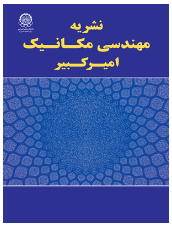

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Investigation of Temperature Distribution During Dynamic Stress Test on the Surface of Lithium-ion Battery used in an Electric Hybrid Vehicle

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ABSTRACT: There are two major challenges for today's world: urban air pollution and the concern that fossil fuels will end, which forces humans to replace fossil fuels sources with renewable energy sources; the automobile industry can have a key role in tackling of both challenges. To overcome these challenges, during the last decade, the development of electric vehicles has been on the agenda for the automotive industry. Lithium-ion rechargeable batteries play a vital role in these vehicles. The performance, safety and life of these batteries are very much affected by their operating temperature. In this study, with the help of experimental data, a lithium-ion battery cell is simulated using the ANSYS Fluent software via a two-potential model. The time variations of the voltage and maximum cell temperature along with the temperature distribution at four constant discharge rates of 2C, 3C, 7C, and 9C and the discharge profile of dynamic stress test -which is a special profile used for testing hybrid vehicles battery systems- are presented. The simulation results indicate that high temperatures as 45℃ are also experienced during the dynamic stress test. Such a temperature which could lead to a battery thermal runaway would be a hazard to the battery and electric vehicle.

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1- Introduction

In recent years, the electric vehicles, hybrid electric vehicles and fuel cell vehicles are commercializing to replace the conventional vehicles [1]. These vehicles have a battery as part of their energy storage. In this regard, lithium batteries are more important than other types of batteries due to their energy density and high power density. Nevertheless, these batteries are very sensitive to operating temperatures and need to be used at a specific temperature range. The high operating temperature of these batteries can directly reduce their service life and even create unbreakable combustion and fire. For this reason, researchers have conducted research on battery thermal management systems, and each has provided solutions for this purpose, and some of them are referred to below. In the air-cooled cooling thermal management system, Chen et al. [2] optimized the dimensions of the air-conducting channel on the batteries using a Computational Fluid Dynamics (CFD) model. In this regard, it can be noted that Lu et al. [3] pointed to the increase in the heat transfer rate between the batteries and the air by simulating the flow of air from the batteries at different rates of flow and different passageways, This results in a decrease in the maximum temperature of the batteries and an improvement in the temperature difference between the batteries. Qian et al. [4] examined the cooling system using a liquid passing through the mini-channels around the battery and, during the simulation of their numerical model, observed that the use of this method can keep the temperature of the batteries in the range of 300 to 312 Kelvin. Greco and Jiang [5] investigated the thermal and electrochemical attribute of a cylindrical lithium-ion battery and in the cooling system they have used composite phase change material, they found that the use of an inactive cooling system can create an appropriate uniform temperature uniformity in battery cells without energy consumption. Using the inactive cooling system, the use of a heat pipe by Zhao et al. [6] has been investigated experimentally. One of the major problems of the inactive thermal management systems is the lack of control in cooling process. To overcome this problem, hybrid cooling systems have been suggested to combine both active and inactive cooling methods. In this regard, we can mention the research by Rao et al. [7] who studied the combination of a cooling system of phase-change material and mini-channels to improve the cooling system of the battery. It should be noted, that the hybrid cooling systems have high power to control the temperature of the battery and the benefits of both active and inactive methods.

2- Numerical method

One of the best sub models to simulate the dynamic behavior of the battery is the NTGK model, which was designed based on the Newman Tiedemann, Gu and Kim research [8, 9]. Because of the heat generated in the battery, it depends on the voltage and current, so in the two-potential model, the two main Eqs. (1) and (2) are solved for the battery [8].

$$\frac{\partial \rho C_p T}{\partial T} - \nabla.(\mathrm{k}\nabla T) = \sigma_+\left|\nabla\phi_+\right|^2 + \sigma_-\left|\nabla\phi_+\right|^2 + \dot{q}_{ECh} + \dot{q}_{short} \qquad (1)$$

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$$\begin{aligned}\nabla.(\sigma_+\nabla\varphi_+) &= -(j_{ECh} - j_{short})\\ \nabla.(\sigma_-\nabla\varphi_-) &= j_{ECh} - j_{short}\end{aligned} \tag{2}$$

σ_+ and σ_-, effective electrical conductivity for positive and negative poles, φ_+ and φ_-, Phase potential for positive and negative poles, j_{ECh} and $\dot{q}_{Ech}$, respectively the discharge rate of the volumetric flow and the heat generated by the chemical reaction, j_{short} and $\dot{q}_{short}$ respectively the transmission of heat and flow is due to short circuit in the battery. It is necessary to mention that j_{ECh} and $\dot{q}_{Ech}$ can be calculated in different ways and $\dot{q}_{short}$, j_{short} typically is considered as zero. Because the short circuit does not normally occur within the battery. In the NTGK electrochemical model, the volumetric discharge rate can be calculated by Eq. (3) [10].

$$j_{ECh} = aY\left[U - (\varphi_+ - \varphi_-)\right] \tag{3}$$

In recent equation a is specific electrode area, Y and U

Are model parameters which are a function of the discharge depth. Eq. (4) is used to calculate the discharge depth.

$$DoD = \frac{Vol}{3600Q_{Ah}}\left(\int_0^t j\,dt\right) \tag{4}$$

Vol is volume of a battery, Q_{Ah} is the total capacity of the battery in Amps-hours. The parameters Y and U can be calculated by Eqs. (5) and (6).

$$Y = \left(\sum_{5}^{n=0} a_n\left(DoD\right)^n\right)\exp\left[C_1\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \tag{5}$$

$$U = \left(\sum_{5}^{n=0} b_n\left(DoD\right)^n\right) - C_2\left(T - T_{ref}\right) \tag{6}$$

where C1 and C2 are constant number on the NTGK model. After calculating j_{ECh} the heat produced by the electrochemical reaction can be calculated from Eq. (7).

3- Results and Discussion

In this section, first, temperature distribution on the cell surface will be monitored for a few fixed discharge rates, and then the temperature distribution will be presented during the dynamic stress test. It should be noted that in all discharges, the ambient temperature is considered to be 300 Kelvin. The below figure shows the maximum cell surface temperature during discharge with different rates. As shown in this figure, over time, the maximum cell temperature increases for all expansion rates, however, the slope of this increase has declined over time and generally tends to be constant. It can also be concluded from this figure that at discharge rates lower than 4C (1C is the discharge rate by which all the battery electrical charge is drained in 1 hr.), the increase in cell surface temperature is not appreciable. So that the maximum temperature of the surface with 1C rate has 1 Kelvin increase and with 3C rate has 8 Kelvin increase. In another view, it can be seen that the increase in discharge rate greater than 4C, the surface temperature rises sharply. So, at discharge rate of 9C, the maximum temperature reaches 337 Kelvin. This increase in temperature confirms the early deterioration of batteries during high discharge.

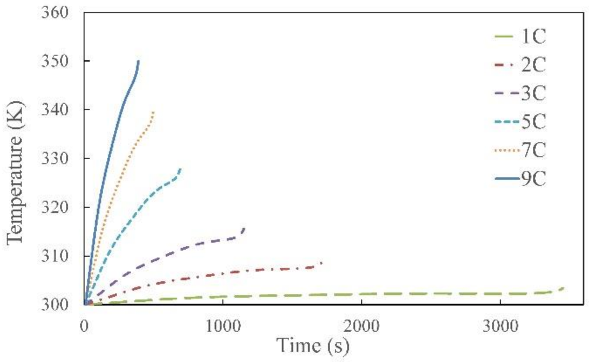

Fig. 1. Maximum cell surface temperature (in Kelvin) with different discharge rates

4- Conclusions

In this study, with the help of experimental data, a lithium-ion battery cell was simulated using the Ansys/Fluent software as a two-potential model and a sub-model of NTGK, And time variations of the voltage and maximum cell temperature along with the temperature distribution at four constant discharge rates 2C, 3C, 7C and 9C was presented, the discharge profile was variable with dynamic stress (hybrid vehicle battery special test. The results of this survey show that whatever the rate of battery discharge increases, the amount of heat generated in the battery will be higher and as mentioned earlier, one of the key factors in reducing battery life is the high heat buildup which causes the electrochemical processes in the battery to be damaged and thus reduce battery life. Therefore, it is recommended that, due to the physical and electrochemical nature of the battery, the discharge rate of the batteries should be 2C or 3C to prevent damage to the battery. Also, high temperatures such as 45 degrees Celsius are also observed during the dynamic stress test, which can lead to rapid and risky exhaustion. Thus, in order to prevent damage to the battery of a hybrid vehicle, it is imperative that an effective thermal management system be used.

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