Battery Thermal Management System (BTMS)

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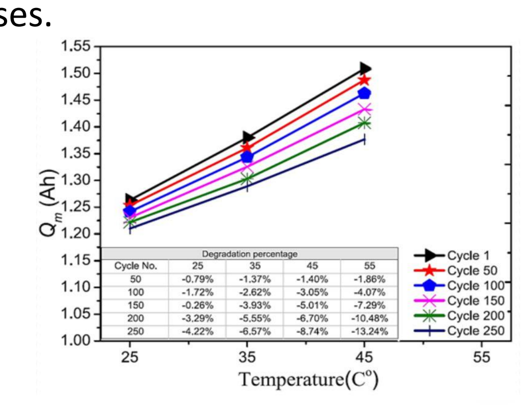
Problem Definition

Heat Generation in Batteries

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

At higher temperatures:

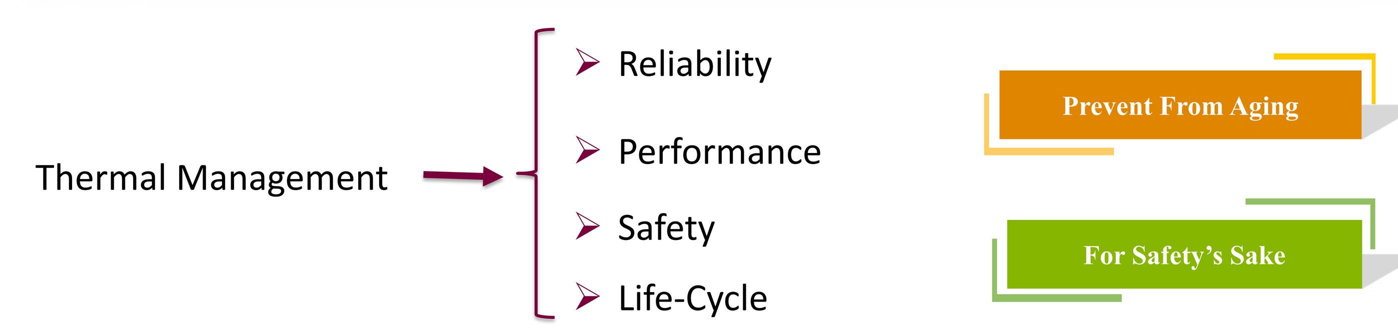
- More power can be extracted from the battery.
- The cell's internal impedance decreases and its capacity increases.
- Increases the degradation rate.



At lower temperatures:

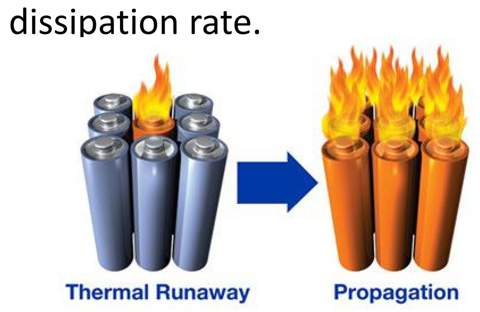
- Electrolyte may freeze.
- Decreases batteries' performance
- Impacts driving range and performance of vehicle .

Objectives



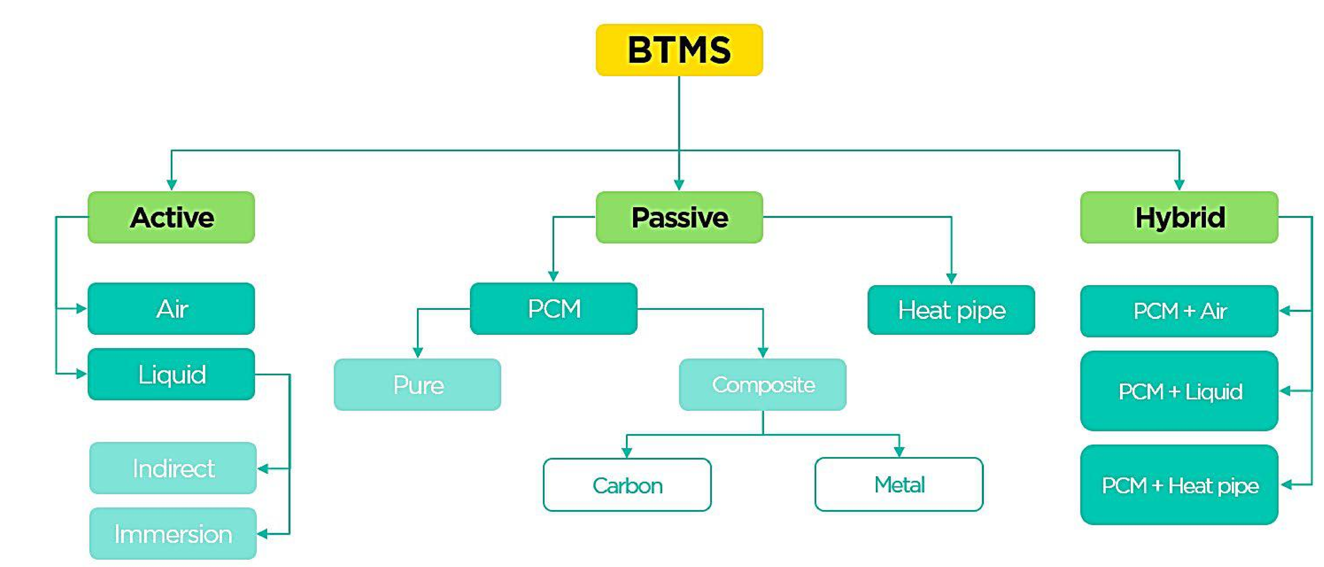
The BTMS´s aim is to prevent accelerated battery deterioration by managing the heat dissipation by the best strategy by considering the constrains and as a result, the cells operate continuously under optimum temperature range.

In addition, exposing the batteries to harsh conditions 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.



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.



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

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

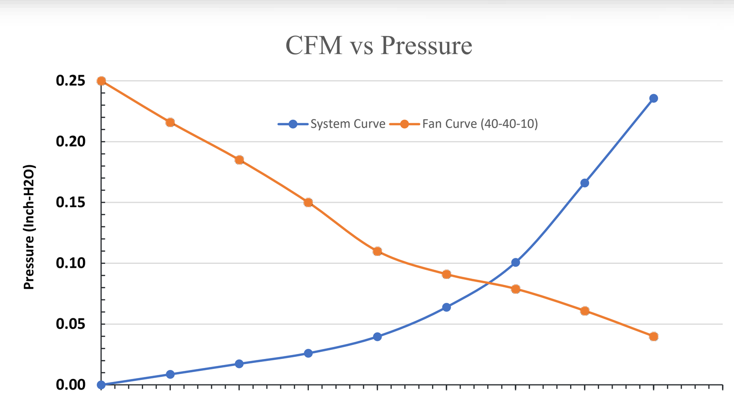


Figure 1. System curve vs fan curve for the cylindrical Li-ion battery pack.

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 (∝*)	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 ºC]
Pressure drop (ΔP)	120.822 [Pa]

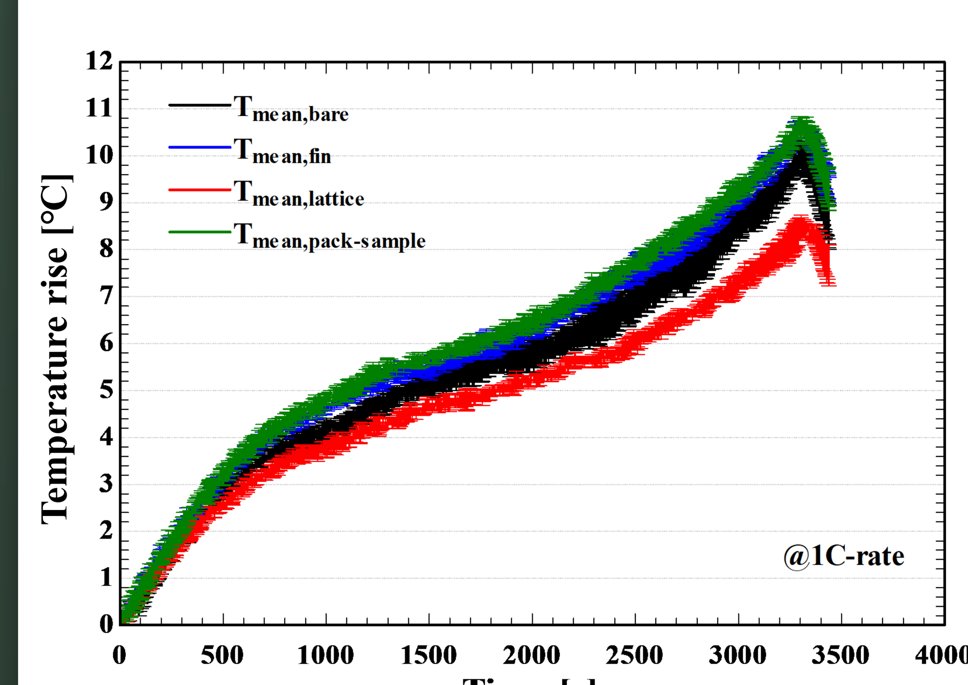
Table 2. Analytical results for the triangular channel.

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 ºC]
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)

Experimental Analysis (Single Cell)

Experimental investigations have been done on a single cell of a Lithium-ion cylindrical battery. This experiment aimed to analyze the thermal response of the cell under natural convection for different conditions to get an outlook over temperature rise, maximum temperature, and various structures' effects on heat dissipation. Obtained results indicated that there is no meaningful difference in temperature rise between the fin, pack sample, and bare cell structure. On the other hand, the lattice structure showed up to a 1.5℃ temperature drop at the end of the discharge process, which was not considerable enough for thermal management purposes.



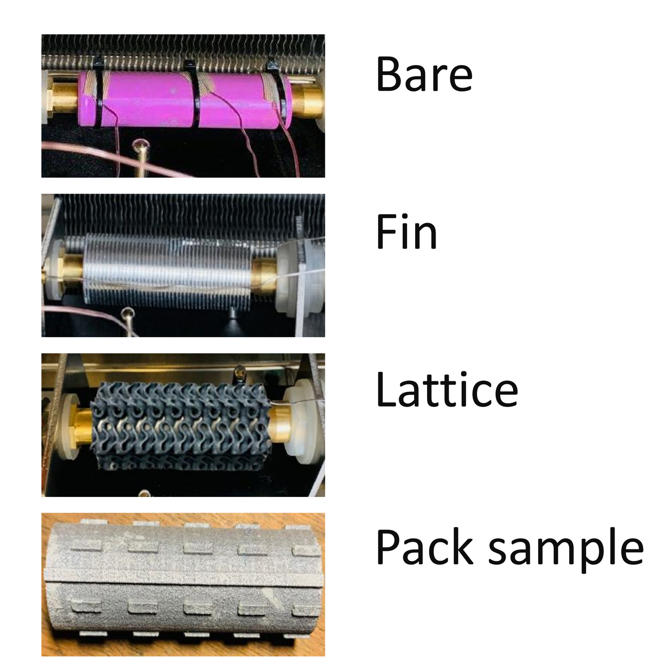
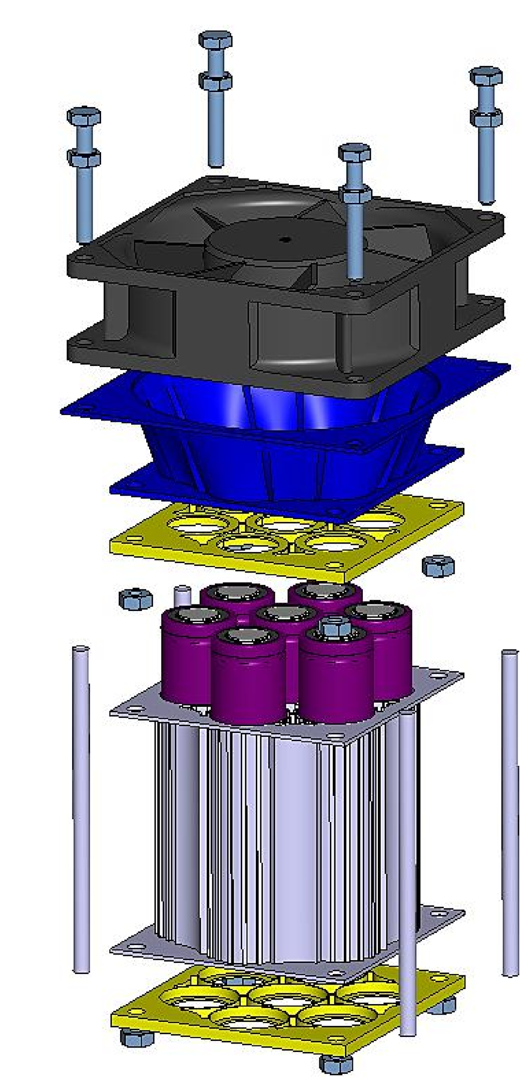


Figure 2. Temperature rise of a single lithium-ion cell under various conditions.

Module Design



The energy density of lithium-ion batteries can be increased by combining multiple cells together. However, it's important to ensure the working conditions of the cells to prevent overheating or thermal runaway. Investigating lithium-ion batteries under a module enables researchers to understand how individual cells behave under serious or parallel connections or even a combination of these. This knowledge is important for designing a safe and reliable battery pack for various applications. That is why a module of cylindrical lithium-ion batteries is designed to pursue experimental investigations under natural and forced convection. Here you can see the 3D CAD model illustration of the module, which was designed by the Centre for Mechatronics and Hybrid Technology (CMHT). The results of this study helped us study the thermofluidic behavior of lithium-ion batteries on a large scale as a pack with a higher number of cells.

Figure 3. CAD design of a cylindrical lithium-ion batteries module.

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