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Short communication

Thermal behavior of overcharged nickel/metal hydride batteries

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ABSTRACT

This work provides a two-dimensional thermal model for cylinder Ni/MH battery. Thermal model is developed to analyze the thermal behavior of the battery when charged and overcharged. Quantity of heat and heat generation rate of the battery during charge and overcharge period are studied by quartz frequency microcalorimeter. Heat generation curve is fitted into a function, and heat transport equation is solved. Analysis with the model and experiment show that temperature rise is about 3 °C and difference between the model and the experiment is no more than 0.1 °C.

1. Introduction

Electric vehicles (EV) and hybrid electric vehicles (HEV) are becoming more attractive because of growing demand for power sources. EV and HEV require the battery with high specific energy, high-rate capability, long cycle life, and low environmental impact as power storage device, which boosts development of battery technology. At present, most research concentrated on Ni/MH and lithium/polymer battery because the two kinds of batteries are green and have good performance. Their performances are both sensitive to temperature change, temperature rise even caused some safety problems of lithium/polymer. Therefore, Ni/MH battery is a popular choice for EV and HEV power storage device. In order to avoid potential problems caused by temperature rise, information about heat generation is required.

It is reasonable to develop a thermal model for the battery to analyze the impact on performance when temperature is rising owing to the necessity of a thermal management for the battery [1–3]. Several methods are used to simulate the battery behavior like computational fluid dynamics (CFD) and finite element methods (FEM) [4]. Bernadi et al. [5] have set up a general energy balance for battery systems with assumption of uniform heat generation. After that Chen and Evans [6,7] developed several two-dimensional and three-dimensional thermal models, and presented some calculation methods for model parameters. Shi et al. [8] studied rapid charging of spirally cylindrical nickel/metal hydride battery with thermal model. Sato et al. [9,10] examined many heat generation ways for electric vehicle battery and found that the battery's temperature rise was usually caused by heat generation due to electrochemical reactions and Joules effect. Wu et al. [11] validated the cooling effect of auxiliary cooling device with thermal model and showed the state of charge, open-circuit voltage, internal resistance, power and available energy changed with battery temperature rise. The mathematical simulation of heat transport in the battery has high efficiency and fairly low cost compared to laboratory experiments, moreover, the agreement between theoretical and experimental values was good in many earlier works.

Once the battery is overcharged, oxygen generated at positive electrode reacts with hydrogen at negative electrode, and considerable amount of reaction heat accompanies recombination. The working condition for the battery would be much worse if the battery were overcharged. As volume and weight in a vehicle are rather limited, the battery system has to be smaller in order to take up less space. Now that temperature is an important factor of the battery performance, the specific cooling device must be effective to avoid excessive temperature rise. We will discuss heat generation in both normal charge and extreme charge and develop a model for the whole process and discuss the model and the experiment results. We hope that some problems can be found like abnormal hot spots or areas to improve thermal management.

2. Experiments

The experiment uses cylindrical Ni/MH battery with spirally design, rating capacity of 8 Ah and actual capacity of 7.5 Ah after cycles. The battery includes electrodes, electrolyte and separator

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Table 1
Some parameters of tested battery

Parameters	Values
R, radius (m)	0.01609
H, height (m)	0.0605
M, mass (kg)	0.18909
V, volume (m^3)	0.000049205

and is assumed to be axial symmetric. Some details are in Table 1.

The tested battery is installed in a special device, which is designed to protect the battery from short circuit. During the experiment, a microcalorimeter with a quartz frequency thermometer is used to measure the surface temperature of the battery and the heat generation rate. The whole set is in the microcalorimeter, as shown in Fig. 1. All data are recorded by a PC.

The Ni/MH battery is charged to fixed SOC (State of Charge) in 1C rate first: 0, 30, 50, 70, 90, and 100%. Then the battery is charged in 1C, 3C, and 5C rate to 150% of its actual capacity. The charging process is controlled by an Arbin instrument, data are saved by the program on a PC.

3. Results and discussions

3.1. Experiment results

The quartz frequency thermometer shows the surface temperature rises after 1C, 3C, and 5C rate charge are 2.714, 2.883, and 2.826 °C. Heat generation rates are shown in Figs. 2–4. Curves in the three figures are charged in 1C, 3C and 5C rate from SOC of 0, 30, 50, 70, 90, and 100%, respectively. It seems that in a certain charge rate, a curve is moving to the left as SOC increasing from 0 to 100%.

During normal charge process, heat generation rate is slowly increasing. Joule heat plays an important role in this period. When the battery is overcharged, curves become much steeper. Heat generated during overcharging takes a great part of total heat generation.

The curves in each figure are quite similar, so other curves can be expressed by curve of SOC 0% through linear transform:

$$t_{SOC} = t_{0\%} - \frac{3600}{\text{rate}}\text{SOC}, \qquad \text{SOC} = 30,\ 50,\ 70,\ 90,\ 100\%,\quad \text{rate} = 1,\ 3,\ 5 \qquad (1)$$

where t_{SOC} denotes charging time of the battery in certain SOC; $t_{0\%}$ denotes charging time of the battery in SOC 0%. Therefore, test result of SOC 0% is chosen for curve fitting to get a function that describes the charge process. Others can be obtained by linear transform.

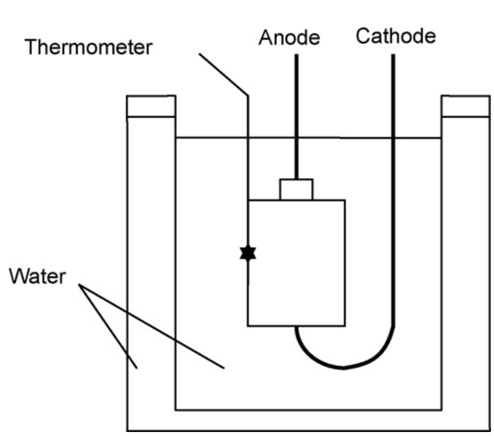

Fig. 1. Experiment device system. Each part of the device in which the tested battery is fixed is labeled.

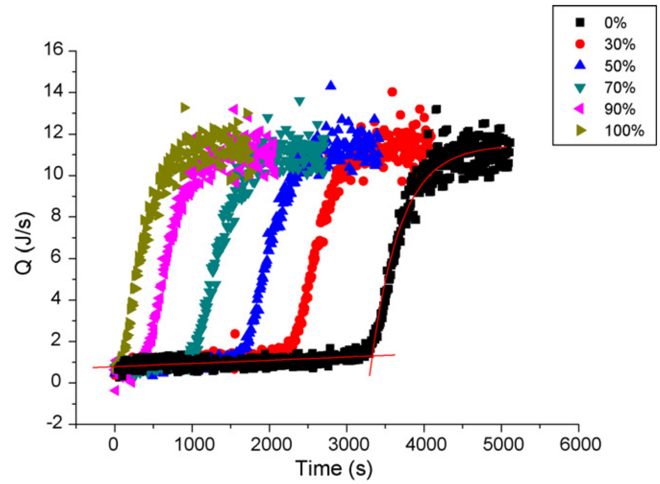

Fig. 2. Heat generation rate of 1C rate charge. Different curves from the right to the left denote SOC from 0 to 100%.

Heat generation becomes more seriously when charge rate increases. One reason is that the amount of heat generated by side reaction in overcharging period remains nearly the same because of the same starting and finishing SOC while time is much shorter. Another reason is heat generated by electrical resistance becomes considerable when the current goes up, which is known as $P = I^2R$ (P denotes power, I denotes current and R denotes internal resistance).

Each curve is divided into two sections to help us understand what happens through the process:

(1) Normal charging section, heat generation rate is slowly increasing. According to Refs. [8–10], the increase is caused by reaction heat and joule heat. In some cases, heat generation rate could be assumed constant, because the slope is small.
(2) Overcharge section, recombination whereby the generated oxygen and hydrogen return to water contributes to Q [10]:

$$2H + \frac{1}{2}O_2 \rightarrow H_2O, \quad -285.8\,\text{kJ}\,\text{mol}^{-1} \qquad (2)$$

In 1C and 3C rate charge, heat generation rate increase asymptotically with charging time. In 5C rate charge, charge time was

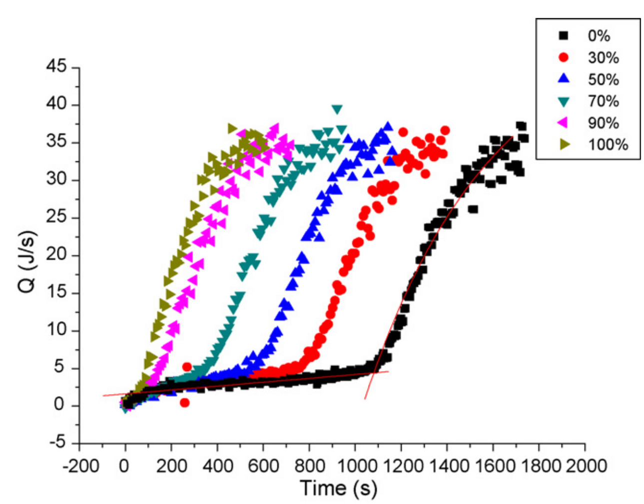

Fig. 3. Heat generation rate of 3C rate charge. Different curves from the right to the left denote SOC from 0 to 100%.