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Abstract: *During the operation of lithium-ion batteries, unexpected heat could be generated, which reduces the energy storage capacity as well as the longevity of the batteries. A unique cooling strategy involving an oscillating heat pipe is suggested as a solution to this study. The cooling channel is mounted on the outside of the battery module since electric vehicles have a little amount of space. This work used ANSYS/Fluent to build a lithium-ion battery model for a rectangular cell and evaluate its performance using the cooling system on the battery cell. The heat generated in the flow direction was absorbed by air-fluid throughout the cooling process, which decreased the cooling capacity. The temperature downstream is therefore always higher than the temperature upstream. In this process, the temperature varies from 288 K to 292 K. . In this study, the temperature of the battery rises quickly in the absence of a cooling system while rising gradually in the presence of one. As a result, the cooling system helped to provide a better outcome.*

Keywords: Cooling ability; Fluid; Li-ion battery; Improved performance; Temperature.

1. INTRODUCTION

Lithium-ion battery packs are well recognized for having significant benefits over other types of battery technologies for high-energy applications, such as electric vehicle propulsion [1,2]. The application of phase change materials for cooling Li-ion battery packs is a revolutionary technique that solves the temperature issue more efficiently. Earlier articles and patents presented and provided examples of the phase change material idea as well as the technical aspects of the technology that made the application feasible. Particularly, comprehensive results from experiments and modeling have been published at several events. In this work, we show examples of a method for applying a protection circuit module (PCM) in portable high-power applications with a regulated thermal environment and demonstrate a passive thermal management system using PCM for high energy [3]. In recent years, Li-ion batteries, one of the most technologically advanced rechargeable, have received a lot of attention. It is presently the only kind of transportable power source for portable electronics, being utilized in many fields such as home, laptops, and cell phones [4]. The market for energy-saving and environmentally friendly electric drive vehicles will expand more if batteries have much more energy, can go farther, and are less expensive. Electric products, electric vehicles, and hybrid electric vehicles all benefit from use the of lithium-ion (Li-ion) batteries [5]. A battery thermal management system that maintains the temperature at an ideal range of 15°C to 35°C is crucial to extending the lifetime and ensuring operating safety. The battery pack produces a lot of heat while the car is running that needs to be vented. It is increasingly difficult to reduce the produced heat and keep a stable temperature due to the rising energy consumption [6]. Due to its unparalleled combination of high energy and power density, lithium-ion batteries are the chosen technology for hybrid and fully electric automobiles, power tools, and portable electronic devices. If electric vehicles replace the majority of the bulk of gasoline-powered cars, greenhouse gas emissions will be reduced significantly due to lithium-ion batteries [7]. Lithium-ion battery's high energy performance may also allow for their use in a wide range of electric grid applications, such as enhancing the level of quality of energy generated by wind, solar, geothermal, and other renewable power, thereby encouraging their wider adoption and boosting the growth of an economy that is energy-sustainable [8]. For some uses, Li-ion batteries are currently costly, and a future lack of lithium and some of the transition metals used in Li-ion batteries would be a challenge [9]. Li-ion batteries, in comparison to other chemistries, have several fundamental advantages. Since Li has the lowest reduction potential of any element, Li-ion batteries have the highest cell potential. Li-ion is the third lightest element and has one of the smallest atomic radii of any single charged ion. In the foreseeable future, there is unlikely to be a severe lithium shortage [10]. The lithium-ion battery diagram defines in Fig. 1.

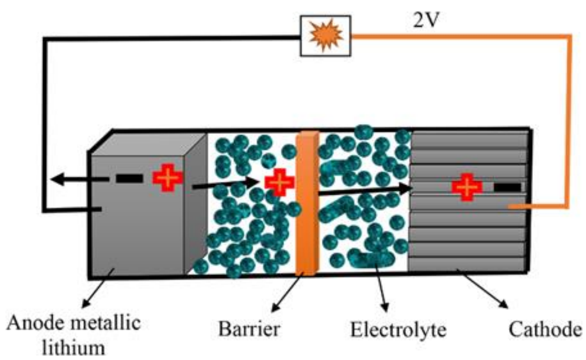

Fig. 1. Schematic diagram of Li-ion battery.

In terms of absolute amounts, there is enough Li in the Earth's crust to fuel an entire world's worth of cars. However, as the cost is the main barrier preventing Li-ion batteries from being widely used in renewable energy applications, rising prices might be an issue. Despite this, lithium no longer significantly affects the cost of Li-ion batteries [11]. Although simulation of each part of a battery has been approached greatly, no efforts have been made to model a Li-ion battery pack that takes into account all relevant physics. In this study, a full model of a lithium-ion battery pack is developed taking into account all of the preceding factors. Then, an interconnected environment may be used to study how various physics interact. When suitable, Memory technology is employed to make the simulation real utilizing such a model. The cathode and electrolyte only make up a little portion of the total cost. For lithium-ion battery technology, silicon (Si) has shown to be a very good and extraordinary anode material. Silicon has the highest specific gravity and volume capacities of all the known elements, and it can be purchased at a very low price. It is rather common in the crust of the earth [12–17]. Due to its low working potential compared to graphite electrodes, it is also less dangerous. However, there are massive, extremely important barriers preventing silicon (Si) anodes from being fully operational and marketed. The first difficulty is the substantial volume change that takes place during the insertion and extraction of lithium ions. In Si-based electrodes, recycling or reusing and de-lithiation are carried out by a conversion reaction. Each silicon atom in this process captures four lithium atoms. With high lithium (Li) storage capacity of 4200 mAh/g, the richest phase of the Li-Si, $Li_{22}Si_5$ ($Li_{4.4}Si$), at 415°C, results in significant volume growth of around 310%. Another $Li_{15}Si_4$ phase with a lithium (Li) capacity of 3579 mAh/g and a lower volume enlargement capacity of 280% is present at a normal temperature. High volume fluctuations pose several issues for silicon-based anodes, such as uneven and unstable electrical contact [18], particle breaking, repeated dynamic solid electrolyte interphase (SEI) layer formation, and inefficient electron transport as given in Fig. 2.

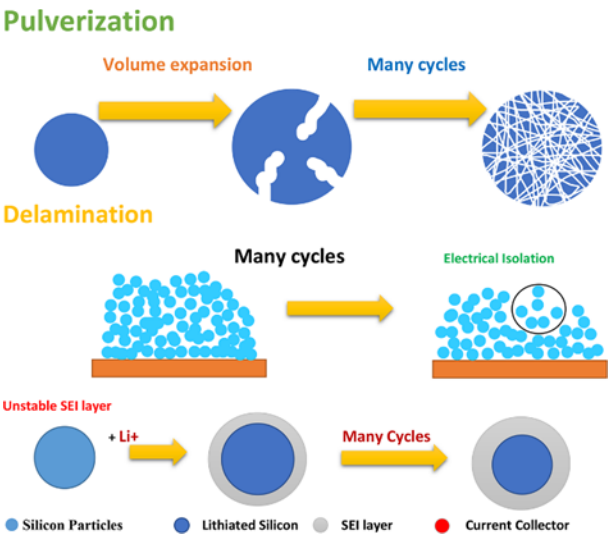

Fig. 2. Structure of compound-based silicon material for anode.

The main influencing elements in these components are the processing and cobalt in cathode costs [19]. Given their advantages, Li-ion batteries will probably remain the majority of portable electrochemical energy storage for many years to come. Because Li-ion batteries are the preferred source of portable electrochemical energy storage, reducing their price and improving their performance will enable technological innovations that need energy storage as well as significantly expand the uses for current ones. The electrode materials have received a lot of attention in Li-ion battery development up to this point [20]. By employing electrodes with superior rate capability, greater charge capacity, and (for cathodes) a suitable voltage level, lithium batteries might well be reduced in size and much less expensive [21]. The charge/discharge rate of a lithium-ion (Li-ion) battery is significantly influenced by the Li-ion and electron transport kinetics across the electrode bulk and electrode surface [22]. Effective high-power Li-ion battery manufacturing techniques up to this point have principally focused on the logical design and synthesis of nanostructured electrode materials. As anodes for lithium ions (Li-ion) full batteries, for instance, germanium or graphene hybrid nanosheets, graphene nanosheets, and manganese oxide nanocrystals have been investigated [23]. Investigations have also been conducted on an all-three-dimensional graphene foam-based Li-ion complete battery that offers a high specific capacity of 117 mAh/g at 10 C while reserving 88 percent of the capacity at 1 C. Two-dimensional nanomaterials, particularly hybrid nanosheets, have attracted increasing interest due to their intriguing properties and various applications in electronics, optoelectronics, catalysis, energy storage, and conversion. Two-dimensional nanostructures provide short ion diffusion length and open charge transport channels, which are advantageous for quick charge and discharge in energy storage applications like Li-ion batteries [24]. There have been several two-dimensional nanomaterials and hybrid nanosheet structures studied as anodes or cathodes for Li-ion batteries, including silicon, graphene, metal oxides, lithium metal oxides, lithium metal phosphate, and many others. Li-ion battery has the unique feature of being lightweight, smaller in size, and good discharge rate [25]. The electrodes of Li-ion batteries can be made of a variety of materials. Graphite and lithium cobalt oxide are the most typical combination. The energy transfer empirical laws for flowing through rectangular channels were used to validate the simulation studies used in this study since the geometric model in the flow through tube banks theory is similar to the present employment. The tubes were arranged in an inline form with the flow direction staggered [26]. The battery cells are handled like tubes and passed by the fluid through a pump. The basic purpose of the simulation of a Li-ion battery with a cooling system is to maintain the temperature. The initial temperature is 288 K applying 1000 iterations final temperature is 292 K. In all, temperatures vary from 288 K to 307 K. Peyman Gholamali Zadeh et al. (2022) the mathematical model was created using Newman's pseudo-two-dimensional (P2D) model, which took electrochemical heat production into account. A large capacity decline was also observed when the battery temperature rise; after 500 cycles at 55 C, there was a 70% capacity loss [27]. Soderberg et al. (2022), ANSYS Fluent, a computational fluid dynamic (CFD) program, will be used to construct a battery pack so that it can be

simulated to determine how cooling techniques affect the energy density of 18650 batteries. In this work, both air and liquid cooling will be employed, with a fan acting as air cooling and plate cooling acting as liquid cooling [28]. G. Murali et al. in (2021), the adoption of a hybrid thermal management system in conjunction with a protection circuit module (PCM) for improving battery thermal management system (BTMS) cooling performance is where the present effort starts. Additionally, a summary of some of the PCM heat transfer enhancement approaches is provided, including the use of cellular foams, thermally conductive particles, and immersion [29]. Hongya Zhang et al. in (2020), found that at a proper coolant inlet velocity and temperature, the battery temperature, and temperature gradients were maintained at a reasonable level even at a 5 C discharge rate and under external shorting circumstances, despite the running battery's temperature quickly rising to 80°C, which could cause an overheating [30]. Hamadou Hampate Ba et al. in (2015), the protection circuit module (PCM) demonstrated fast transient characteristics than forced convection cooling in the test scenario under investigation. The protection circuit module cooling can delay the transient time for temperature rise and maintain a lower maximum temperature throughout the melting process. Additionally, it is determined that a crucial variable for optimizing the protection circuit module (PCM) cooling method is the bulk density of the graphene matrix [31].
In this work, ANSYS Fluent software was used to determine the lithium-ion battery's temperature. To control the temperature, we use an air-cooling battery. Because it features an air-cooling system, which is used in the latest innovations like autos, mobile phones, UPSs, etc., this battery application is more efficient than other batteries. In comparison to previous studies, our simulation produced better findings.

2. ANSYS SIMULATION

ANSYS is software nowadays that is very famous for studying different projects and is also used in different fields for calculating data of projects. Many researchers have used ANSYS software for simulation fabrication [32,33,42–48,34–41]. We used an Analysis System (ANSYS) fluid fluent for the simulation of the Li-ion battery with the cooling system. In geometry draw the three simple sketches using rectangular of different sizes for the cooling system and apply the dimension of the main body and the other two bodies one is the anode terminal and the next is the cathode. The surface area of the active body cell is $7211.8x10^3$ m^2, the depth is 5 mm, the dimension is 80 mm, volume is $15087x10^3$ m^2, with 6 faces, 12 edges, and 8 vertices. The surface area of the cathode is $500x10^3$ m^2, volume is $415x10^3 m^2$, with 6 faces, 12 edges, and 8 vertices. Also, the anode is the same. In the last used two solid blocks on the surface of the active cell on both sides. The surface area of the block is $7211.8x10^3$ m^2, volume is $15087x10^3$ m^2 another block area and volume are the same respect given in Fig. 3.
In meshing for good results and more accurate simulation change the values of element size, maximum size, and defeature size. The element size is $1.09x10^{-3}$ m^2, the maximum size is $4.45x10^{-3}$ m^2, and the growth rate is 1.2. The above two parts of the active body selecting fluid and assigning the name are entering points of both is inlet and another outside is the outlets. Assign the name of all parts such as anode and cathode. In the last, selecting the span angle is fine. For better meshing use Hexa cell minimum orthogonal quality is 1 and the maximum aspect ratio is 1.8248902. There are 50040 nodes and 39830 elements. The meshing diagram is shown in Fig. 4.

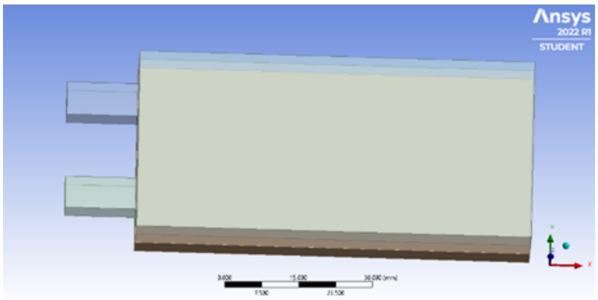

Fig. 3. The geometry of the Li-ion battery.

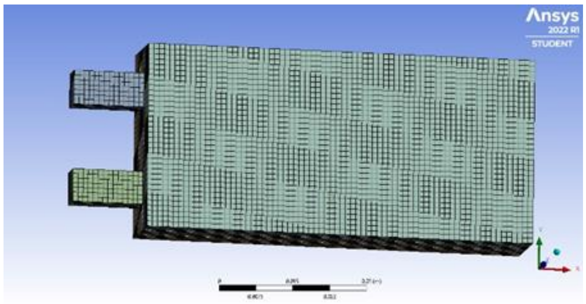

Fig. 4. The meshing of Li-ion battery.

The next step is setup simulation in this part we add the different materials and also put the different values for observing the different results. In the first step, we use the command (#define models addon-module) after this command the total tenth methods are shown on display. So from there select method number eight this method is called the multi-scale multi-domain (MSMD) battery model. After loading, this model put the different values. First of all, put the value of the current rate as 0.5 C current under the relaxation time as 0.8 C. for a better results power increase from 60 W to 80 W, and also put a minimum and maximum value of voltage. The minimum value is 3V and the maximum value is 4.5 V. Now put the value of storing power capacity of a battery cell is 16.5 (Ah). In the third step select conducting point with the battery cell. In this step, we identify the terminals of the battery if there are no points shown then issue in the geometry structure which means the terminal did not connect with the active cell. In the fourth step choose the positive and negative terminal and click on print display values for checking all the connections.
In the fifth step, we are adding the different materials and put the different values of metals. In this process, we used three materials Air, Aluminium, and Copper. The first material is Air. Air is used for the cooling system. By using the air, the temperature of the battery does not increase more rapidly. It prevents the battery from short circuits and also increases the lifetime of the battery. The next martial is Almunium and the next one is copper so Almunium(Al) is used for the active material of the

battery cell and Copper (Cu) is used for the positive and negative terminals. The thermophysical properties of Aluminum, copper, Air, and other parameters are the density of Air is 1.225 Kg/m^3, the density of Almunium is 2719 Kg/m^3, the density of Almunium of active material is 2095 Kg/m^3, and the density of copper is 8978 Kg/m^3. The second parameter of the heat capacity of all materials is the heat capacity of Air is 1006.43 J/KgK, the heat capacity of Almunium is 671 J/KgK, and the heat capacity for Almunium active material is 672 J/KgK, and the heat capacity of copper is 381 J/KgK. The third material is the thermal conductivity of Air is 0.0242 W/mK, the thermal conductivity of Almunium is 202.4 W/mK, the thermal conductivity of Almunium active material is 18.8 W/mK, and the thermal conductivity of copper is 387.6 W/mK.

When battery charging is started add the initial temperature is 288 K and apply the 1000 iteration. The temperature starts to increase reaching 307 K during the (0-50) iteration and gradually starts to decrease till reaching 292 K for 200 remaining iterations. There is no change in the temperature for the next 800 iterations. The temperature graph diagram is given in Fig. 5.

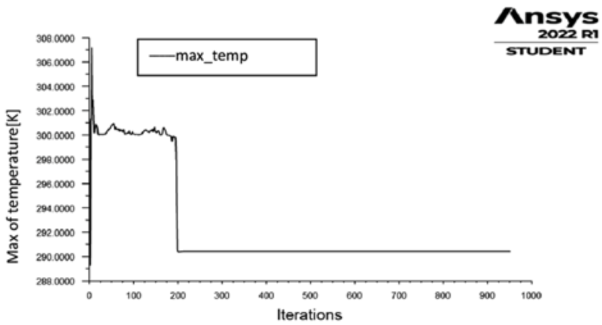

Fig. 5. Graph of temperature.

3. RESULTS AND DISCUSSIONS

For ANSYS simulation use the student version (2022) of the simulation lithium-ion (Li-ion) battery temperature control through the air-fluid. The initial temperature is 288 K and after the 1000 iteration temperature remains 292 K and varies from 288 K to 307 K. The depth is 5 mm and the volume of the battery is $7211.8x10^3$ m^2. The simulation results are in good agreement with the standard formulation results. The result of the work concluded that control temperature through air fluid. Many researchers are used ANSYS Fluent for the simulation of lithium-ion batteries. To simulate temperature rise, a thermoelectric coupling module is typically used in workbenches, but only for steady-state issues. ANSYS Fluent Module is utilized in this study to simulate transient electrothermal coupling. The computation time is set to 40 s during the simulation procedure under all operational circumstances. Under various thicknesses and currents, the connector's highest temperature curve changes over time. Xinke Li et al. (2021) use the air for the cooling system and the initial temperature is 313 K to 336 K. Shahabeddin K. Mohammadian et al. (2015) Farshad Dehghani et al. in (2011) the temperature at 0.5 C current rates increased from 300 K to 324 K. In these circumstances, there were more energy and power required for the cooling system of battery in previous research papers. They had to consume greater current rates for the cooling system. Furthermore, the battery pack's temperature ranges from 300 K to 312 K on the outside and 310 K to 324 K in the center when cooling is done by airflow and a 0.5 C current discharge rate. When cooling is carried out by a heat sink in the vacuum condition and 0.5 C current discharge rate, the temperature of the battery pack is between 286 K to 305 K on the outer sides and 290 K to 314 K in the middle. The diagram of the temperature contour mapping defines in Fig. 6 of this study. From the study, we have found the 288 K to 292 K temperature of the battery for the cooling system through ANSYS/Fluent. This result shows great agreement with the previous finding.

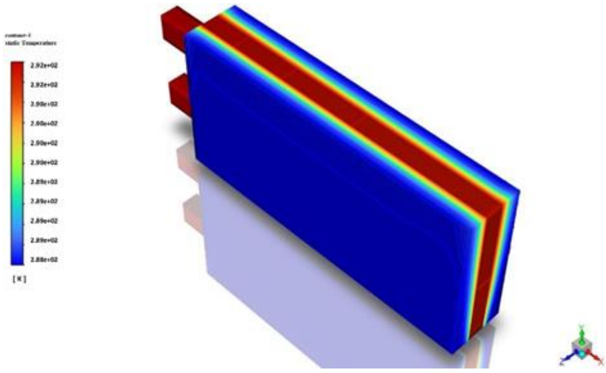

Fig. 6. Temperature contour of Li-ion battery with the air-cooling system.

Previous work used the same initial value of temperature from 288 K to 300 K and without the cooling system, it has a lot of temperature differences between them. Graphs of the temperature difference between the Li-ion battery with the cooling system and without the cooling system as shown in Fig. 7.

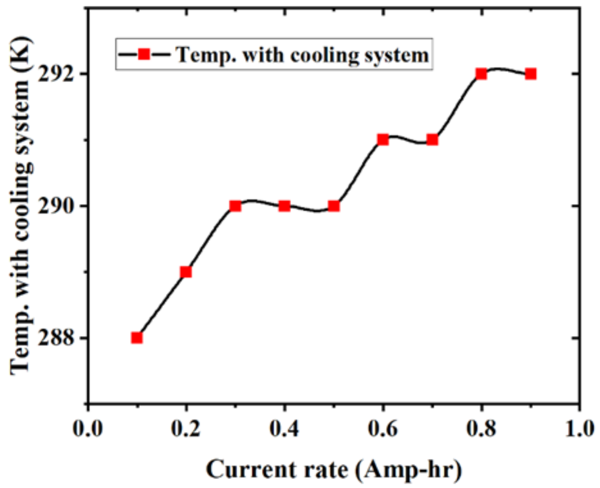

Fig. 7. Graph of temperature with cooling system.

In this Fig. 8 graph of temperature without the cooling system, temperature increases rapidly from 288 K to 300 K whereas the temperature of the battery varies from 288 K to 292 K with the cooling system graph as given in Fig 7.

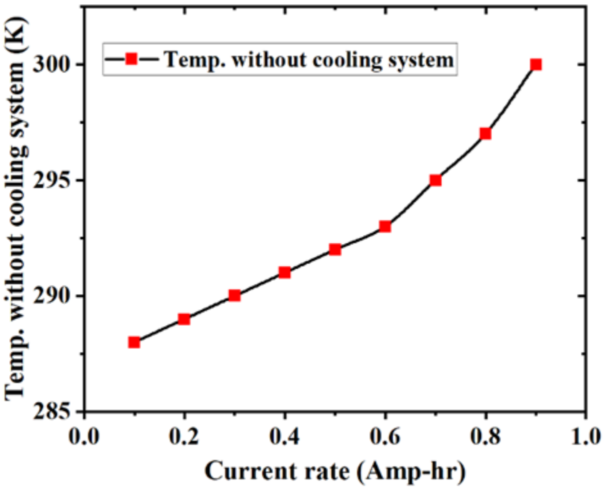

Fig. 8. Graph of temperature without the cooling system.

4. CONCLUSION

In this study, an ANSYS/Fluent model of an electrochemical-thermal battery for a rectangular cell was designed, and its performance was verified. The temperature begins at 288 K and reaches 292 K at the end of the process and without the cooling system temperature approaches 300 K. Without a cooling system also decreases the battery lifetime and has bad effects on the material of the device. The main recommendations and findings of our paper are to air-cooling battery thermal management system (BTMS) and the numerical analysis of the effects of air-flow configurations to determine an optimal design. This can effectively improve the non-uniformity temperature distribution and air-flow rate. The maximum temperature in the coolant passages is 292 K directly impacted by the inlet temperature of 288 K, although the temperature difference between the passages is less affected. Battery temperature from 288 K to 300 K rises quickly without the cooling system, but gradually when one is present. The cooling system, therefore, enriched the performance of the Li-ion battery outcome.

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