# BATTERY THERMAL MANAGEMENT by CFD

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FYP Draft Report

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# BATTERY THERMAL MANAGEMENT by CFD

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**BATTERY THERMAL MANAGEMENT by CFD**

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**A report submitted**
**in fulfilment of the requirements for the degree of**
**Bachelor of Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

## DECLARATION

I declare that this project report entitled "battery thermal management by CFD" is the result of my work except as cited in references.

| | |
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| Signature | :__________________ |
| Name | :__________________ |
| Date | :__________________ |

**APPROVAL**

I at this moment declare that I have read this project report. In my opinion, this report is enough in term of scope and quality for the award of bachelor's degree in Mechanical Engineering.

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| Signature | :___________________ |
| Name | :___________________ |
| Date | :___________________ |

## DEDICATION

To my beloved mother and father

# ABSTRACT

The aim of this study is to compare the cooling effect of a liquid flow channel with different types of inner edge on the battery surface. The numerical study was performed using ANSYS FLUENT. A geometric model of cuboid-shaped battery with two tabs was created. Cooling plate with the fluid channel was attached on both sides of the battery cell. The flow channel with a sharp edge was compared with the one with 5mm and 10mm fillet corner. The simulation of the battery was carried out by using Multi-Scale Multi-Domain (MSMD) method, which was provided in ANSYS FLUENT. All three cases were simulated under the same operational condition. The results showed that the fluid channel with fillet corner gives a neglectable small temperature different on battery cell. This may due to the velocity is not high enough to have a presence of separation region in sharp edge case or fillet corner and mesh size generated may also not small enough to capture the detailed result.

**ACKNOWLEDGEMENTS**

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## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF SYMBOLS

| | |
|---|---|
| Li | Lithium |
| C | Carbon |
| e- | Electron |
| O | Oxygen |
| Q | Heat transfer rate |
| K | Thermal conductivity |
| A | Area |
| dt/dx | Temperature different between distance |
| H | Convection heat transfer coefficient |
| T | Temperature |
| Re | Reynolds number |
| Nu | Nusselt number |
| D | Diameter |
| V | Velocity |
| Pr | Prandtl number |
| $\mu$ | Viscosity |
| MSMD | Multi-Scale Multi-Dimension |
| UDS | Use define scalar |
| Min | Minimum |
| Max | Maximum |
| c-rate | Charge of discharge rate |

# Chapter 1

# Introduction

## 1.1. Background of study

In the mid-1970s, the lithium-based battery has been proposed and start to research at academic institutions. In the next decade, the technology has been developing, and the very first lithium–ion battery come to commercial in 1991 released by two Japanese materials science Company Sony and Asahi Kasei. In the next twenty years, the characteristic of the battery has been studied and its technology rapidly improved. Due to it good performance, its soon surpassed other battery types such as nickel cadmium and nickel-metal-hydride.

Lithium-ion batteries are commonly used in many portable electronics such as personal electronic devices, hand-held power tools. They are among the most popular types of rechargeable batteries due to its high energy density, tiny memory effect and low self-discharge. With all these advantages, it also became the solution for battery electric vehicles and hybrid electric vehicles. (Wang Tao, et al., 2014)

Lithium-ion battery needs a good operation environment which is extremely sensitive to heat. Thermal management is one of the most important factors while designing and producing a battery. There are cooling methods that are widely used to maintain the temperature of the battery. For example, passive and forced air cooling, water-based coolant cooling, phase change material conduction cooling and others. A good thermal management system can ensure life and provide a safe operation.

### 1.2. Problem statement

Lithium-ion battery have an issue, which is the temperature generate during charge and discharge. Typically, it has a wider range of operation temperature during discharge and narrower during charge. The operation temperature of lithium-ion battery when charging is between 0°C to 45°C and while discharging is between –20°C to 60°C. Operating the battery out of the temperature range will degrade the battery which will affect the performance and the life cycle of the battery. If the temperature of the battery went too high during its operation, it might also have safety issues. (Battery University, 2016)

Indirect cooling method cools the battery surface by conduct the heat to the aluminum plate. Inside the plate, it has a liquid channel to allow the liquid to enter to cool the aluminum plate. At the corner of the channel, there will be either sharp edge corner or rounded edge corner; this study will concentrate on the fillet radius of the edge to study the fluid flow and heat transfer of the cooling plate.

### 1.3. Objective

- Perform CFD simulation of the indirect cooling method on battery cell.
- Verify the effect of the radius of the fillet at the corner edge in the liquid channel on the operation temperature and temperature different.

## 1.4. Scope

- Study on prismatic lithium-ion battery
- Study the radius of the fillet at the corner edge in the liquid channel.
- Coolant use in the project is water–ethylene glycol
- Study fully based on simulation through ANSYS software.

# Chapter 2

# Literature review

## 2.1. Lithium-ion battery

Lithium-ion battery was categorized as a secondary battery or commonly named as a rechargeable battery. This battery consists of some main components such as anode, cathode and electrolyte to conduct electricity. It is named lithium-ion battery because the battery function when the lithium-ion in the battery moves from either cathode to anode during charging or anode to cathode during discharging. (Jiling Li, et al, 2014)

### 2.1.1. How it works

From the basic components of lithium-ion battery, the material of cathode is metal oxide and the material of anode consists of porous carbon. The electrolyte in the battery is the lithium salt which dissolved in the organic solvent. During discharge, the lithium-ion ($Li^+$) will be removed from the anode and move freely in the electrolyte. At the same time, a cathode which is made from metal oxide will receive the $Li^+$ from the electrolyte. The electrolyte is the medium that allows the $Li^+$ to move between the electrodes will the electrodes are isolated by a separator. During the charging, the same concept is applied in the reverse method. (Jiling Li, et al, 2014)

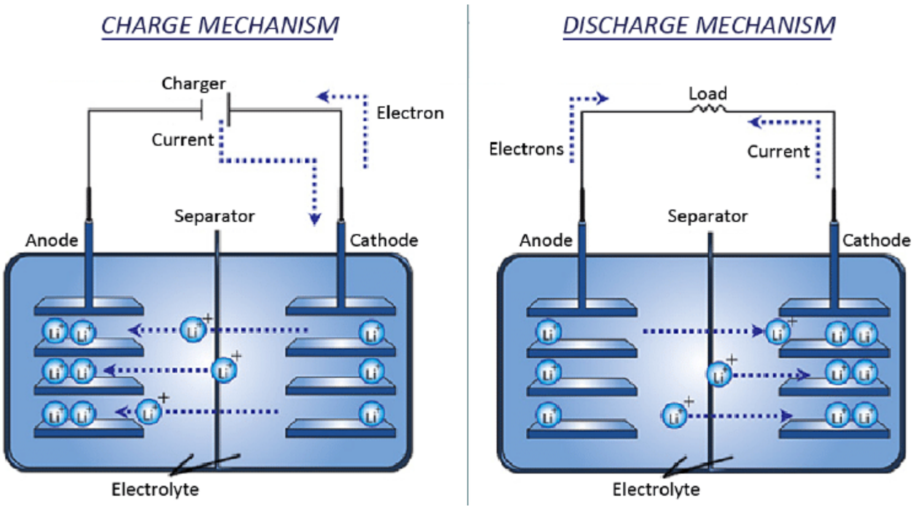


Figure 2.1. Charge and discharge mechanism of lithium-ion battery (Mancini, M., 2008 cited in Noshin Omar, et al, 2012)

By using Li-cobalt as an example, the electrochemical reactions in the positive electrode and negative electrode are expressed as follows:

The positive electrode reaction is:

$$\mathrm{Li}COO_2 \Leftrightarrow Li1-xCOO_2+xLi++xe-$$

The negative electrode reaction:

$$xLi++xe-+xC_6 \Leftrightarrow xLiC_6$$

For other types of lithium-ion battery, the chemical reaction is roughly similar.

### 2.1.2. Charge and discharge rate

Charge and discharge rate of battery also named as C-rate is the performance of the battery current over time. Battery discharge at 1C is normal operation condition where it is representing the battery can provide 1A of current for 1hour while it is fully charged (Battery University, 2016). The temperature at different C-rate increase if the C-rate increased. The higher the C-rate the shorter the time to achieve the max temperature. (Tao Wang, et al, 2014) Figure 2.2 shows the average temperature against time with different C-rate that are 1, 2 and 3C while at maximum temperature is the time taken for the batteries to fully discharge.

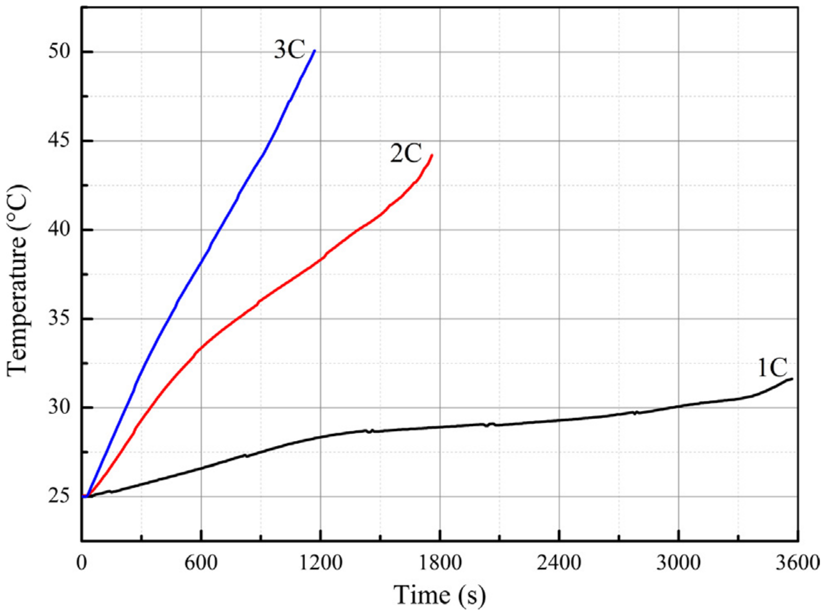

Figure 2.2. Average temperature against time at different C-rate. (Tao Wang, et al, 2014).

2.1.3. Type of lithium-ion battery

There are several types of lithium-ions battery available in the market nowadays. The name other battery is depending on the oxide cathode used in the battery. Each of the battery types has a different characteristic which allow it to use under different condition or requirement. (Jiling Li, et al, 2014)

Several types of lithium-ion batteries and the characteristic are list below:

Table 2.1. List of Lithium-ion battery. (Jiling Li, et al, 2014)

| **Material** | **Chemical name** | **Short form** | **Note** |
|---|---|---|---|
| Lithium Cobalt Oxide | LiCoO2 | Li-cobalt | High capacity; for cell phone laptop, camera |
| Lithium Manganese Oxide | LiMn2O4 | Li-manganese | Most safe; lower capacity than Li-cobalt but high specific power and long life. Power tools, e-bikes, EV, medical, hobbyist. |
| Lithium Iron Phosphate | LiFePO4 | Li-phosphate | |
| Lithium Nickel Manganese Cobalt Oxide | LiNiMnCoO2 | NMC | |
| Lithium Nickel Cobalt Aluminium Oxide | LiNiCoAlO2 | NCA | Gaining importance in electric powertrain and grid storage |
| Lithium titanate | Li4Ti5O12 | Li-titanate | |

2.1.4. Thermal issue on battery

During the operation of the lithium-ion battery, it generates or stores electricity by the chemical reaction inside it. Due to the chemical reaction, lithium-ion batteries are sensitive to temperature will it increase the rate of reaction at high temperature. Operating the battery cooler or hotter than its operating temperature will affect the performance of the battery and make irreversible damage to the battery. The temperature of the battery mainly affected by the heat generated by itself during operation and the heat from surrounding from table 2.3 show that the best operating temperature for battery during discharge is between 20 to 40 °C and drop dramatically after 40 °C. (Jiling Li, et al, 2014)

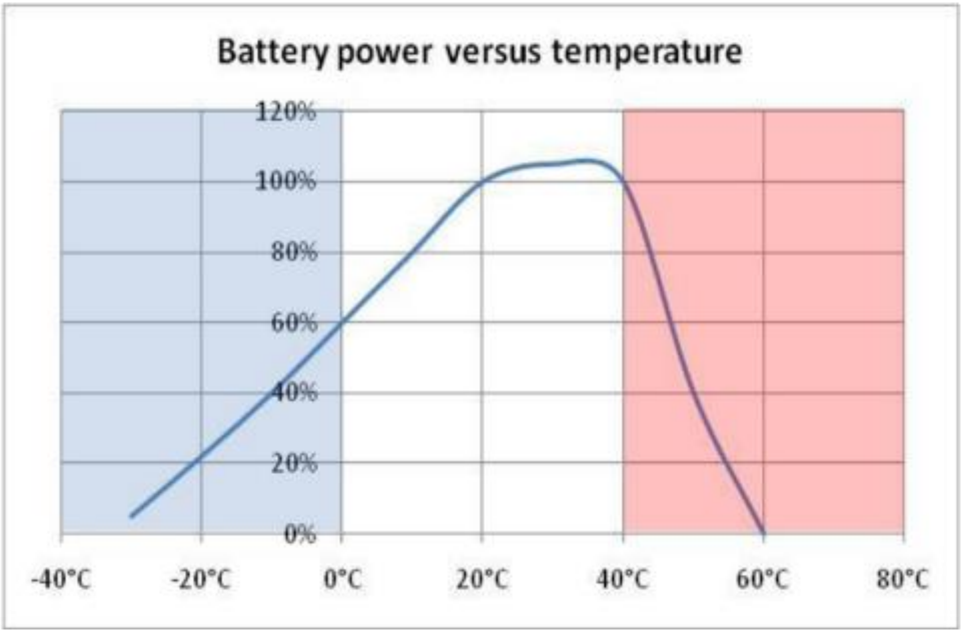

Figure 2.3. Battery power versus temperature during discharge (Matthe, et al., 2011)

## 2.2. Heat transfer

### 2.2.1. Conduction heat transfer

Conduction occurs where two objects in contact will having different temperature. Heath from the warmer object will transfer to the cooler until both temperatures meet equilibrium. (J.P. Holman, 2002). Conduction can be calculated with the equation:

$$Q = -kA\frac{dT}{dx} \tag{2.1}$$

Where, Q = Heat transfer rate, W

k = thermal conductivity, W·m−1·K−1,

A = Surface area in contact, $m^2$

$\frac{dT}{dx}$ = temperature different between distance, m

### 2.2.2. Convection heat transfer

Convection occurs when the adjacent fluid in motion flow on the solid surface create a thermal boundary layer where heat transfer from a warm surface to cool liquid. When a fluid is forced to move on the surface either by pump, fan or wind, this process is called forced convection. (J.P. Holman, 2002). General equation of convection is expressed as:

$$\dot{Q} = hA(T_s - T_\infty) \tag{2.2}$$

Where, $h$ = convection heat transfer coefficient, $W/m^2 \cdot {}^\circ C$

$A_s$ = surface area through which convection heat transfer takes place, $m^2$

$T_s$ = surface temperature, ˚C

$T_\infty$ = temperature of fluid sufficiently far from the surface ˚C

There are some important equations used for convection.

Velocity boundary layer thickness:

$$\delta = \frac{4.91\ x}{\sqrt{Re_x}} \tag{2.3}$$

Thermal boundary layer thickness:

$$\delta = \frac{4.91\ x}{Pr^{1/3}\sqrt{Re_x}} \tag{2.4}$$

Local Nusselt number

$$Nu_x = \frac{h_x x}{k} = 0.332\ Pr^{1/3}{Re_x}^{1/2}\ , Pr > 0.6 \tag{2.5}$$

Reynolds number

$$Re_x = \frac{\rho v x}{\mu} \tag{2.6}$$

$$Re_d = \frac{\rho v D}{\mu} \tag{2.7}$$

Where, R = the Reynolds number, unitless

ρ = fluid density in kilograms-per-cubic-meter, $kg/m^3$

v = velocity in meters-per-second, m/s

x = distance from leading edge, m

D = diameter of the pipe in meters, m

μ = viscosity of the fluid. Pa·s

Pr = Prandtl number, unitless

Nu= Nusselt number, unitless