance between the Al-plastic film package and the electrode core. Using optimization techniques, these thermal parameters are adjusted step by step till the difference between the simulated and the experimental temperature responses at the corresponding locations reaches a minimum. As one validation of the developed method, the estimated specific heat capacity agreed with the value measured with an accelerating rate calorimeter within 10%. The proposed method can be applied to simultaneously determine the thermal parameters of generic objects consisting of anisotropic internal materials and an outer packaging made of different material.

Link to Purchase Paper:: http://www.sciencedirect.com/science/article/pii/S0378775314002729

Characterization of large format lithium ion battery exposed to extremely high temperature

Journal of Power Sources 272 (2014)

Xuning Feng [a], [b], Jing Sun [b], Minggao Ouyang [a], Xiangming He [a], [c], Languang Lu [a],
Xuebing Han [a], Mou Fang [c], Huei Peng [d]
[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI 48109, USA
[c] Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing 100084, China
[d] Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109, USA

Abstract
This paper provides a study on the characterizations of large format lithium ion battery cells exposed to extreme high temperature but without thermal runaway. A unique test is set up: an extended volume-accelerating rate calorimetry (EV-ARC) test is terminated at a specific temperature before thermal runaway happens in the battery. The battery was cooled down after an EV-ARC test with early termination. The performances of the battery before and after the EV-ARC test are investigated in detail. The results show that (a) the melting point of the separator dictates the reusability of the 25 Ah NCM battery after a near-runaway event. The battery cannot be reused after being heated to 140 °C or higher because of the exponential rise in ohmic resistance; (b) a battery can lose up to 20% of its capacity after being heated to 120 °C just one time; (c) if a battery is cycled after a thermal event, its lost capacity may be recovered partially. Furthermore, the fading and recovery mechanisms are analyzed by incremental capacity analysis (ICA) and a prognostic/mechanistic model. Model analysis confirms that the capacity loss at

extremely high temperature is caused by the increase of the resistance, the loss of lithium ion (LLI) at the anode and the loss of active material (LAM) at the cathode.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775314013597

2013

Lithium-ion capacitors: Electrochemical performance and thermal behavior

Journal of Power Sources Volume 243, 1 December 2013, Pages 982–992

Patricia H. Smith[a],, Thanh N. Tran[a], Thomas L. Jiang [a], Jaesik Chung [b]*
[a] *Naval Surface Warfare Center, Carderock Division, 9500 MacArthur Blvd., West Bethesda, MD 20817-5000, USA*
[b] *PCTEST Engineering Laboratory, Inc., 9017 Mendenhall Ct., Columbia, MD 21045, USA*

Abstract
We report on the electrochemical performance of 500 F, 1100 F, and 2200 F lithium-ion capacitors containing carbonate-based electrolytes. First and second generation lithium-ion capacitors were cycled at temperatures ranging from −30 °C to 65 °C, with rates from 5 C to 200 C. Unlike acetonitrile-based electric double-layer capacitors, whose performance has been reported to be relatively insensitive to temperatures between −30 °C and 40 °C, lithium-ion capacitor performance degrades at low temperatures and displays characteristics typical of a lithium-ion battery. Three-electrode lithium-ion capacitor cycling tests revealed that reduced capacity at low temperatures is due to the polarization of the lithiated, negative electrode. The self-discharge of cells at the various temperatures was studied and compared to an electric double-layer capacitor and a lithium-ion battery cell. Lithium-ion capacitors and batteries were observed to have significantly lower self-discharge rates than electric double-layer capacitors. Accelerating rate calorimetry and differential scanning calorimetry were used to assess the thermal runaway behavior of full cells along with the thermal properties of the cell components. Our study showed that the thermal behavior of the lithium-ion capacitor is in between those of an electric double-layer capacitor and a lithium-ion battery.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0378775313010033

Thermal characterization of a high-power lithium-ion battery: Potentiometric and calorimetric measurement of entropy changes

Energy Volume 61, 1 November 2013, Pages 432–439

Akram Eddahech*, Olivier Briat, Jean-Michel Vinassa
Univ. Bordeaux, IMS, UMR 5218 CNRS, F-33400 Talence, France

Abstract
This paper focuses on the thermal behaviour of high-power lithium-ion cells during charge-discharge at several current rates. A series of tests are conducted using an accelerating rate calorimeter to promote an adiabatic environment. Cell heat capacity is identified and the overall heat generated is quantified. Cell entropy is measured, using both potentiometric and calorimetric methods. The part of reversible reaction in the overall thermal behaviour is determined during charge-discharge tests and compared to joule losses. The influence of the state-of-charge variation and the impact of charge-discharge current rate on battery heat generation are highlighted. Experimental results for two lithium-ion technologies are presented and discussed.

Link to Purchase Paper: http://www.sciencedirect.com/science/article/pii/S0360544213007792

Presentations citing use THT ARC

Battery Presentations

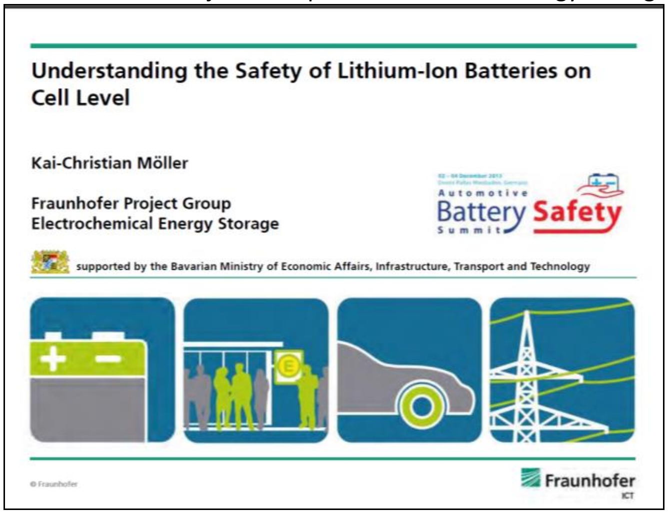
2013

Understanding the Safety of Lithium-Ion Batteries on Cell Level

Presented at Automotive Battery Safety Summit, Wiesbaden, Germany

Kai-Christian Möller

Fraunhofer ICT Project Group Electrochemical Energy Storage

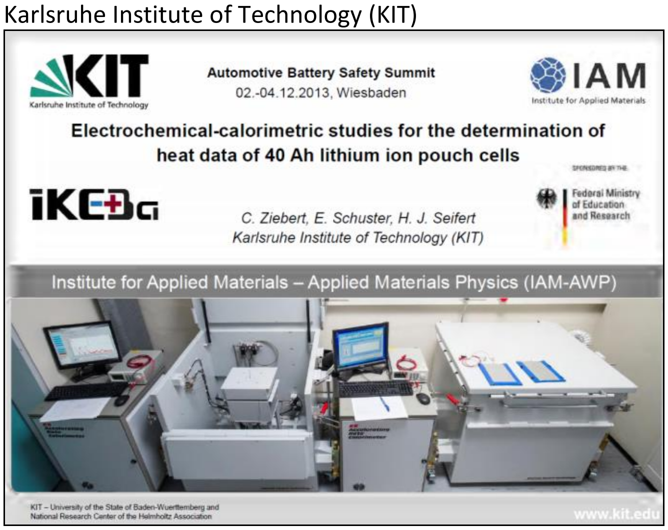


Electrochemical-calorimetric studies for the determination of heat data of 40 Ah lithium ion pouch cells

Presented at Automotive Battery Safety Summit, Wiesbaden, Germany

C. Ziebert, E. Schuster, H. J. Seifert

Karlsruhe Institute of Technology (KIT)



[***Multiscale electrochemical-thermal modeling of cylindrical Li-ion cells and comparison with electrochemical-calorimetric studies***]

Presented at 17th Topical Meeting of the International Society of Electrochemistry, St. Malo, France, 31.05-03.06.2015.

C. Ziebert, A. Melcher, B. Lei, A. Ossipova, M. Rohde, H.J. Seifert

Karlsruhe Institute of Technology, Institute for Applied Materials - IAM-AWP, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

[***Combination of electrochemical-calorimetric studies on cylindrical lithium ion cells and thermal modelling by COMSOL Multiphysics software***]

Presented at 225th ECS Meeting, Orlando, USA, 11.-16.05.2014.

C. Ziebert, A. Ossipova, M. Rohde, H.J. Seifert

Karlsruhe Institute of Technology, Institute for Applied Materials - IAM-AWP, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

[***Thermal runaway of lithium ion batteries***]

Presented at 7th Asian Conference on Electrochemical Power Sources (ACEPS ‐ 7), Osaka, Japan

Xiangming He

Tsinghua University