ABSTRACT

The rapid growth of the electric vehicle industry necessitates more research into electric vehicle management systems, particularly in light of the present transition from internal combustion engines toward electric drivetrains. An electric vehicle's overall design and construction would be incomplete without a battery temperature control system. With battery thermal management systems in electric vehicles, the temperature of the batteries can be maintained at a reasonable threshold while simultaneously enhancing temperature uniformity. Adopting efficient cooling systems for electric vehicles is necessity to enhance battery safety, increase life of the battery, and minimize the detrimental effects of high surface temperatures on battery cell. As a result, several BTMS have been developed by academics and producers, but only a small number of these researchers have focused on the use of nanofluid as a cooling medium. Using self-rewetting fluids with nano-particles could further improve the heat capacity of BTMS. Therefore, this research focuses on creating novel hybrid cooling method by incorporating nano-particles in a self-rewetting liquid coolant medium in order to enhance the rate of heat transfer.

Keywords: Battery Thermal Management System, Cooling Methods, Hybrid Cooling, Nano-fluid.

CHAPTER 1
1. Introduction
1.1 Background

The goal of the BTMS (Battery Thermal Management System) is to avoid premature battery degradation by regulating the heat produced by its components so that it can work constantly at optimal temperature levels. Despite the fact that commercially available cells can function safely between -40° and 60°C, the operating range suggested by manufacturers to enhance their performance is in reality between 15° and 35°C. There should be no more than a 5° C differential between the cells in a battery pack, according to this recommendation. If the battery is exposed to extreme circumstances, it might prove fatal. The thermal runaway may result in fire and, in the worst case, an explosion of the battery, putting the user's safety at risk. This is especially true if the battery is used at temperatures over 80 °C.

Interest in electric-powered vehicles such as battery electric vehicles (EV), hybrid electric vehicles (HEV), and plug-in hybrid vehicles (PHV) has grown in response to stringent greenhouse gas emission rules. Many researchers have used different techniques to minimize the pollutants from conventional IC engines. However, due to their inherent disadvantages, IC Engines are liable to produce greenhouse gasses. On the other hand, Electric vehicles (EVs) offer several advantages over conventional IC Engine-powered vehicles, including reduced emissions and excellent fuel efficiency. A vital component of EVs is the Li-ion battery pack. The current lithium-ion (Li-ion) batteries are widely employed in electric vehicles (EVs) because of their high specific energy, high specific power, low self-discharge rate, higher voltage, relatively long lifespan, and strong recyclability. Inappropriate operating temperatures (such as very high temperature, very low temperature, and high differential temperature) and even storage temperature will have an impact on battery performance, efficiency, and longevity, limiting the capabilities of EVs. Temperature is the primary factor determining battery aging, negatively affecting capacity and internal resistance. Furthermore, uneven temperature distributions inside a battery pack could result in electrically imbalanced cells. In turn, electric imbalance in a battery pack can lead to capacity loss and overcharging of the affected cells during charging, which leads to power losses and increased cell temperatures. A lot of usable battery energy will be lost at high temperatures because of capacity/power fading, self-discharge, and other things.

EVs' safety can be jeopardized by thermal runaway and overheating due to a short circuit when severe conditions, such as when the ambient temperature is extremely high. Reduced charge acceptance, capacity/power, longevity, and round-trip efficiency are all negatively impacted by low temperatures. In the case of a battery pack, a thermal runaway is a critical event that results in the fast creation of temperature and gases, as well as the explosion of the battery pack.

Chemical reactions and battery materials are important factors in battery temperatures. A typical EV battery pack functions best in a temperature range of -40° C to 60° C. However, most researchers agree that EV batteries function best when

operated at a temperature between 15°C and 35°C. There is a detrimental effect on the thermal performance of batteries when exposed to temperatures above and below given limits. It's predicted that every degree of temperature rise reduces the battery's lifetime by two months. However, a battery pack's maximum temperature differential should not exceed 5 °C. Studies suggest that power supply capacity suffers 1.5–2 % higher loss when the temperature differential increases by 5°C.

At higher temperatures, the battery pack's reaction rate increases, resulting in an increase in output power and a better capacity. Contrarily, this results in a higher temperature and an increased thermal load on the battery pack. High temperatures may also reduce capacity due to electrolyte degradation and non-uniformity in the passivation layer. Similarly, when the ambient temperature drops to -40 °C, the amount of electricity that can be delivered is only 1.25 % of what it is at 20 °C. As a result of the non-uniform temperature distribution in the cell, during charging or discharging operations, the cell's performance and cycle life also worsen. The increase in the internal resistance of the battery pack leads to a 60% reduction in capacity at -20 °C. Because of this, charging and discharging in subzero temperatures is great difficulty.

It is necessary to examine the temperature on the battery pack surface in conjunction with the temperature profile within the battery. Building heat transfer models for the outside cooling structures is necessary for a more realistic BTMS simulation. With the use of the electrochemical and thermal models, various battery models may be used to derive the internal state of battery cells. In most cases, the interior temperature of batteries can be determined by observing the surface temperature profile because obtaining the temperature inside the battery cells is difficult.

Figure 1: Schematic layout of BTMS
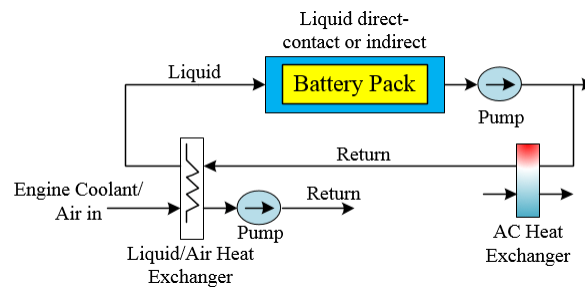
1.2 Battery Heat Generation Model

The cooling medium flow field and cell temperature pattern in a battery module are determined by the amount of heat generated in the cells and the amount of heat dissipated from the cell to the surrounding air. The electrochemical processes that generate heat on the battery surface raise the battery surface temperature. In the Lithium-ion battery, reversible heat and irreversible heat are the primary forms of heat generation. The generation of reversible heat (also known as entropic heat) occurs due to a change in entropy. Electrical resistance and higher potential resistance lead to the generation of irreversible heat (also known as ohmic heat). Cell internal resistance and electrochemical processes cause the Ohmic heating or over-potential heat production,

always considered positive. Bernardietal presented a heat generation equation to estimate the rate of heat generation in a single cell:

$$Q = Q_{irreversible} + Q_{reversible} = I^2.R_{int} - IT.\frac{dE_{OV}}{dT}$$

Where, I= Electric Current

R_{int} = Internal Resistance,

C = Rate and State of Charge,

T= Temperature,

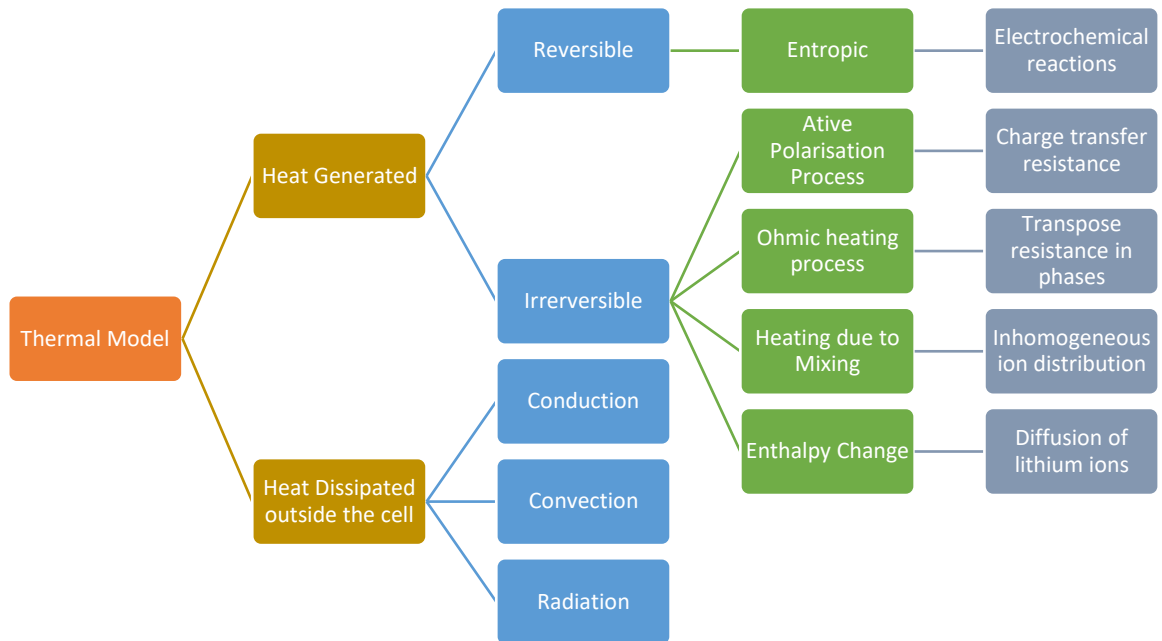dE_{OV}/dT= Entropic Coefficient (Function of Density and Temperature)

Figure 2: Heat Issues of Battery

1.3. Classification of Battery Thermal Management System

   BTMS are categorized into two types, viz., active and passive. In active BTMS, in order to keep the battery pack cold, a cooling liquid is constantly circulated through the system. It makes an active BTM system easier to manage, but it also adds to the total complexity and cost. On the other hand, passive BTM systems are less expensive, easier to maintain, and use less energy; nevertheless, exact control over these systems is often difficult. Zhaoetal. presented a new classification criterion for examining the current BTMS. In addition to basic BTMS, hybrid BTMS are classified into five types. The integration of both active and passive methods is a standard aspect. Hybrid BTMS, in contrast to basic BTMS, has an emphasis on integrating and combining.
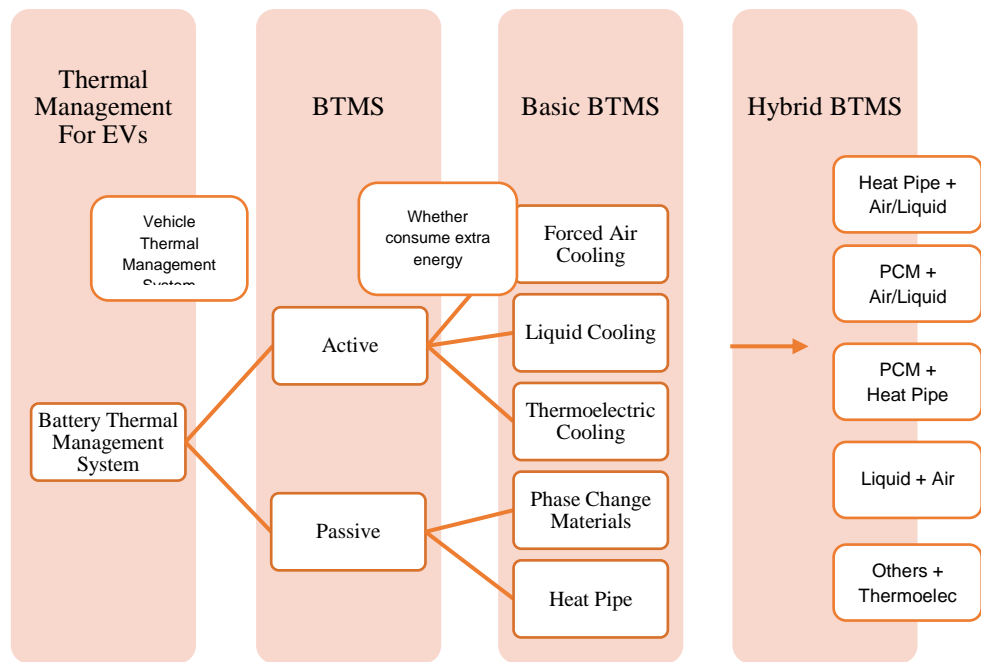
Figure 3: Classification of battery thermal management systems (BTMS)

CHAPTER 2

2.0 Related Work:
2.1 Air BTMS

Air Cooling BTM systems employ air as a medium for heat transfer. There are two types of Air BTMS: one method uses natural air convection, and the other uses forced air convection. In the case of the natural convection method, one method uses the air directly from the atmosphere (at ambient temperature) while the second method uses pre-conditioned cabin air. Another battery thermal management system uses a second evaporator to cool the battery pack specifically and considers the different cooling requirements of the cabin and battery pack . Due to lower heat capacity and low thermal conductivity of air, it is practically challenging to cool down the battery, limiting the application of these systems in high rate operation, i.e., 5°C. However, Air BTMS systems are compact, low-maintenance, and cost-effective.

Similarly, in the case of forced air convection BTMS, a greater airflow rate is required to achieve the same cooling performance as the liquid-based BTMS. The forced-air cooling system creates uneven temperature distribution in the battery pack, which is a critical issue that must be addressed due to its lower heat capacity.

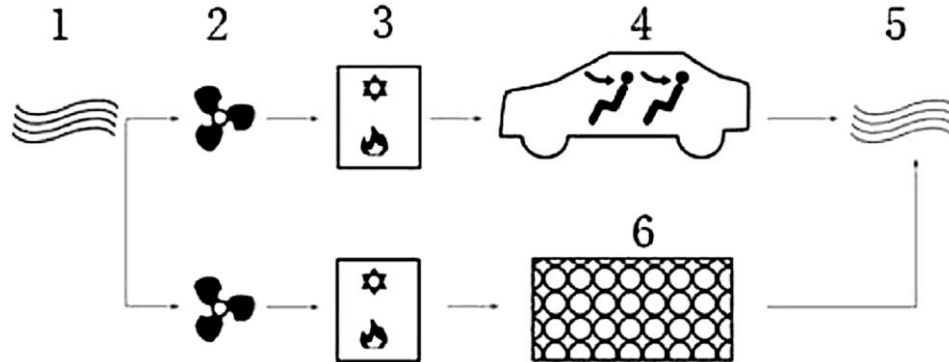1-external air; 2- fan; 3- HVAC; 4- Car; 5- exhaust; 6- Battery pack

Figure 4: Independent Air-cooled BTMS 'HVAC module' powered by batteries.

Open and confined Li-ion battery packs were evaluated by Jilte et al. for its thermal transient performance. In open flow and confined flow battery modules, the temperature response of the battery cell differs. For an open flow module, there is a high temperature difference at the early discharge time (25 s); however, this is not the case for a confined flow module. In contrast to the open flow module, the restricted flow module has a lower surface temperature of 3.42–6.19 °C, indicating that it is more thermally efficient. The confined flow module ensures that the temperature of the battery packs remains low and almost constant throughout the depth of the battery pack.

Figure 8: Simulation Model of Battery (a) Confined flow Module (b) open flow

(a)   (b)
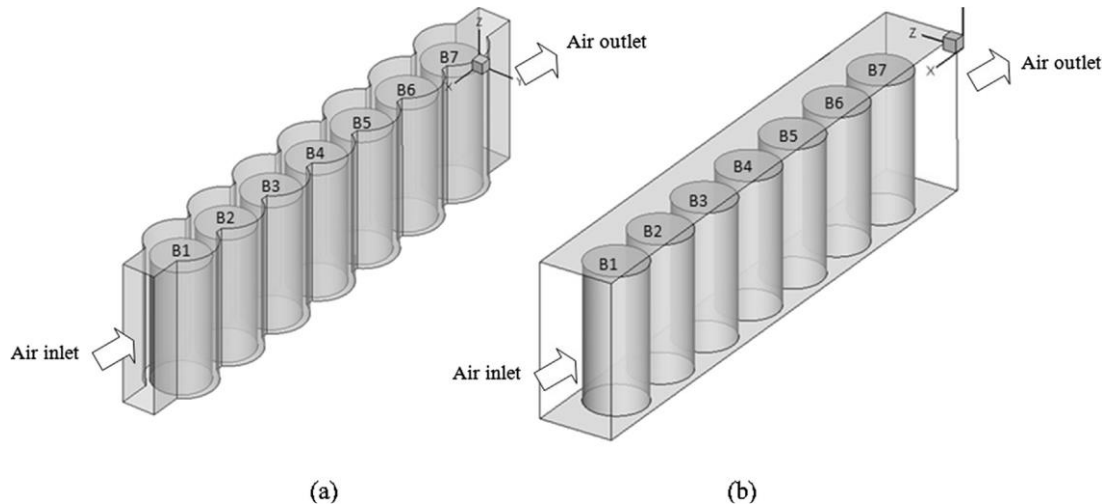
module

2.2 Liquid Cooled BTMS

There has been considerable interest in liquid-based cooling systems for electric car batteries because of their superior heat transfer coefficients compared to air cooling BTMS. In addition, under the high discharge rate circumstances, the air cooling approach proved insufficient. Also, air cooling method consumes 2 to 4 times higher energy to keep the batteries at the same average temperature than liquid-cooling system. The battery's performance and lifespan can only be enhanced and extended if a more efficient cooling and heating method is used. The disadvantages of this cooling methods are the higher complexity, higher maintenance, chances of leaks, higher weight, and higher cost, as well as the decreased rigidity of the cooling structure. In liquid cooled BTMS, direct-contact and indirect-contact methods may be distinguished based on whether the battery is in direct touch with the heat transfer medium, which has a comparatively greater heat transfer coefficient.

2.2.1 Direct Contact Liquid Cooling Method

Battery packs or modules are often submerged in dielectric liquids such as mineral oil, de-ionized water and silicone oils in the direct contact liquid cooling method. Since these cooling fluids have a greater viscosity, more energy must be used while pumping.

As discussed, this method offers higher heat transfer rate because of submersion of battery surface in fluid medium. In direct contact method, almost all of the convection

heat transfer occurs on the battery's surface. Direct contact method can be used with Li-ion batteries wherever fast charge rates and high power are required, despite if it isn't the most practical way. Because of the difficulty in integrating heating into a thermal management system when using direct liquid cooling, other BTMS types should be considered for applications where the ambient temperature goes lower than $0° C$.

The direct contact method can be classified as phase change cooling method or single-phase cooling method. During the cooling process, the phase change of cooling medium (HTF) will occur if the boiling point of phase change cooling medium is lower than the battery's maximum temperature (Tmax). This is sometimes referred to as boiling cooling. As a result of the high latent heat, the temperature rise towards the boiling point is greatly delayed in phase change cooling method.

Sr. No	Fluid type	Fluid mix ratio (in %)	Cooling method	Flow configuration	Cooling structure material	Reference
1	1.Mineral Oil 2. Water/ Glycol	1. 100 2. 50/50	1.Direct 2. Indirect	1. Direct Contact Mini-channel 2. Jackets on cooling plate	1. Aluminum 2. Aluminum	46
2	Water	100	In-direct	Silica plate coupled with cooper tubes	Silica Plate and Copper	48
3	Water	100	In-direct	Aluminum blocks with flow channels	Aluminum	49
4	Water	100	In-direct	Mini-channels	Aluminum	50
5	1. Water, 2. Silicone Oil 3. Air	1. 100 2. 100 3. 100	1. In-direct 2. Direct 3. Direct	1. Thin Copper separator 2. Direct Immersion 3. Direct Immersion	1. Copper	51
6	Water-Ethylene glycol	Unknown	Indirect	Cooling plate with 18 geometric design variants	Aluminum	52
7	1. Water/ Ethylene glycol 2. PEG-1000 (PCM)	84/16	Indirect with Hybrid Cooling	Honeycomb shaped cooling plate	Aluminum	53
8	Water	100	Indirect Cooling	Liquid Cooled Mini-channel Cylinders (LCC)	Aluminum	54
9	1. Water 2. Air	1. 100	1. Indirect	1. Cooling Channels	1. Aluminum	59

Table 1: Overview of Liquid cooling methods and flow configurations
2.3 STRUCTURAL DESIGN OF LITHIUM ION BATTERY:

A battery is made up of an anode, cathode, separator, electrolyte and two current collectors. The anode and cathode store with the lithium. The electrolyte carries positively charged lithium ion form the anode to the cathode and vice versa through the separator. The movement of the lithium ion creates free electron in the anode which creates a charge at the positive current collectors. The electrical current then flows from the current collector through a device being powered to the negative current collector the separator blocks the flow of electron inside battery.

A Lithium-ion or Li-ion battery is a type of rechargeable battery which uses the reversible reduction of lithium ions to store energy. It is the predominant battery type used in portable consumer electronics and electric vehicles. It also sees significant use for grid-scale energy storage and military and aerospace applications. Compared to other rechargeable battery technologies, Li-ion batteries have high energy densities, low self-discharge, and no memory effect (although a small memory effect reported in LFP cells has been traced to poorly made cells). based on the flammability and volatility of the organic solvents used in the typical electrolyte. Strategies include aqueous lithium-ion batteries, ceramic solid electrolytes, polymer electrolytes, ionic liquids, and heavily fluorinated systems.

2.4 History:

Research on rechargeable Li-ion batteries dates to the 1960s; one of the earliest examples is a CuF_2/Li battery developed by NASA in 1965. The breakthrough that produced the earliest form of the modern Li-ion battery was made by British chemist M. Stanley Whittingham in 1974, who first used titanium disulphide (TiS_2) as a cathode material, which has a layered structure that can take in lithium ions without significant changes to its crystal structure. Exxon tried to commercialize this battery in the late 1970s, but found the synthesis expensive and complex, as TiS_2 is sensitive to moisture and releases toxic H_2S gas on contact with water.

2.5 Electrolyte:

Electrolyte plays a key role in transporting the positive lithium ions between the cathode and anode the most commonly used electrolyte is compromised lithium salt such as LiPf6 in an organic solution. The reactants in the electrochemical reactions in a lithium-ion cell are materials of anode and cathode, both of which are compounds containing lithium atoms. During discharge, an oxidation half-reaction at the anode produces positively charged lithium ions and negatively charged electrons. The oxidation half-reaction may also produce uncharged material that remains at the anode. Lithium ions move through the electrolyte, electrons move through the external circuit, and then they recombine at the cathode (together with the cathode material) in a reduction half-reaction. The electrolyte and external circuit provide conductive media for lithium ions and electrons, respectively, but do not partake in the electrochemical reaction. During discharge, electrons flow from the negative electrode (anode) towards the positive electrode (cathode) through the external circuit. The reactions during

discharge lower the chemical potential of the cell, so discharging transfers energy from the cell to wherever the electric current dissipates its energy, mostly in the external circuit. During charging these reactions and transports go in the opposite direction: electrons move from the positive electrode to the negative electrode through the external circuit. To charge the cell the external circuit has to provide electric energy. The following equations exemplify the chemistry:
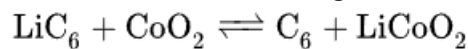
The positive electrode (cathode) half-reaction in the lithium-doped cobalt oxide substrate

$$CoO_2 + Li^+ + e^- \rightleftharpoons LiCoO_2$$
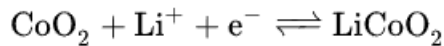
The negative electrode (anode) half-reaction for the graphite is

$$LiC_6 \rightleftharpoons C_6 + Li^+ + e^-$$
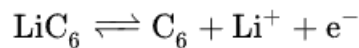
The full reaction (left to right: discharging, right to left: charging) being

$$LiC_6 + CoO_2 \rightleftharpoons C_6 + LiCoO_2$$

The overall reaction has its limits. Over discharging supersaturates lithium cobalt oxide, leading to the production of lithium oxide possibly by the following irreversible reaction:

$$Li^+ + e^- + LiCoO_2 \longrightarrow Li_2O + CoO$$
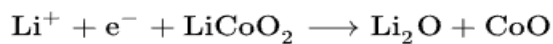
Overcharging up to 5.2 volts leads to the synthesis of cobalt (IV) oxide, as evidenced by x-ray diffraction:

$$LiCoO_2 \longrightarrow Li^+ + CoO_2 + e^-$$
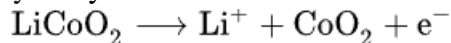
In a lithium-ion cell, the lithium ions are transported to and from the positive or negative electrodes by oxidizing the transition metal, cobalt (Co),in $Li_{1-x}CoO_2$ from Co^{3+} to Co^{4+} during charge, and reducing from Co^{4+} to Co^{3+} during discharge.

2.6 Charging and Discharging:

During discharge lithium ions carry the current within the battery cells from the negative to the positive electrode through non aqueous electrolyte and separator diaphragm. During charging an external electrical power source applies an over voltage, forcing a charging current to flow within each cell from the positive to negative electrode, i.e. in the reverse direction of a discharge current under normal condition. The lithium ion then migrate from the positive to the negative electrode, where they become embedded in the porous electrode material in a proces known as intercalation. Energy losses arising from electrical contact resistance at interfaces between electrode layers and at contacts with current collectors an be as high as 20% of the entire energy flow of batteries under typical operating conditions. The charging procedures for single li-ion cell, and complete li-ion batteries, are slightly different.

2.7 Cells:

Li-ion cells are available in various shapes but they broadly divided in four types:

1. Small cylindrical (solid body without terminals, such as those used in most e-bikes and most electric vehicle battery and older laptop batteries)
2. Large cylindrical (solid body with large threaded terminals)
3. Flat or pouch (soft, flat body, such as those used in cell phones and newer laptops; these are lithium-ion polymer batteries.
4. plastic case with large threaded terminals (such as electric vehicle Rigid traction packs)

Fig. Lithium ion cell

The absence of a case gives pouch cells the highest gravimetric energy density; however, for many practical applications they still require an external means of containment to prevent expansion when their state of charge (SOC) level is high, and for general structural stability of the battery pack of which they are part. Both rigid plastic and pouch-style cells are sometimes referred to as prismatic cells due to their rectangular shapes. Battery technology analyst Mark Ellis of Munro & Associates sees three basic Li-ion battery types used in modern (~2020) electric vehicle batteries at scale: cylindrical cells (e.g., Tesla), prismatic pouch (e.g., from LG), and prismatic can cells (e.g., from LG, Samsung, Panasonic, and others). Each form factor has characteristic advantages and disadvantages for EV use.

2.8 Battery Pack:

A battery consists of multiple connected lithium-ion cells. Battery packs for large consumers electronics like laptop computers also contain temperature sensors, voltage regulator circuits, voltage taps, and charge -state monitors. These components minimize safety risks like overheating and short circuiting. To power larger devices, such as electric cars, connecting many small batteries in a parallel circuit is more effective than connecting a single large battery.
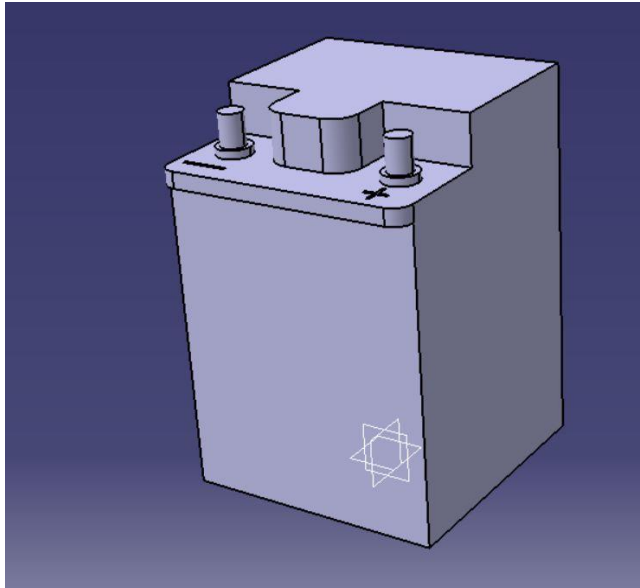
2.9 BATTERY COOLING SYSTEM:

Phase change material absorbs heat energy by changing state from solid to liquid. While changing phase, the material can absorb large amounts of heat with little change in temperature. Phase change material cooling systems can meet the cooling requirements of the battery pack, however, the volume change that occurs during a phase change restricts its application. Also, phase change material can only absorb heat generated, not transfer it away, which means that it won't be able to reduce overall temperature as well as other systems. Although not favorable for use in vehicles, phase change materials can be useful for improving thermal performance in buildings by reducing internal temperature fluctuations and reducing peak cooling loads. Direct cooling systems place the battery cells in direct contact with the coolant liquid. These thermal management schemes are currently in the research and development stage, with no cars on the market using this system.

Direct cooling is more difficult to achieve, due to the fact that a new type of coolant is required. Because the battery is in contact with the liquid, the coolant needs to have low to no conductivity. Indirect cooling systems are similar to ICE cooling systems in that both circulate liquid coolant through a series of metal pipes. However, the construction of the cooling system will look much different in electric vehicles. The structure of the cooling system that achieves maximum temperature uniformity is dependent on the shape of the battery pack and will look different for each car manufacturer.
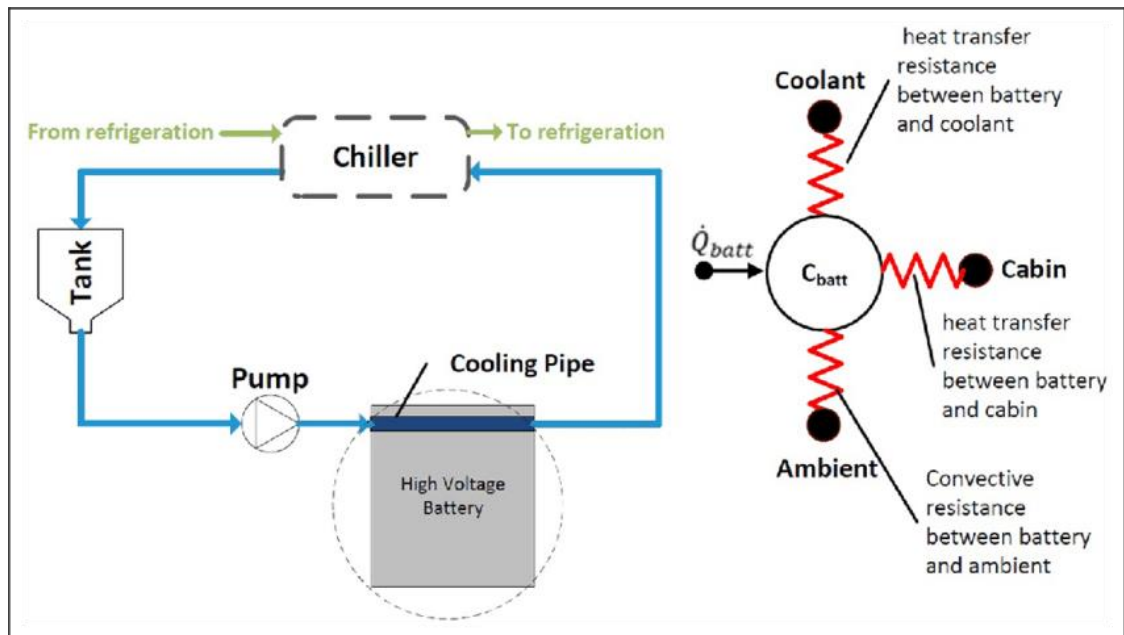
Fig. Schematic layout of battery cooling system

CHAPTER 3

3.0 Literature Review:

The study aims to investigate the inverse-thermocapillary effect in an evaporating thin liquid film of self-rewetting fluid, which is a dilute aqueous solution (DAS) of long-chain alcohol : Thermocapillary flow is a type of Maragoni flow induced by the surface tension gradient, which is temperature dependent (Ellahi et al., 2016; Lappa, 2017). The liquid circulation in an evaporating liquid film is inherently interrupted attributed to the presence of a thermocapillary effect (Jiang and Zhou, 2019; Liu et al., 2020). The sign of the surface tension gradient is important in determining the fluid flow direction in an evaporating thin liquid film (Dong et al., 2020). A positive surface tension gradient assists the fluid flow, while a negative surface HFF tension gradient hinders the fluid flowing towards the evaporating thin-film region. To overcome the shortcoming of the thermocapillary effect engendered by the negative surface tension gradient, a working fluid with a positive surface tension gradient is introduced. A dilute aqueous solution (DAS) can be prepared by adding a diminutive proportion of long-chain alcohol with four or more carbon atoms to the water. Within the range of 103 mole per litre of additive, the surface tension characteristics of water can be altered without affecting other thermo-physical properties of water (Oron and Rosenau, 1994; Zhang, 2001; Chao and Zhang, 2004; Senthilkumar et al., 2012). Only long-carbon-chain alcohols comprising of four or more carbon atoms are applicable for water to generate a surface tension with the quadratic function of temperature (Chao and Zhang, 2004; Dong et al., 2020). The non-linear variation of surface tension with temperature induces the change of surface tension gradient from negative to positive when the temperature increases. Different DASs of alcohol possess different minimum surface tension where the surface tension experiences a turning point (Legros, 1986; Chao and Zhang, 2004; Dong et al., 2020). As the number of carbon atoms of the alcohol increases, the corresponding temperature for the minimum surface tension decreases. For attaining a positive surface tension gradient, the operating temperature of the DAS must be higher than the temperature of the minimum surface tension. The DAS of alcohol is generally known as self-rewetting fluid (Oron and Rosenau, 1994; Zhang, 2001; Chao and Zhang, 2004; Senthilkumar et al., 2012). The thermocapillary convection induced by the positive surface tension gradient exhibits self-rewetting behaviour, which drives the fluid flowing from the low-temperature region to the high-temperature region (di Francescantonio et al., 2008; Cecere et al., 2011; Senthilkumar et al., 2012; Cheng and Park, 2017). It has been shown that the inverse thermocapillary flow of the self-rewetting fluid improves the dry-out limit and enhances the thermal performance compared to other volatile liquids (Abe et al., 2004; Savino et al., 2007; di Francescantonio et al., 2008; Savino et al., 2009; Cecere et al., 2011; Senthilkumar

et al., 2012; Hu et al., 2014b; Hu et al., 2015; Cheng and Park, 2017; Fumoto et al., 2019). An experimental study shows that the evaporative heat transfer rate of pure ethanol is higher than that of the ethanol-water mixtures (Cecere et al., 2014). As water is less volatile than ethanol, the evaporative heat transfer rate of the ethanol-water mixture decreases when the concentration of water increases in the binary mixture. The reduced concentration of ethanol in the mixture also results in the decrement of heat flux. However, if the concentration of ethanol is less than approximately 1.6 mole per cent in the aqueous ethanol solution, the evaporation rate per unit mass of ethanol is drastically increased, which is even greater than that of pure ethanol (Spedding et al., 1993). It was postulated that the enhanced evaporation rate was because of the excess adsorption of alcohol at the interface, while the surface tension characteristics of the aqueous ethanol solution were not considered. The thermocapillary effect induced by the surface tension gradient prompts the fluid flowing to the hotter region (Lim et al., 2017; Hayat et al., 2019), thus enhancing the heat transfer and increasing the dry-out limit. The significance of the thermocapillary effect in an evaporating liquid film has been justified, particularly at a high excess temperature (Lim and Hung, 2014; Lim and Hung, 2015; Chhay et al., 2017; Ye et al., 2019; Zhu et al., 2019). The surface tension gradient is the determinant in affecting the thermocapillary characteristics of an evaporating thin liquid film. By applying the evolution equation established under a long-wave approximation theory, Dong et al. (2020) investigated the dynamics of a self-rewetting film falling along a vertical fiber under the influence of gravity. It was shown that the thermocapillary effect on absolute and convective instability depends on the difference between the temperature at the interface and the temperature corresponding to the minimum surface tension. The surface tension plays an essential role in determining the heat and fluid flow characteristics (Ho et al., 2018; Dijksman et al., 2019; Wang et al., 2019). The effect of surface Thin liquid film of selfrewetting fluid tension gradient vitally affects the capillarity and dry-out limit of a microscale phase-change heat transfer device (Fumoto and Kawaji, 2011; Hu et al., 2014a; Fumoto et al., 2015; Sitar and Golobic, 2015; Hu et al., 2018). While most of the working fluids possess a negative surface tension gradient, the thermal performance of a working fluid is overrated when the thermocapillary effect is neglected (Lim and Hung, 2015). To examine the effect of the sign of surface tension gradient in the thermocapillary flow, we use a DAS of long-chain alcohol with a positive surface tension gradient. Its surface tension is a non-linear function of temperature (Oron and Rosenau, 1994; Chao and Zhang, 2004; Dong et al., 2020). In this work, the thermocapillary effect of three different working fluids, namely, water, heptanol and DAS of heptanol, are investigated and compared. Both water and heptanol have a negative surface tension gradient, while the DAS of heptanol possesses a positive surface tension based on the empirical correlations. The DAS of heptanol is assumed to have the identical thermo-physical properties of water (Oron and Rosenau, 1994; Chao and Zhang, 2004; Hu et al., 2015). This can be further justified by the solubility of the alcohol in the water. As the length of the hydrocarbon chain in the alcohol increases, the solubility of alcohol in the water

reduces. This reduction is noticeable, especially for long-chain alcohol containing four or more carbon atoms. Heptanol is considered immiscible in water, hence the thermo-physical properties of water are not affected by the addition of a small quantity of heptanol, except that the surface tension gradient is altered. Although the thermal enhancement induced by the self-rewetting fluid in a two-phase flow microscale system is evident (Fumoto and Kawaji, 2011; Hu et al., 2014a; Fumoto et al., 2015; Sitar and Golobic, 2015; Hu et al., 2018), the fundamental characteristics of evaporation and the heat transfer enhancement have not been fully understood. To elucidate the underlying physical transport phenomena associated with the inverse thermocapillary effect in an evaporating thin film of self-rewetting liquid, we numerically model and study the hydrodynamic and thermal characteristics of such liquid. The shooting scheme is applied for solving the nonlinear governing equations (Hayat et al., 2018; Waqas et al., 2020). The current study aims to investigate the inverse thermocapillary effect in a self-rewetting evaporating thin film liquid (DAS of heptanol) that has not been attempted previously. With the variations of the excess temperature, the effect of inverse thermocapillary on the heat transfer enhancement is scrutinized. The factors contributing to the heat transfer enhancement are identified and discussed. The current investigation on the inverse thermocapillary effect in a self-rewetting evaporating thin film liquid has not been attempted previously. This study provides insights into the significance of the inverse thermocapillary effect in an evaporating thin film of self-rewetting liquid, which gives rise to the performance enhancement of the microscale phase change heat transfer device.

3.1 Literature Conclusions

The impact of the sign of surface tension gradient on thermocapillary flow in evaporating thin liquid film is investigated in this study. A DAS of heptanol with a positive surface tension gradient is self-rewetting. By using the long-wave evolution model based on the first principles of fluid flow and heat transfer, the surface tension characteristics of the DAS are examined and compared with water and heptanol with a negative surface tension gradient. The DAS, which possesses identical thermo-physical properties with water, displays an invariant liquid temperature contour with water as well. At a high excess temperature, the negative surface tension gradient increases the liquid film thickness while the positive surface tension gradient decreases the liquid film thickness of an evaporating thin film. When the thermocapillary action induced by negative surface tension gradient is neglected, the evaporative heat transfer is overestimated for water and heptanol, while that of DAS is underestimated. The thermocapillary action engendered by the positive surface tension gradient promotes liquid flow and enhances the evaporation rates by driving the flow in the favourable direction. Analysis reveals that the thermocapillary effect of a working fluid is affected by the sign of the surface tension gradient and the effect is prominent when a high excess temperature is applied. The inverse thermocapillary effect manifested in the

selfrewetting evaporating thin liquid film is favourable in the performance enhancement of the microscale phase-change heat transfer devices.

(a)
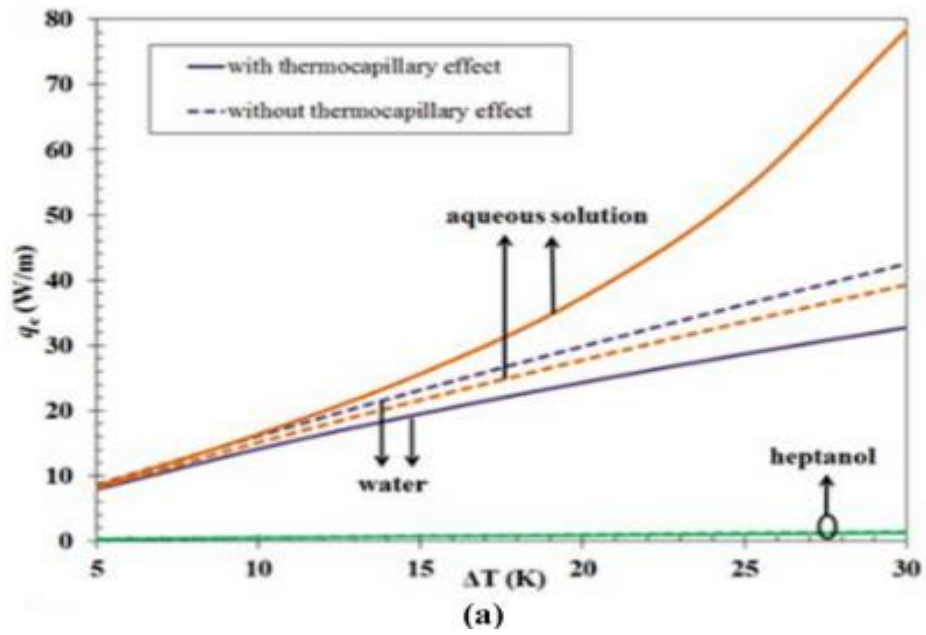
Literature Review on heat pipe:

Thermal management analysis using heat pipe in the high current discharging of lithium-ion battery in electric vehicles.

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Abstract: Thermal management system (TMS) for commonly used lithium-ion (Li-ion) batteries is an essential requirement in electric vehicle operation due to the excessive heat generation of these batteries during fast charging/discharging. In the current study, a thermal model of lithium-titanate (LTO) cell and three cooling strategies comprising natural air cooling, forced fluid cooling, and a flat heat pipe-assisted method is proposed experimentally. A new thermal analysis of the single battery cell is conducted to identify the most critical zone of the cell in terms of heat generation. This analysis allowed us to maximize heat dissipation with only one heat pipe mounted on the vital region. For further evaluation of the proposed strategies, a computational fluid dynamic (CFD) model is built in COMSOL Multiphysics and validated with surface temperature profile along the heat pipe and cell. For real applications, a numerical optimization computation is also conducted in the module level to investigate the cooling capacity of the liquid cooling system and liquid cooling system embedded heat pipe (LCHP). The results show that the single heat pipe provided up to 29.1% of the required cooling load in the 8C discharging rate. Moreover, in the module level, the liquid cooling system and LCHP show better performance compared with natural air cooling while reducing the module temperature by 29.9% and 32.6%, respectively.

Experimental setup: The experimental setup was built to investigate the performance of the heat pipe for the cooling of the LTO battery cell. The selection of a proper heat pipe is an essential item in designing a cooling system. Cylindrical heat pipes are broadly used in the past decades in many research and industrial applications for their efficient cooling. However, the ability to connect on the surface of the heat source is a crucial item. Therefore, a flat heat pipe from Digi Key was made of copper has been selected . For the working fluid in the same configuration, a water heat pipe probably have a lower thermal resistance compared with a methanol heat pip. Moreover, it has a suitable range of operation temperature for the thermal management of the battery.
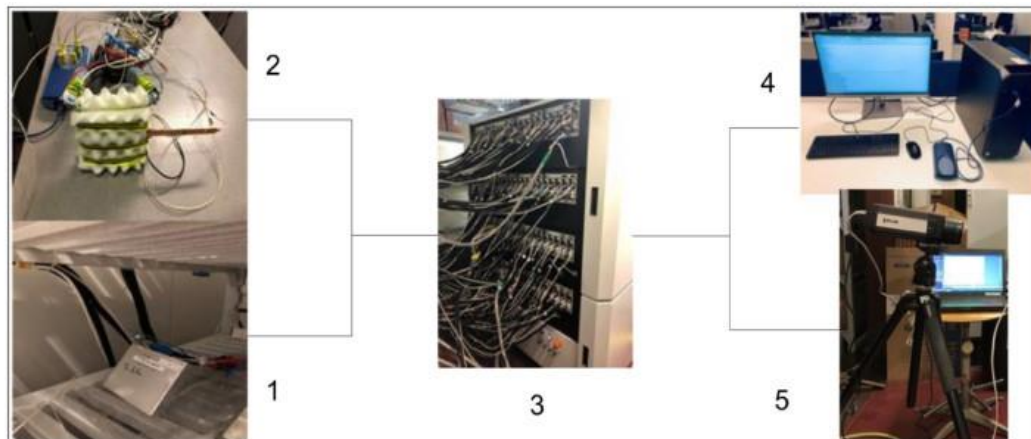
Fig. 2.prismatic cell; (2) isolated prismatic cell and heat pipe; (3) PEC® battery tester (4) personal computer and data logger; (5) thermal Camera
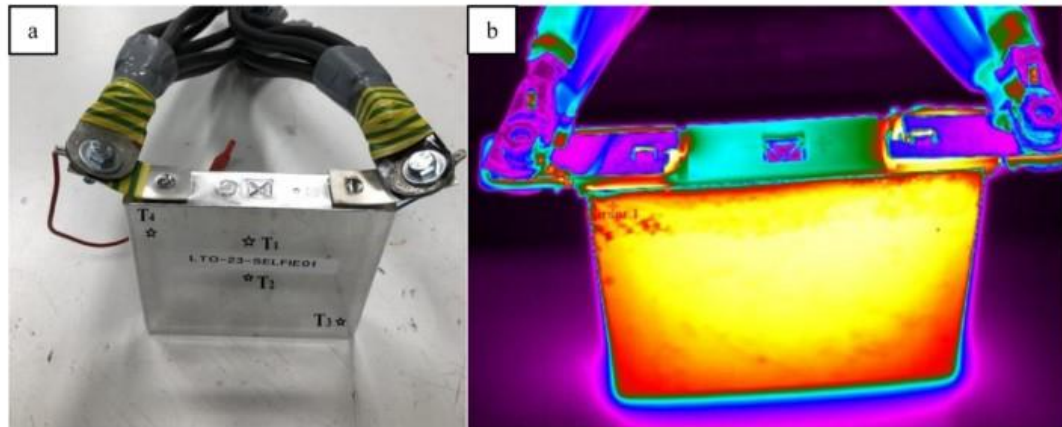

Fig. 4. The picture of the experimental test (a) and location of thermocouples in the presence of natural air cooling and (b) its infrared picture at the end of the 8 C discharging rate test (446s)

Experimental results and disscussion:

Natural air cooling: Considering the effect of natural air cooling on the cell is the initial phase to investigate thermal performance. Fig. 3 shows the generated heat inside the battery cell in the 8 C discharge rate. The average of the heat generation is 37.65 W which is calculated based on Eq. (1). Fig. 4 is taken by a thermal camera and shows the temperature distribution of the cell in a natural air cooling strategy while the ambient temperature is 22 °C at the end of the discharging process (446 s). As it is evident in the temperature distribution of the cell, there is a hot zone in the middle and top of the cell. The natural air cooling test was done comprising of discharging the cell with a high constant current of 184 A from 100% to 0% of the state of charge (SOC) and at an initial temperature of 22 °C. The thermocouples of T1-T4 are shown in Fig. 4a that measures the temperature of the cell. The temperature difference of the tests is calculated by subtracting the current battery temperature with the initial battery temperature. Fig. 5 shows the temperature variation of the LTO cell in natural air cooling. The temperatures of thermocouples T1 and T2, which are in the center and the top of the battery, are higher compared with the thermocouples of T3 and T4.

Forced air cooling: The experimental test by forced air cooling is designed to investigate the cooling effect and thermal performance of the heat pipe on the LTO cell. Fig. 6 shows the cell embedded with a flat heat pipe to test the effectiveness of the forced air cooling system. Twelve thermocouples were used to monitor the temperature at different locations of the heat pipe and cell. Fig. 6a shows the schematic front side of the LTO battery cell with the heat pipe and the location of thermocouples. Fig. 6b illustrates the location of thermocouples in the front and backside of the cell that is embedded with a heat pipe.

Conclusion: The efforts of this study were undertaken to consider the cooling effect of the heat pipe on the LTO prismatic cell/module in high current discharging. In order to achieve this aim, several studies were performed on different boundary conditions and design as follows:The temperature of the cell in natural air cooling for the initial temperatures of 22 °C in the 8 C discharging rate is considered. The thermal distribution inside the cell is monitored using the thermal camera. Through thermal analysis, only one heat pipe is placed in the most effective position for maximizing the performance of the cooling system and decreases the weight and volume of the cooling system. The cooling effect of the flat heat pipe is evaluated experimentally with LTO prismatic cell in the 8C discharging rate. It was found that the single heat pipe provided up to 29.1% of the required cooling load. Also, the thermal conductivity of the heat pipe is calculated. The numerical results are validated with the experimental results. In order to have a precise thermal model, using the COMSOL Multiphysics the cell domain is divided into nine heat source domains. For optimization, a module consisting of 15 cells equipped with liquid cooling and LCHP is simulated. It was found that the liquid cooling system and LCHP compared with natural air cooling reduced the maximum module temperature by 29.9% and 32.6%, respectively.

CHAPTER 4
Study of self-rewetting fluid applied to loop heat pipe by using method of surface tension calculation and make coolant by using trail and error method.
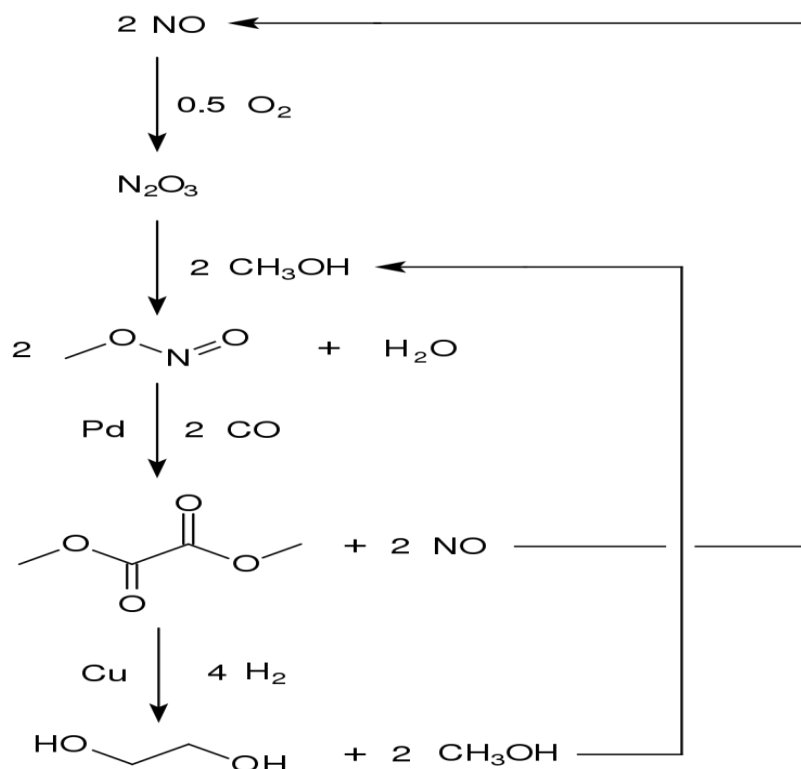**Materials and methods:**

Mono Ethylene Glycol: Mono ethylene glycol (IUPAC Name: ethane-1,2-diol) is an organic compound (a vicinal diol) with the formula (CH_2OH_2). It is mainly used for two purposes as raw material in the manufacture of polyester fibers and for antifreeze formulation. It is an odorless, colorless, flammable, viscous liquid. Ethylene glycol has a sweet taste, but it is toxic in high concentrations. Ethylene glycol is produced from ethylene (ethene), via the intermediate ethylene oxide. Ethylene oxide reacts with water to produce ethylene glycol according to the chemical equation:

$$C_2H_4O + H_2O \rightarrow HO-CH_2CH_2-OH$$
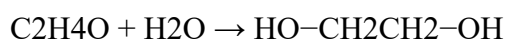
This reaction can be catalyzed by either acids or bases, or can occur at neutral pH under elevated temperatures. The highest yields of ethylene glycol occur at acidic or neutral pH with a large excess of water. Under these conditions, ethylene glycol yields of 90% can be achieved. The major by products are the oligomers diethylene glycol, triethylene glycol, and tetraethylene glycol. The separation of these oligomers and water is energy-intensive. About 6.7 million tonnes are produced annually. A higher selectivity is achieved by the use of Shell's OMEGA process. In the OMEGA process, the ethylene oxide is first converted with carbon dioxide (CO_2) to ethylene carbonate. This ring is then hydrolysed with a base catalyst in a second step to produce mono-ethylene glycol in 98% selectivity. The carbon dioxide is released in this step again and can be fed back into the process circuit. The carbon dioxide comes in part from ethylene oxide production, where a part of the ethylene is completely oxidized. Ethylene glycol is produced from carbon monoxide in countries with large coal reserves and less stringent environmental regulations. The oxidative carbonylation of methanol to dimethyl oxalate provides a promising approach to the production of C1-based ethylene glycol. Dimethyl oxalate can be converted into ethylene glycol in high yields (94.7%) by hydrogenation with a copper catalyst.

Pure ethylene glycol has a specific heat capacity about one half that of water. So, while providing freeze protection and an increased boiling point, ethylene glycol lowers the specific heat capacity of water mixtures relative to pure water. A 1:1 mix by mass has a specific heat capacity of about 3140 J/(kg·°C) (0.75 BTU/(lb·°F)), three quarters that of pure water, thus requiring increased flow rates in same-system comparisons with water.

2 NO

0.5 O_2

N_2O_3

2 CH_3OH

2 [methyl nitrite structure] + H_2O

Pd | 2 CO

[dimethyl oxalate structure] + 2 NO

Cu | 4 H_2

HO–CH₂CH₂–OH + 2 CH_3OH

Properties:

Chemical formula	C2H6O2
Molecular mass	62.068 g·mol−1
Appearance	Clear, colourless liquid
Odour	Odourless
Density	1.1132 g/cm3 (0.04022 lb/cu in)
Melting point	−12.9 °C (8.8 °F; 260.2 K)
Boiling point	197.3 °C (387.1 °F; 470.4 K)
Solubility in water	Miscible
Solubility	Soluble in most organic solvants
Log P	-1.69
Vapour pressure	0.06 mmHg (20 °C)
Viscosity	1.61×10−2 Pa·s

Uses: The major use of ethylene glycol is as an antifreeze agent in the coolant in for example, automobiles and air-conditioning systems that either place the chiller or air handlers outside or must cool below the freezing temperature of water. In geothermal

heating/cooling systems, ethylene glycol is the fluid that transports heat through the use of a geothermal heat pump. The ethylene glycol either gains energy from the source (lake, ocean, water well) or dissipates heat to the sink, depending on whether the system is being used for heating or cooling. Pure ethylene glycol has a specific heat capacity about one half that of water. So, while providing freeze protection and an increased boiling point, ethylene glycol lowers the specific heat capacity of water mixtures relative to pure water. A 1:1 mix by mass has a specific heat capacity of about 3140 J/(kg·°C) (0.75 BTU/(lb·°F)), three quarters that of pure water, thus requiring increased flow rates in same-system comparisons with water. The mixture of ethylene glycol with water provides additional benefits to coolant and antifreeze solutions, such as preventing corrosion and acid degradation, as well as inhibiting the growth of most microbes and fungi.[20] Mixtures of ethylene glycol and water are sometimes informally referred to in industry as glycol concentrates, compounds, mixtures, or solutions.

Anti-freeze: Pure ethylene glycol freezes at about −12 °C (10.4 °F) but, when mixed with water, the mixture freezes at a lower temperature. For example, a mixture of 60% ethylene glycol and 40% water freezes at −45 °C (−49 °F). Diethylene glycol behaves similarly. The freezing point depression of some mixtures can be explained as a colligative property of solutions but, in highly concentrated mixtures such as the example, deviations from ideal solution behaviour are expected due to the influence of intermolecular forces. It's important to note that though pure and distilled water will have a greater specific heat capacity than any mixture of antifreeze and water. The use of ethylene glycol not only depresses the freezing point of aqueous mixtures, but also elevates their boiling point. This results in the operating temperature range for heat-transfer fluids being broadened on both ends of the temperature scale. The increase in boiling temperature is due to pure ethylene glycol having a much higher boiling point and lower vapor pressure than pure water, as is typical with most binary mixtures of volatile liquids.

Chemical Reaction: Ethylene glycol is used as a protecting group for carbonyl groups in organic synthesis. Treating a ketone or aldehyde with ethylene glycol in the presence of an acid catalyst (e.g., p-toluenesulfonic acid; BF3·Et2O) gives the corresponding a 1,3-dioxolane, which is resistant to bases and other nucleophiles. The 1,3-dioxolane protecting group can thereafter be removed by further acid hydrolysis. In this example, isophorone was protected using ethylene glycol with p-toluenesulfonic acid in moderate yield. Water was removed by azeotropic distillation to shift the equilibrium to the right.
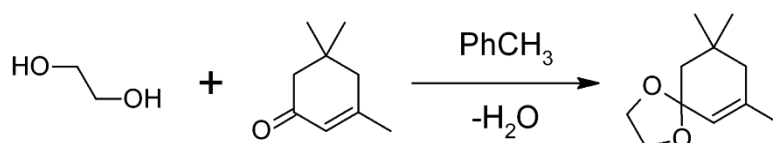
Toxicity: Ethylene glycol has relatively high mammalian toxicity when ingested, roughly on par with methanol, with an oral LDLo = 786 mg/kg for humans.[29] The major danger is due to its sweet taste, which can attract children and animals. Upon ingestion, ethylene glycol is oxidized to glycolic acid, which is, in turn, oxidized to oxalic acid, which is toxic. It and its toxic byproducts first affect the central nervous system, then the heart, and finally the kidneys. Ingestion of sufficient amounts is fatal if untreated.[30] Several deaths are recorded annually in the U.S. alone. Several hundred children die of acute kidney failure in Indonesia and Gambia because the paracetamol syrup made by New Delhi-based Maiden Pharmaceuticals contains ethylene glycol and diethylene glycol, ingredients that have been linked to child deaths from acute kidney injury in the gambia.

Environmental Effect: Ethylene glycol is a high-production-volume chemical; it breaks down in air in about 10 days and in water or soil in a few weeks. It enters the environment through the dispersal of ethylene glycol-containing products, especially at airports, where it is used in de-icing agents for runways and airplanes. While prolonged low doses of ethylene glycol show no toxicity, at near lethal doses (≥ 1000 mg/kg per day) ethylene glycol acts as a teratogen. Based on a rather extensive database, it induces skeletal variations and malformations in rats and mice by all routes of exposure. This molecule has been observed in outer space.

Butane: It is organic compound with the formula C_4H_{10}. Butane is a saturated hydrocarbon containing 4 carbons, with an unbranched structure.

Butane is primarily used as a gasoline mixture, either alone or in a propane mixture. It is also used as a feedstock for ethylene and butadiene production. Butane, like propane comes from natural gas or petroleum refineries and the two gases are usually found together. The butane is stored under pressure as a liquid. When the curler is switched on, butane is released and changes to a gas. Other names – Methylethylmethane, n-Butane.

Properties:

C$_4$H$_{10}$	Butane
Density	2.48 kg/m^3
Molecular weight/ molar mass	58.12 g/mol
Boiling point	-1 ^{0}C
Melting point	-138 ^{0}C
Chemical formula	C$_4$H$_{10}$
Odour	Odourless
Appearance	Colourless gas
Covalently-bonded unit	1
Specific gravity	0.601
Complexity	2
solubility	Insoluble in water

Butane structure- C$_4$H$_{10}$
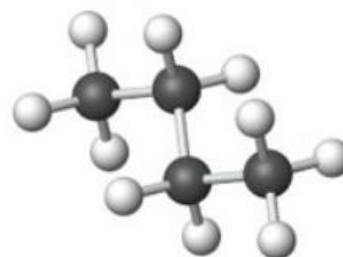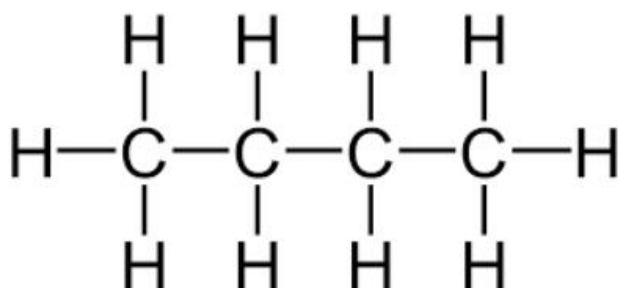
Chemical properties:

- Butane undergoes oxidation which results in the formation of carbon dioxide and water. The chemical equation is given below.

    2C4H10 + 13O2 → 8CO2 + 10H2O
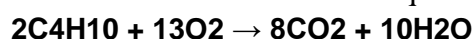
- Butane reacts with chlorine resulting in the formation of butyl chloride and hydrogen chloride. The chemical equation is given below.

    C4H10 + Cl2 → C4H9Cl + HCl
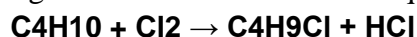
Uses of butane:

- Generally used for domestic purposes in cylinders painted red and is sold under various trade names.
- Used for gasoline blending, as fuel gas and as a feedstock in the production of ethylene and Butadiene.
- Used to produce methyl tertiary-butyl ether (MTBE)
- Used in catalytic dehydrogenation of butane or cracking of feedstocks to n-butenes and higher and lower boiling fractions

Working fluid chioces: The choice of working fluid is an important factor in the heat transfer performance of the LHP. This study focused on selfrewetting fluids; both the concentrations and solutes of selfrewetting fluids were investigated. The different solutes in this study were butanol.

Different concentrations: Since the surface tension curves as functions of temperature for alcohol aqueous solutions vary for different concentrations, changing the concentrations of alcohol aqueous solutions can have significant impact on the surface tensions. In addition, as suggested by literature, the best concentration should be around the saturation concentration; under standard conditions, the saturation concentrations for butanol, pentanol, and hexanol aqueous solutions are 6%, 2%, and 0.6%, respectively. Therefore, in this study, the following concentrations were chosen for surface tension measurements to find the best concentrations: 2%, 4%, 6%, and 8% for butanol aqueous solutions.

Different kind of solutes: Concerning the different solute choices for alcohol aqueous solutions, since the surface tension trend reversal becomes less obvious the longer the carbon chain in an alcohol is, butanol, pentanol, and hexanol were chosen as the solutes in this study. The best concentration for each alcohol aqueous solution determined was applied to LHP for performance testing to find the best solute choice for self reweeting fluid.

Water properties:
1. Chemical Formula: The chemical formula of water is H2O, which means it consists of two hydrogen atoms bonded to one oxygen atom.
2. Odorless and Tasteless: Pure water is odorless and tasteless. It does not have a distinct smell or flavor.
3. Colorless: Water appears colorless to the human eye. It does not have any inherent color.
4. State of Matter: Under normal conditions, pure water exists as a liquid. However, it can exist in other states of matter, such as ice (solid) and steam (gas), under specific temperature and pressure conditions.
5. Boiling Point and Freezing Point: The boiling point of water is 100 degrees Celsius (212 degrees Fahrenheit) at sea level and standard atmospheric pressure. The freezing point of water is 0 degrees Celsius (32 degrees Fahrenheit) at sea level and standard atmospheric pressure.
6. Density: The density of pure water is approximately 1 gram per cubic centimeter (g/cm³) at 4 degrees Celsius (39.2 degrees Fahrenheit). This density is often used as a reference point for comparing the densites of other substances.
7. High specific heat capacity: water has a high specific capacity which means it can absorb and retain a significant amount of heat energy without experincing a large increase in temperature. This property makes water useful for moderating temperature changes in various environiments.

8. High heat of vaporiazation: water has a high heat of vaporization meaning it requires a significant amount of heat energy to convert from liquid to gas. This property contributes to the cooling effect of sweating in living organisms.
9. Solvant properties; water is often called the universal solvant because it can dissolve a wide range of substances, including salts, sugars, gases, and many other polar and iconic compounds. This property makes water essential for various biological and chemical process.
10. Surface tension: water exhibits surface tension, which allows it to from droplets and maintain a distinct surface. Surface tension is responsible for capillary action and other phenomena related to the behaviour of water it interfaces.
11. High boiling and freezing points: Water has a relatively high boiling point (100 degrees Celsius or 212 degrees Fahrenheit) and freezing point (0 degrees Celsius or 32 degrees Fahrenheit) compared to many other common liquids. This allows water to exist in liquid form over a wide range of temperatures, making it suitable for various biological processes.
12. High dielectric constant: Water has a high dielectric constant, making it a good electrical conductor. It facilitates the dissolving and ionization of substances in aqueous solutions, playing a crucial role in many biological processes. pH neutrality.
13. Pure water has a pH of 7, which is considered neutral on the pH scale. It can act as a buffer and help maintain stable pH levels in biological systems.

Calculation and results:

CHAPTER 5
Battery pack design and heat pipe design and analysis in CFD.
 Battery cell specification:
1. Cell number: 18650 lithium ion
2. Dimensions: The 18650 designation refers to the dimensions of the battery. The "18" represents an 18mm diameter, while "65" signifies a height of 65mm.
3. Nominal Voltage: The nominal voltage of an 18650 cell is usually 3.6 to 3.7 volts. However, it can vary depending on the specific chemistry and manufacturer.
4. Capacity: The capacity of an 18650 battery cell indicates the amount of charge it can store. It is typically measured in milliampere-hours (mAh) or ampere-hours (Ah). Common capacities range from 1500mAh to 3500mAh, although higher-capacity cells are available. Slected cell capacity is 2200mAh.
5. Chemistry: The most common chemistry used in 18650 batteries is lithium-ion. However, there are variations within lithium-ion chemistry, such as Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LiFePO4), and Lithium Nickel Cobalt Aluminum Oxide (NCA). These variations offer different trade-offs in terms of energy density, discharge rate, and cycle life.
6. Discharge Rate: The discharge rate indicates the maximum current that can be drawn from the battery without damaging it. It is usually specified in terms of "C" ratings, where 1C refers to the battery's capacity. For example, a 2000mAh battery with a 2C discharge rate can safely provide a continuous current of 4 amps (2C * 2000mAh = 4000mA = 4A).
7. Cycle Life: The cycle life represents the number of charge-discharge cycles a battery can undergo before its capacity significantly degrades. Higher-quality 18650 cells can typically endure several hundred cycles, while lower-quality cells may have shorter lifespans.
8. Protection Circuit: Some 18650 batteries come with built-in protection circuits to prevent overcharging, over-discharging, and short circuits. These circuits enhance the safety of the battery but can add slightly to its overall size.

Design procedure of battery pack:
- Step 1: Determine the total capacity of the battery pack: Since each 18650 lithium-ion battery cell has a capacity of 2200mAh or 2.2Ah, and there are 9 cells in the battery pack, the total capacity of the battery pack can be calculated as follows: Total Capacity = Capacity per cell × Number of cells Total Capacity = 2.2Ah × 9 = 19.8Ah.
- Step 2: Calculate the energy capacity of the battery pack: The energy capacity can be calculated by multiplying the total capacity by the nominal voltage of the individual cells: Energy Capacity = Total Capacity × Nominal Voltage Energy Capacity = 19.8Ah × 3.7V = 73.26Wh.
- Output voltage : 12V.

- Step 3: calculate the number of battery cells required in series since the output voltage will be 12V and the nominal voltage of each 18650 cell is 3.7V, we need to calculate the number of cells required in series to achieve the desired output voltage: Number of Cells in Series = Output Voltage ÷ Nominal Voltage per cell Number of Cells in Series = 12V ÷ 3.7V = 3.24 (approximately). So we take number of cells in serries are 3 cells.
- Step 5: Calculate the number of parallel groups: To achieve the desired total capacity of 19.8Ah, we need to determine the number of parallel groups of cells. Each parallel group will consist of 3 cells.
- Step 6: Number of Parallel Groups = Total Capacity ÷ Capacity per cell Number of Parallel Groups = 19.8Ah ÷ 2.2Ah = 9 (since 9 cells were used in the battery pack).
- Final configuration are:
  - Number of cells in series: 3
  - Number of parellel groups: 9

Cell Balancing:

To calculate the cell balancing requirements for the battery pack, we need to consider the number of cells in series and parallel. In this case, the battery pack has 4 cells in series and 9 parallel groups. Cell balancing ensures that all the cells in the parallel groups have similar voltages, which helps optimize the performance and lifespan of the battery pack. The balancing process involves redistributing the charge among the cells to equalize their voltages.

Step 1: Determine the total number of cells in the battery pack: Total Number of Cells = Number of Cells in Series × Number of Parallel Groups Total Number of Cells = 4 cells × 9 parallel groups = 36 cells.

Step 2: Calculate the average voltage of the parallel groups: Average Voltage of Parallel Groups = Output Voltage ÷ Number of Parallel Groups Average Voltage of Parallel Groups = 12V ÷ 9 parallel groups = 1.33V (approximately).

Step 3: Identify the cell with the highest voltage: Assuming all cells have similar voltages initially, we can consider the voltage of any one cell as the highest voltage. Let's assume Cell A has the highest voltage.

Step 4: Determine the voltage difference between the highest voltage cell and the average voltage of parallel groups: Voltage Difference = Voltage of Cell A - Average Voltage of Parallel Groups.

Step 5: Calculate the required balancing current: Balancing Current = Voltage Difference ÷ Internal Resistance of Cells.

Internal resistance = 50 millioham.

So fninal voltage difference is 1.9V

Balancing current= 3.8A (depends on C battery capacity)

Balanced voltage of cell is denote as peak max voltage and peak less voltage because it control the charging and discharging of cell so to prevent cell failure it set value

Peak max voltage = 3.2V

Peak less voltage= 1V

State of Charge (SOC): SOC can be estimated based on the voltage measurements in relation to the voltage range.
- ➤ SOC = (Current Voltage - Peakless Voltage) / (Peak Maximum Limit - Peakless Voltage) * 100% • SOC = (3.7V - 3.2V) / (4.2V - 3.2V) * 100% • SOC = 50%.

State of Health (SOH): Determining SOH typically requires monitoring the capacity degradation over time. However, we can estimate an approximate SOH based on the initial capacity and the current SOC.
- ➤ SOH = (Current SOC / Initial SOC) * 100% • Assuming the initial SOC is 100% (considering a new battery): • SOH = (50% / 100%) * 100% • SOH = 50%.

Heat pipe design configuration:

An aluminum sheet heat pipe with a thickness of 0.5mm and its diameter is 8mm(0.31 inches):

Properties:

1. Lightweight: Aluminum is known for its low density, making it a lightweight material compared to other metals. This property makes it advantageous for applications where weight reduction is desired.
2. Corrosion Resistance: Aluminum has a natural oxide layer that forms on its surface, providing excellent resistance to corrosion. This inherent property makes aluminum sheets suitable for various outdoor and marine applications.
3. Good Thermal Conductivity: Aluminum has high thermal conductivity, allowing it to efficiently conduct and dissipate heat. This property makes it useful in applications that require heat transfer or dissipation, such as heat sinks or automotive components.
4. Electrical Conductivity: Aluminum is also a good conductor of electricity, though not as conductive as copper. It finds use in electrical applications where weight reduction is a consideration.
5. Formability: Aluminum sheets can be easily formed and shaped through processes like bending, rolling, or stamping, making them versatile for various manufacturing applications.
6. Strength: Aluminum exhibits moderate strength characteristics. While it is not as strong as some other metals, such as steel, it can still provide adequate strength for many applications.
7. Reflectivity: Aluminum has excellent reflectivity for both heat and light. This property is utilized in applications such as reflective coatings, mirrors, and solar panels.
8. Non-magnetic: Aluminum is non-magnetic, making it suitable for applications where magnetic interference needs to be minimized.