Battery Thermal Management System (BTMS)

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Problem Definition

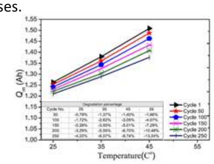
$$\dot{Q}_{gen} = \dot{Q}_{rev} + \dot{Q}_{irr} + \dot{Q}_{mix} \quad \begin{cases} \dot{Q}_{rev} = IT\frac{\partial(U_p - U_n)}{\partial T} \\ \dot{Q}_{irr} = I[V - (U_p - U_n)] = RI^2 \end{cases}$$

At higher temperatures:

- More power can be extracted from the battery.
- The cell's internal impedance decreases and its capacity increases.
- Increases the degradation rate.

At lower temperatures:

- Electrolyte may freeze.
- Decreases batteries' performance
- Impacts driving range and performance of vehicle .



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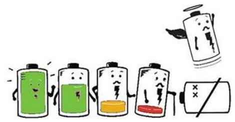
Objectives

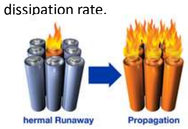
Thermal Management →
- Reliability
- Performance
- Safety
- Life-Cycle

The BTMS´s aims to prevent accelerated battery deterioration by managing the heat dissipation via the best strategy by considering the constrains and as a result, the cells operate continuously under optimum temperature range.

In addition, exposing the batteries to harsh condition can have fatal consequences. one of the main concerns in batteries is thermal runaway issue, which occurs when the rate of heat generation within the battery exceeds its heat dissipation rate.



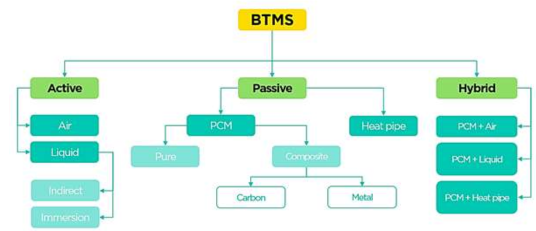
https://www.maxworldpower.com



https://www.batteryconsortium.sg

BTMS Methods

There is no one single option when picking a BTMS for a battery-pack, which are often divided into passive, active, and hybrid cooling techniques. An active system, which is typically utilized in liquid and air-cooling methods, uses energy to manage the temperature by employing some equipment like power pumps and fans. However, the passive cooling system does not use energy for thermal management such as PCMs or HPs. Active systems are more complicated but often more effective in dissipating heat. The leading thermal management technologies are illustrated in the following figure.



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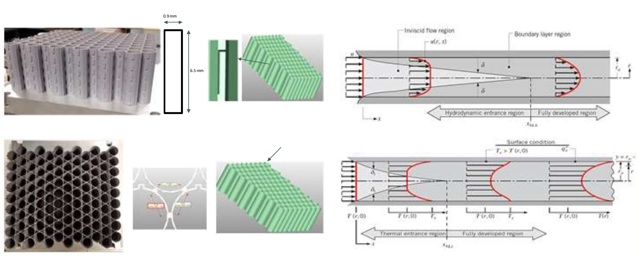
Heat Transfer & Pressure drop



- The Centre for Mechatronics and Hybrid Technology (CMHT) has been investigating on a thermal management system for a single cell and cylindrical lithium-ion battery pack to predict thermal response of pack's ducts under various conditions.
- This part of the research was focused on thermo-fluid analysis for two different ducts of the pack. In addition, temperature rise, maximum temperature, and temperature uniformity of the surface of a single cell were studied.

Internal Flow Analysis

$$\mathrm{Re} = \frac{VD_h}{\nu} \qquad \mathrm{Nu} = \frac{hD_h}{k}$$

hydraulic diameter
$D_h = 4\,A_c / p$
where
A_c : area section of the channel
p :perimeter of the channel

mean velocity
$V = \dot{m} / (\rho A_c)$
where
ρ : coolant density
$\dot{m}$: coolant mass flow rate

$$\Delta p^* = \frac{\Delta p}{\rho u_m^2 / 2g_c} = f_{app}\frac{x}{r_h} \qquad \mathrm{Gz} = \frac{D_H}{L}\mathrm{Re}\,\mathrm{Pr}$$

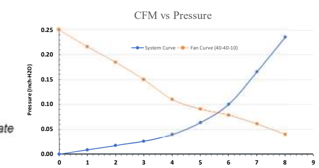


Figure 1. System curve vs fan curve for the cylindrical Li-ion battery pack.

Table 1. Analytical results for the rectangular channel.

Parameter	Value
Reynolds number (Re)	192.666
Hydraulic developing length (L_e)	0.015 [m]
Thermal developing length ($L_{e,th}$)	0.010 [m]
Aspect ratio of cross section ($\propto^*$)	0.138 [m]
Friction factor (f)	0.420
Dimensionless axial distance (X^+)	0.050 [m]
Nusselt number (Nu)	6.98
Heat transfer coefficient (h)	117.616 [W/m² °C]
Pressure drop (ΔP)	120.822 [Pa]

Table 2. Analytical results for the triangular channel.

Parameter	Value
Reynolds number (Re)	709.684
Hydraulic developing length (L_e)	0.203 [m]
Thermal developing length ($L_{e,th}$)	0.144 [m]
Dimensionless axial distance (X^*)	0.022 [m]
$1/X^*$	44.444
Dimensionless axial distance (X^+)	0.016 [m]
Nusselt number (Nu)	4.95
Heat transfer coefficient (h)	22.809 [W/m² °C]
Pressure drop (ΔP)	2.240 [Pa]

In this section, pressure drop magnitude has been found for the two different channels and by comparing the results, it is shown that using the triangular channel as cooling ducts are more reasonable due to lower pressure drop. Then by utilizing energy equation, the system curve was obtained for the battery pack. Subsequently, to find the best operational point for the fan, both the system cure and fan curve are plotted in the same graph to illustrate that. (Figure 1)

Lattice Structure

TPMS type structure was decided to be examined in designing and manufacturing of the battery pack (Figure 2). Therefore, by using the properties of TPMS-type lattice structure, all parameters for this investigation are calculated such as porosity, tortuosity, and permeability. Then obtained results were compared with simple duct to visualize the pressure drop differences at various velocities. Analytical results indicated that the pressure drop in the lattice structure is much more than in the simple duct(Table 3).

Lattice Type: TPMS

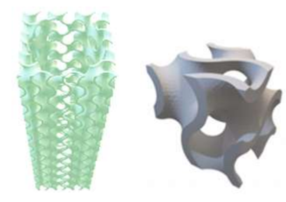


Figure 2. (a) Battery case with lattice structure method. (b) TPMS type lattice.

Table 3. Pressure drop comparison between the lattice structure and a simple duct..

V	Pressure drop [Pa]	
[m/s]	For Simple duct	Lattice Structure ε=0.92- 6.9 PPI
1.83	2.170	458.8
3.66	4.340	1555
5.49	6.509	3256
7.32	8.678	5552
9.15	10.848	8436
10.98	25.132	11906
12.80	41.509	15936
14.63	51.399	20568

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