INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–10

Available online at www.sciencedirect.com

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Measurement of heat generation in a 40 Ah $LiFePO_4$ prismatic battery using accelerating rate calorimetry

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ARTICLE INFO

Article history:
Received 23 November 2017
Received in revised form
9 March 2018
Accepted 10 March 2018
Available online xxx

Keywords:
Lithium-ion battery
Large capacity
Heat generation
Accelerating rate calorimeter
Adiabatic condition

ABSTRACT

Accurate characterization of the heat generation behavior of a battery is crucial to a good design of its thermal management system. Concerning the thermal properties, much attention has been paid to small-sized batteries such as the 18650- or button-type and little information is available for large-capacity Li-ion prismatic cells under adiabatic conditions. In this work, heat generation of a commercial 40 Ah prismatic $LiFePO_4$/C battery is evaluated using an accelerating rate calorimeter under an adiabatic condition. The battery cell is charged or discharged at an initial temperature from −12.5 to 40 °C and a current rate from 0.2C to 2C. The experiment results show that heat generated in the battery is highly dependent on its operating temperature, state of charge and current rate. Internal resistance and entropy coefficient of the battery cell are also determined by the Hybrid Pulse Power Characterization method and potentiometric method, respectively. Relationship between the internal resistance and the heat generation behavior is highlighted. Entropy coefficient and volumetric heat generation rate of the battery cell obtained in this work are compared with those of other Li-ion batteries reported in literature.

Introduction

Air pollution, fossil fuel shortage and greenhouse effect are among the urgent issues in the world. Tests on the polluted air show that motor vehicle is one of the primary sources to greenhouse gases and a major contributor to the poor air quality [1–4]. To solve the problems related to automobiles, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicle (BEVs) and fuel cell vehicles (FCVs) are more and more popular due to their higher energy efficiency and lower emission in comparison with those conventional internal combustion vehicles [5–8].

The lithium ion battery is currently the first choice to those HEVs and BEVs as their power supply due to its high power density, long cycle life and favorable safety. However, these distinguishing features are significantly affected by the battery's temperature [9–14]. For instance, when working below 0 °C, usable capacity and output power of a Li-ion battery drop distinctly and in this case, the vehicle may fail to start [10,11]. When the operating temperature is high, cycle life of a Li-ion battery would decay apparently [13,14]. More importantly,

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https://doi.org/10.1016/j.ijhydene.2018.03.057
0360-3199/

when used as a vehicle power, hundreds or even thousands of cells have to be collected into pouches and under such circumstances, there would be poor temperature consistency among cells in a pouch. Since overall performances of a battery pack are decided by the weakest cell, the inconsistency among cells would result in decrease in capability and cycle life of the whole pack [15]. Therefore, a reliable thermal management system (TMS) that enables a battery pack to work in an ideal temperature range is vital and essential [5,9,16–20].

Designing an excellent TMS requires good understanding of the heat generation behaviors of power batteries. Thermal performances of Li-ion batteries have been investigated experimentally and numerically by many researchers [21–39]. These researches are mainly focused on small-scale batteries among which the 18650-type [24–26] and the button-type [27–29] are typical ones. With more and more applications in electric vehicle, Li-ion batteries are currently developing towards large capacity and high current rate. Articles on heat generation properties of large capacity batteries are seen in literature. In these researches, shape of the large type battery is mainly prismatic [30,31] and capacity generally falls in the range of 12 Ah–50 Ah. A. Eddahech et al. [32] evaluated a 12 Ah $LiMnNiCoO_2$ battery cell on its entropy changes through both potentiometric and calorimetric methods. A 20 Ah $LiFePO_4$ pouch battery was examined by K. Chen et al. [33] on its heat generation during discharge at current rates from 0.25C to 3C and temperatures from −10 to 40 °C using a custom-made calorimeter. S. Panchal et al. studied a 20 Ah $LiFePO_4$ prismatic battery on its surface temperatures influenced by current rates [34] and temperature distribution inside the cell by means of calculation using a neural network-based model [35]. Researches on larger capacity batteries were made by E. Schuster et al. [36] who presented quantitative data on the heat generation of commercial 40 Ah $LiNiCoMnO_2$ pouch cells at current rate form 5A–40A and by C. Veth et al. [37] who investigated a 50 Ah pouch type Li-ion cell on its thermal behavior during high current discharge processes. A. Nazari [38] studied heat generation in Li-ion batteries with different nominal capacities and electrode materials using modeling and simulation. The authors of this work also analyzed thermal performances of large size lithium ion prismatic cells both experimentally and numerically [39]. Calorimeter usually plays an important role in measurements of heat performances of batteries with various capacities and material systems [24–26,29,32,33,36,39]. Though there is some thermal data of large capacity batteries available in literature, more and accurate heat generation information are still demanding especially to prismatic batteries with large capacities which are widely used in electric vehicles as their power sources.

This work presents heat generation of a 40 Ah prismatic lithium ion phosphate battery under different conditions and influences of temperature, state of charge (SOC), current rate and charge/discharge states on heat generation rate of the battery. To further elucidate the possible reasons for the battery thermal behaviors, internal resistance and entropy coefficient of the battery cell are analyzed. Comparison between the heat generation rates of the target battery cell in this work and other Li-ion batteries reported in literature is also made. It is desired that this work is helpful to the design of the battery's TMS and improvement of the battery safety.

Experimental

Battery cell

The target battery with 100 mm in length, 32 mm in width and 180 mm in height in this work belongs to the $LiFePO_4$/C family. It is 40 Ah in capacity, 1.1384 kg in mass and 1.066 kJ kg^{-1} K^{-1} in specific heat capacity (measured using calorimetry [39]). Other parameters and detail description of the battery can be referred to Ref. [17,39].

Experimental setup

During the measurement of the battery heat generation, the battery was placed inside a calorimeter, and charged or discharged by a battery cycler. Valuable information of the external battery cycler (NEWARE BTS-20V100A, Shenzhen Neware Electronics Co., Ltd., China) is as follows: working voltage is in a range of 0.1 V–20 V, and working current in the range of 0.5 A–100 A; resolutions of these parameters are ±0.1% FS and ±0.1% FS, respectively. The calorimeter used in this work was an extended volume-accelerating rate calorimeter (EV^+-ARC), provided by the Thermal Hazard Technology®. The adiabatic mode can ensure that the chamber temperature of ARC is able to be controlled exactly the same as that of the battery and therefore an adiabatic environment in the chamber is created [39,40]. Images of the instrument [40] and its chamber in which a battery sample is suspended by a holder are shown in Fig. 1. In the chamber, the battery cell lay on its holder, two thin metal bars which were able to diminish the contact surface of the battery cell. The bottom of the sample holder was wrapped by high-temperature insulation tape to avoid thermal conduction between the battery and the chamber. Before measurement, a calibration test that the chamber had only the sample holder in it was done, and thus the holder's role can be eliminated from the sample's experiments.

It may be necessary to point out that battery heat generation was also measured using the EV^+-ARC device in a previous report by the authors [39]. During that measurement, the battery cell was sandwiched between two thin aluminum alloy clamps to avoid the cell ballooning under a high temperature environment. Between the clamp and the cell, there was a phenolic resin film which was expected to play a role of electric and thermal insulation. It is unavoidable for the clamps and the resin film bringing about errors to the battery heat generation measurement. In this work, there is no such clamp or film used, and thus the error is avoided. Precision degrees of each instrument used in this work are summarized in Table 1.

Experiment process

The ARC chamber temperature was adjusted to the set point by adding liquid N_2 when it was lower than the room