THINK INDIA Journal

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Three-Dimensional CFD Study on Cell-Wise Heat Dissipation In Lithium-Ion Battery Module

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Abstract*:*
In this paper, a three-dimensional CFD study is presented for cell-to-cell heat generation in the battery module. The battery module is comprised of widely spaced cylindrical Li-ion cells. Large spacing is assumed for safer removal of cell reaction gases in modules.. The cell heat generation is computed based on the thermal model. The user-defined code is used to calculate heat generation in each cell, and it considers both heats generated due to electrochemical reaction and Joule or Ohmic heating. The battery module experiences a higher temperature on the upstream side as the fluid passes across each row of cells and absorb the battery heat. Throughout the discharging process, maximum battery temperature and cell temperature uniformity are found much lower than permissible range applicable for safe operation of Li-ion module

Introduction

Electric vehicles are employed with lithium-ion batteries. Among the various factors that affect lifespan of battery, cell temperature plays a significant role[1]–[4]. Due to requirement of acceleration uphill, electric vehicles demand higher power and draws at higher discharge rate [5-6].

Many studies have reported battery thermal management systems (BTMS) and emphasis safer operating temperature range 20° to 40° [7]. The extreme operational range can vary from -10° to 50°C [8]. The availability of air and its lightweight proved advantages for its use in BTMS. [9].

In the present work, the transient study of stacked Li-ion battery module subjected to forced air cooling have been reported considering cell- to- cell heat interaction. The cylindrical batteries are widely stacked in a module for greater air flow circulation. The three-dimensional model is simplified considering the complete pathway for flow of cooling air.

Li-ion Battery module

The battery system comprised of widely spaced 9 cylindrical Li-ion cells in inline arrangement (Fig.1). BTMS considered here is forced convection air cooled unit with two sides completely open respectively for inlet and outlet of air. The system size are 212 × 212 mm and a total height 123.9 mm considered allowing the sufficient spacing on top of the battery. Battery details along with thermal properties are given in Table 1.

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Vol-22-Issue-16-August-2019

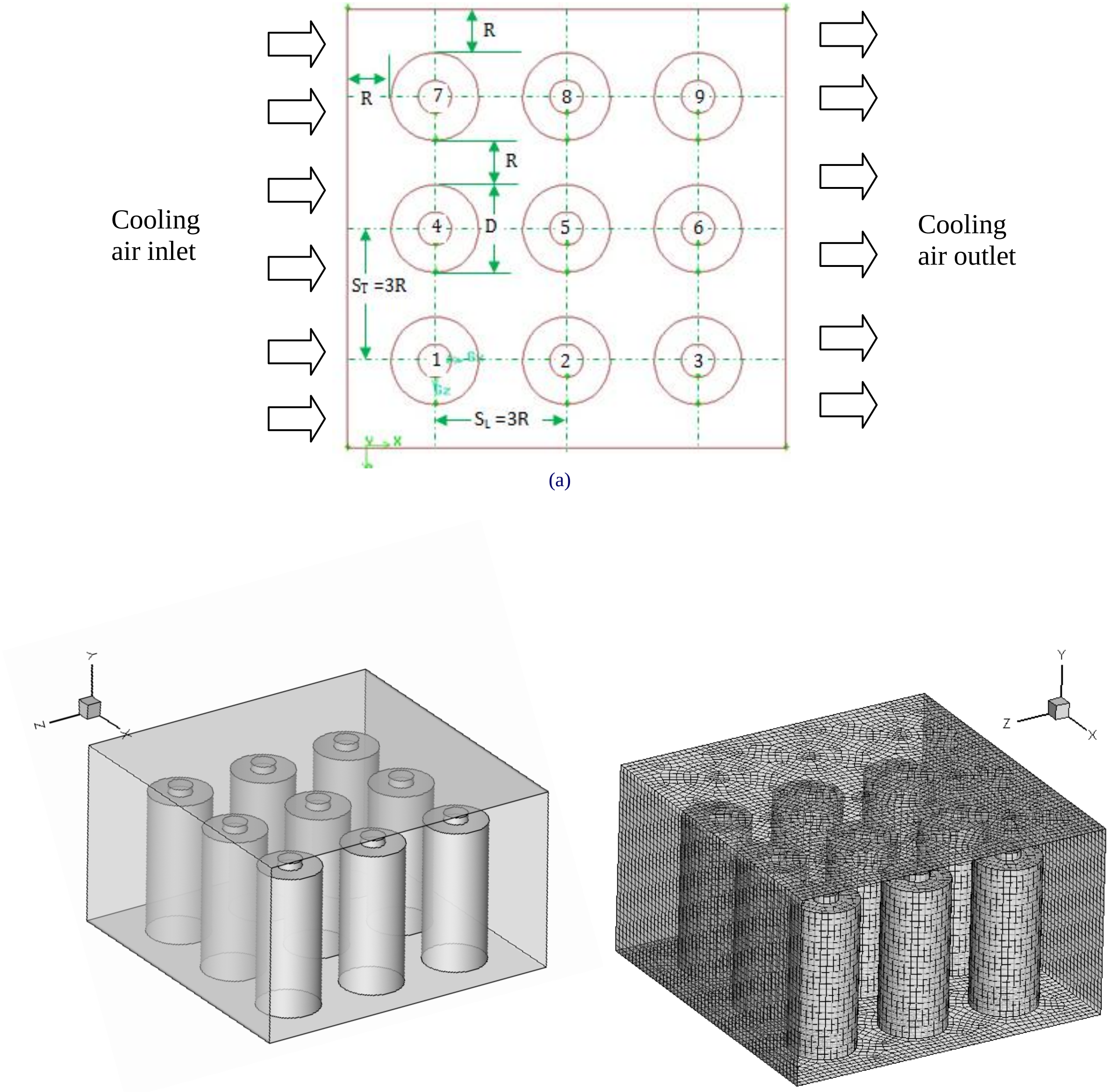

Fig. 1 Battery module (a) Li-ion battery module (b) Three-dimensional model (c) Meshing

Table 1 Battery specifications

Each cell capacity, Ah	3.6 Ah
Total cells used in module	9
cell diameter	42.4 mm
Cell length	97.7 mm
Density kg/m^3	2007.7
Thermal conductivity	3 W/mK
Specific heat	837.4 J/kgK

The heat generation (Q_g) in a cell is due to (i) electrochemical reactions generate entropic heat ($Q_{entropic}$) and (ii) internal electrical resistance(R) gives Ohmic heating (Q_{Ohmic})[1]

ISSN:0971-1260
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$$Q_g = Q_{entropic} + Q_{Ohmic} \qquad (1)$$

Joule or Ohmic heat can be computed by

$$Q_{ohmic} = I(E - E_{oc}) = I^2 R \qquad (2)$$

where I denotes the current, cell potential and open circuit potential are E and E_{oc} respectively. The internal electrical resistance of cell in terms of temperature [10] and can be expressed

$$R = -0.0001T^3 + 0.0134T^2 - 0.5345T + 12.407 \qquad (3)$$

where T is cell temperature in degree centigrade and R is in mOhms.

The entropic heat by [11]

$$Q_{entropic} = -IT\frac{dE_{OC}}{dT} \qquad (4)$$

A user-defined code is written based on Eq. (1)-(4) for providing heat generation source values during CFD simulation in the each cell

Result and Discussions

CFD simulations have been carried out for galvanostatic discharge at 6.94 C (25 Amp). To understand cell-cell-cell heat interaction of cell surface with the cooling media, plots of temperature contours are taken on six planes in longitudinal and transverse direction (Fig. 2). It can seen that cells in Row1 (cell index: 1, 4, 7) easily dissipates heat to incoming air and at lower temperature. The cells present in Row2 (cell index: 2, 5, 8) dissipates heat to warmer air surrounding as it pick up heat in flow direction heat with comparable hot air.

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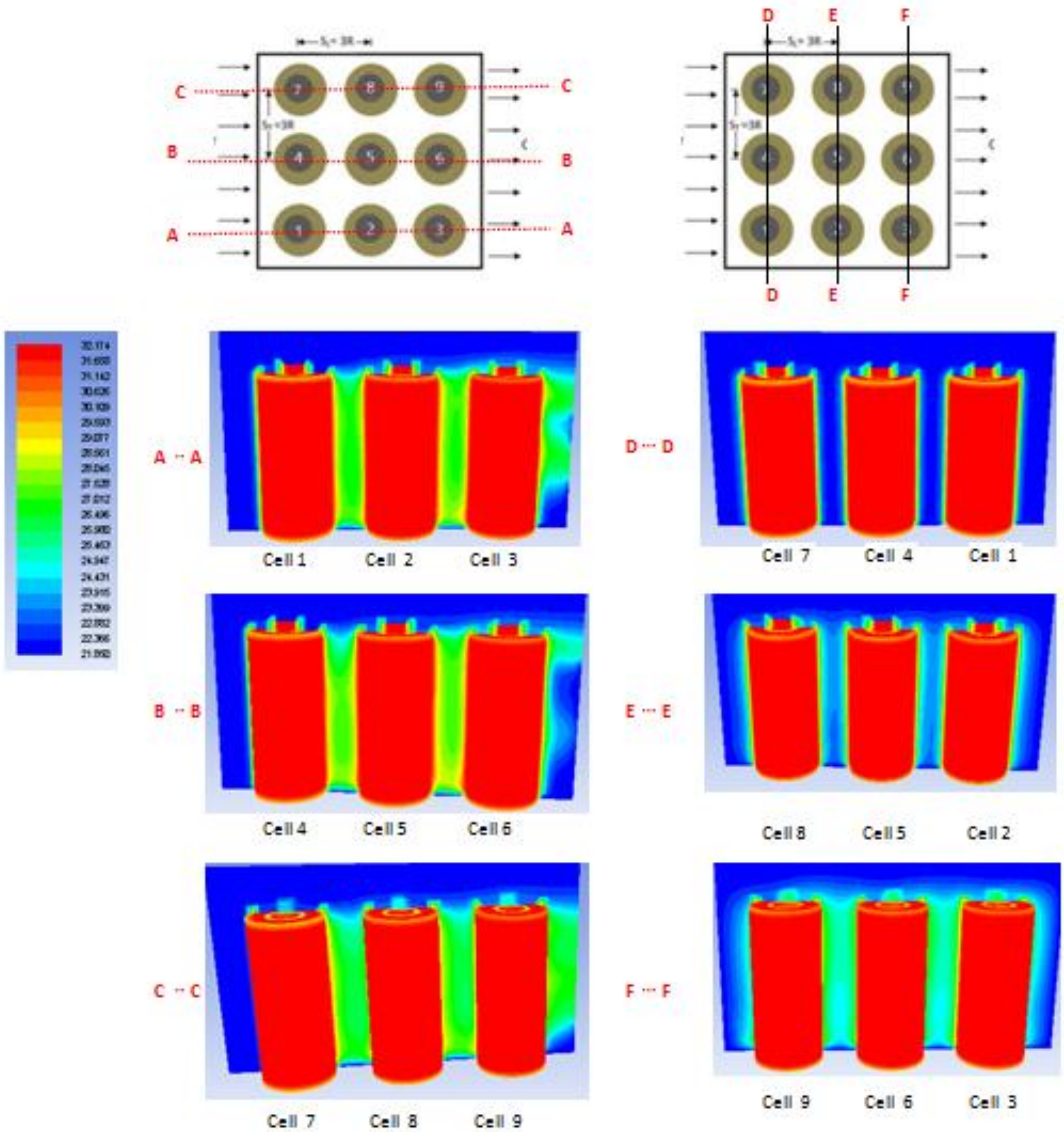

Fig. 2 The cooling media (air) temperature patterns inside battery module (v = 0.1 m/s, T_∞ = 22°C)

The transient response of cell temperature can be plotted based on volume- weighted average temperature of the cell. Figure 2 shows transient response of battery module along with cell-to-cell heat dissipation at a very low flow rate (v = 0.1m/s) and at moderate temperature (22°C). Initially complete battery module is at ambient condition. At a discharge time of 100 s, there is appreciable change in battery temperature. At this interval of time, maximum and minium cell temperature is 24.216°C and 24. to 24.204°C. Therefore maximum cell tempetaure difference in the entire battery module is restricted to 0.013 °C. As per the termporal progression, cell tempetaure increases with discarging process. It is observed that under this low flow condition (laminar Reynold number) battery temperature reaches highest permissible range. The flow physics involved in the module configurations shows lower battery temperature for cells present near the inlet of domain. It can be seen that throughout the discharging process, maximum battery temperature and cell temperature

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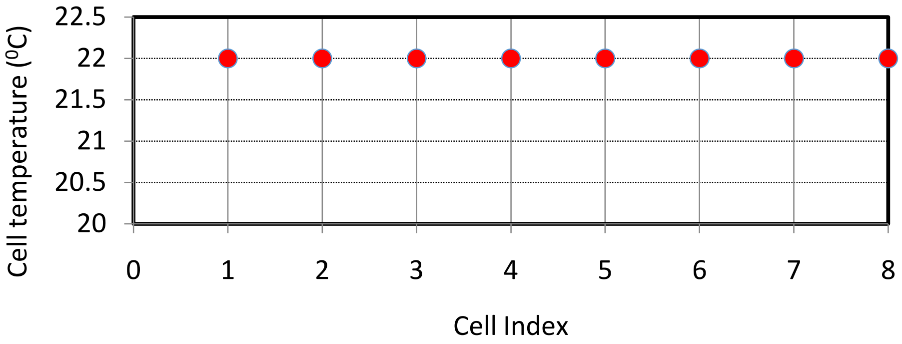
uniformity are much lower than permissible range applicable for safe operation of Li-ion module

<table>
<tr><th>Discharge time</th><th>Cell-wise temperature development in Li-ion battery module</th></tr>
<tr><td>0 s</td><td>
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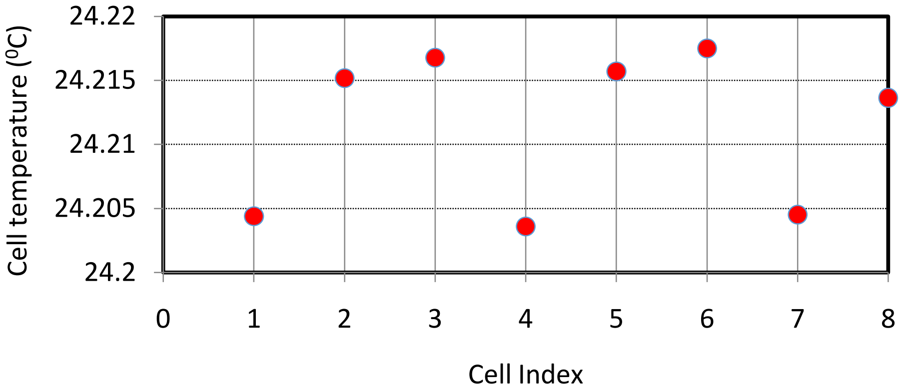
<tr><td>100 s</td><td>
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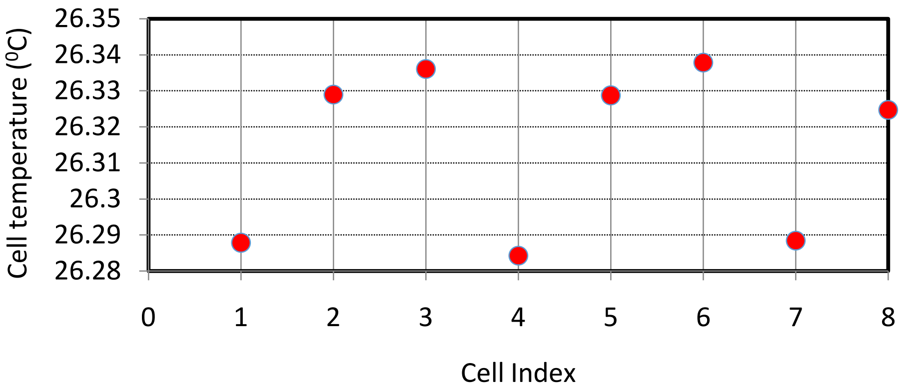
<tr><td>200 s</td><td>
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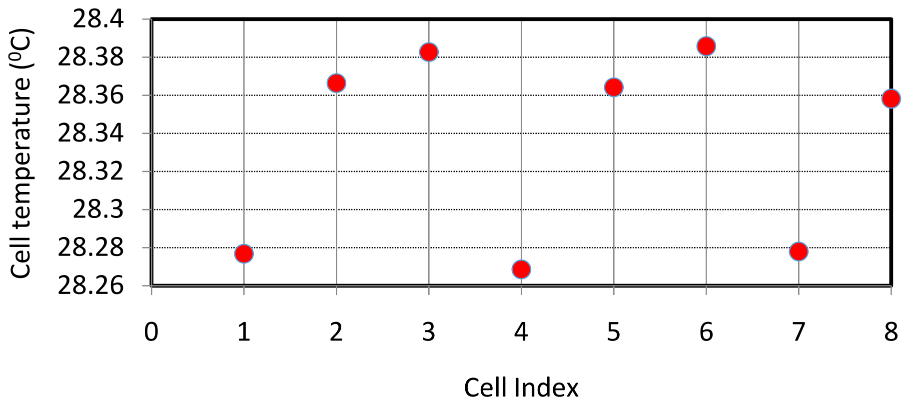
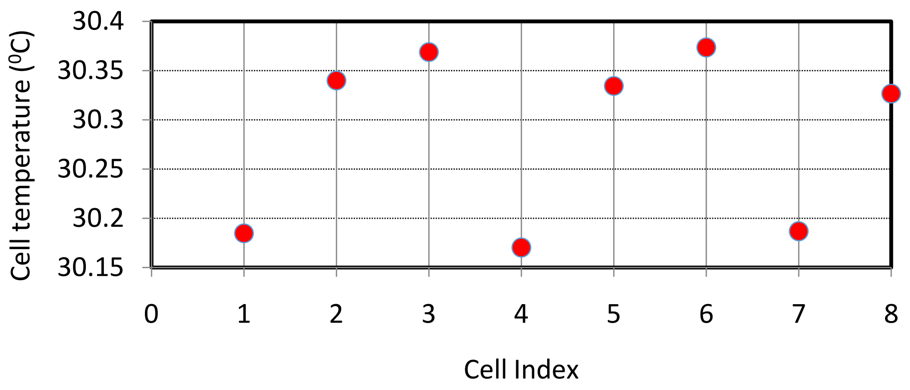
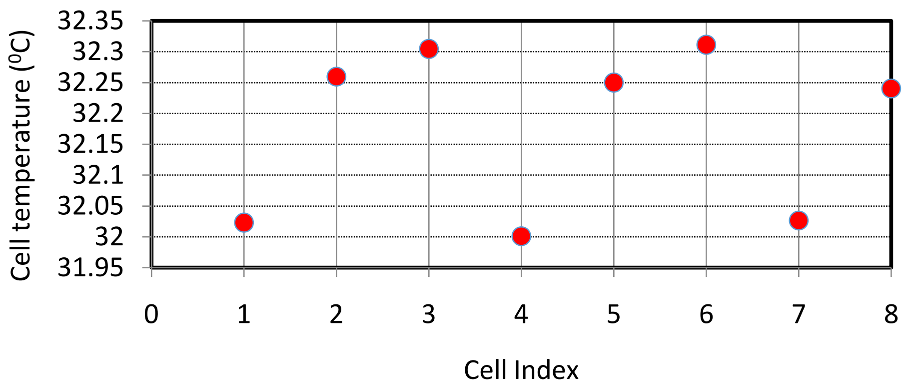
300 s	
400 s	
500 s	

Fig. 4 Temporal cell-wise temperature variation (air flow = 0.1 m/s, ambient air temperature = 22°C)

5. Conclusions

In this paper, three-dimensional CFD study is presented for cell-wise cooling in the battery module. The battery heat generation is computed based on the thermal model with user defined function (UDF). The computational results are well validated with the published correlation. The attainment of temperature in a module is directly depends its proximity to cooling air. The temperature of cells located at the second row of a module is about 0.25°C higher. It rises to ~ 0.35°C for cells present at the downstream side.

ISSN:0971-1260
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