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Thermal Analysis of Forced Liquid Cooling on Li-Ion Battery

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ABSTRACT Battery packs are extensively used in electrical vehicles (EV). The safety, aging and life of battery pack are significantly related to its thermal behavior. This work concerns with thermal analysis on Zig Zag and U tube Staggered Lithium battery module. A Battery module is tasked with maintain a fixed range of temperature throughout the battery operation, thus enhancing its life and efficiency. The objective of our work is to compare temperature and coolant flow rate on Zig Zag and U tube battery module. Thermal Analysis is performed using Ansys Fluent. Simulation results show that the zigzag pattern has a lower surface temperature than the Ushaped pattern at the same coolant flow rate. In addition, the study investigates the effect of velocity Stream line on heat pipe. The result of this study can be used to can be used to optimize the design of cooling systems for Lithium ion batteries and improve their thermal management.

KEYWORDS: Electric Vehicle, battery module ,battery pack.

I. INTRODUCTION

Battery thermal management systems (BTMS) play a critical role in ensuring the safeand efficient operation of batteries, which are used in various applications electric vehicles,renewable energy storage, and portable electronic devices. BTMS is designed to control thetemperature of batteries within optimal operating ranges and maximize their performance,reliability and lifespan. These systems use passive and/or active cooling techniques to dissipateor extract heat from the batteries, maintain a constant temperature, and prevent thermalrunaway or overheating.

Passive and active BTMS are the two main categories used to categories contemporaryBattery management. Passive battery thermal management depends on the design and materialsused in the battery pack to passively dissipate heat. This can include heat sinks, phase changematerials, and insulation to control temperature. Although passive systems are relatively simpleand inexpensive, they may struggle to adequately control temperature under extremeconditions. On the other hand, active battery thermal management uses active cooling orheating methods to control the battery temperature more precisely. This includes the use offans, pumps, or liquid cooling systems to actively remove or supply heat as needed.

Our project focuses on thermal analysis of Lithium battery module by varying itsgeometry. Main parameters that taken into considerations are Channel parameters and numberof turns. Two geometries are taken into consideration i.e., U tube and Zig Zag module. Thefindings from this project can be utilized to optimize thermal management for EV battery packsor other systems requiring efficient temperature control. Ultimately, the project aims tocontribute to the development of more effective and reliable cooling solutions that enhance theperformance and longevity of batteries in various applications.

II. OBJECTIVES AND THEORY

To perform thermal analysis on Lithium 18650 battery module by varying geometry.Geometries taken to perform thermal analysis are U tube and Zig Zag module. Parameters like coolant mixture, Coolant parameters and coolant flow rate are all finalized. Both U tube module and zig zag module is designed and conducted thermal analysis on both U tube and Zig zag module is conducted on ANSYS Fluent.

The Overall structure of ANSYS Fluent consists of 3 steps they are pre-processing, solver, post- processing. In pre-processing, mesh generation, assigning various thermophysical properties and boundary conditions are performed. Solving is done by selecting appropriate solver, which is PISO solver and inputting data variables. After solving, post processing will shows graphical contours and results of performed analysis.Standard lithium 18650 batteries are used as Battery in thermal module. As coolant we'll be using Ethylene glycol – water mixture. The material properties are given in below Table 1.

Table 1 – Material properties

Name	Density	Specific Heat	Thermal Conductivity	Viscosity
Ethylene Glycol-50%	1012	3940	.43	.0033
Lithium Ion battery	1206	212.	.223	NA
Heat Pipe	8978	381	387.6	NA

Since we are not considering Thermo-chemical reaction and internal reaction inside battery. The batteries interior was modelled as a simplified solid and the following assumptions were made:

1. Cell is considered to be isotropic for sake of analysis.
2. The battery has uniform heat source.
3. Only conductive heat transfer is considered
4. Thermal capacity of cell is constant over time.

Energy conservation equation is used to understand energy transfer between battery cell and heat pipe.In simple term,energy equation can be written as,

Energy Input - Energy Output = Change in Energy Stored

Energy input is the energy supplied by the lithium cell, energy output is the energy consumed by coolant or heat pipe, and the change in energy storage gives relative energy stored in body.

$$\rho C\frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + Q$$

Where ρ is denoted as density, C as heat capacity and T is temperature of the given lithium battery and k is the thermal conductivity. Q is the rate of heat generation.

The energy conservation equation of a coolant, is used to understand heat transfer in coolant. There are 2 interactive surfaces with coolant heat pipe and battery pack

The energy saving equation can be expressed as,

$$\rho_c C_c\frac{\partial T_c}{\partial t} + \nabla(\rho_c C_c v T_c) = \nabla(k_c \nabla T_c)$$

The continuity equation is a fundamental principle in the study of fluid dynamics that describes the conservation of mass in a flowing fluid. It asserts that the mass flow rate into a specific region must be equal to the mass flow rate out of that region provided there are no mass sources or sinks in the fluid.

Mathematically, the Continuity equation can be expressed as:

$$\frac{\partial \rho_C}{\partial t} + \nabla(\rho_C v) = 0$$

Assuming the liquid is incompressible and the density does not change over time, the equation above is:

$$\nabla(v) = 0$$

The momentum equation can be expressed as

$$\rho_c\frac{dv}{dt} = -\nabla P + \mu\nabla^2 v$$

Where P represent the static pressure and μ denotes the dynamic viscosity of the coolant

III. DESIGN

Lithium 18650 cells are a type of rechargeable battery that has become increasingly popular in recent years. The "18650" refers to the battery's dimensions - 18mm in diameter and 65mm in length given in figure 1(a).High energy density, long life cycle,low cost and self discharge rating make Li 18650 cells popular amoung electric vehicles ,industries and others.This characteristics also make them suitable for hybrid electric vehicles.

In a staggered configuration, the batteries are arranged to offset each other, helping to maximize space utilization and reduce the overall dimensions of the battery pack module. This design helps to minimize the resistance between the batteries and improves the overall capability of the battery pack. To ensure better comparability and visualization of the thermal simulation experiments, both structures maintain an identical configuration in terms of battery count and the number of inlets and outlets. Specifically, both structures consist of 21 batteries and have 4 inlets and outlets each.

The battery has dimensions of 65 mm by 16 mm, is configured with 21 batteries, and a collapsible channel is designed using SolidWorks. The channel is designed to achieve maximum surface contact between the battery and the coolant channel in order to maximize heat transfer. The heat pipe is made of copper. Which is having thermal conductivity 385W/Km. Maximum battery-to-heat pipe contact is made possible by the heat pipe as a Zig Zag channel. As coolant we’ll be using ethylene glycol-water mixture. Both dimension and CAD is shown in Figures 1(b) and 1(c).

The arrangement of the 21 batteries is staggered with spacing of 10 mm between each battery. The coolant enters through the inlet, passes through the lithium battery pack, and exit through the outlet, thereby facilitating the cooling and dissipation of heat. The Channel is having a cross section area of 10 x 15 mm. Shown in Figure 1(d).

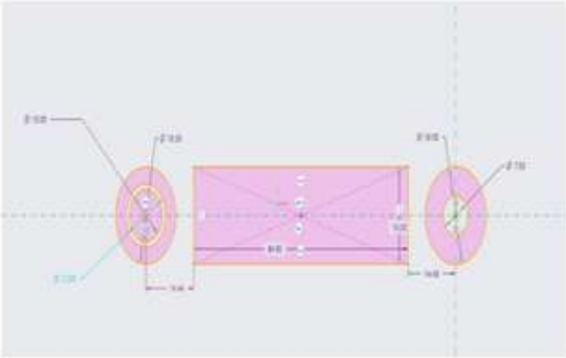


Figure 1 (a)

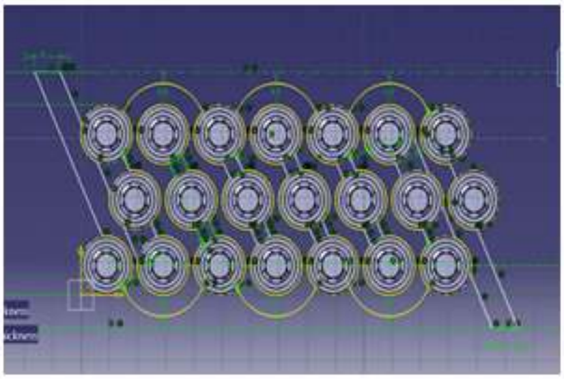


Figure 1(b)

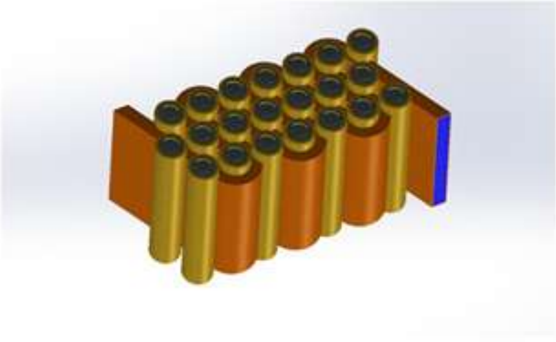


Figure 1(c)

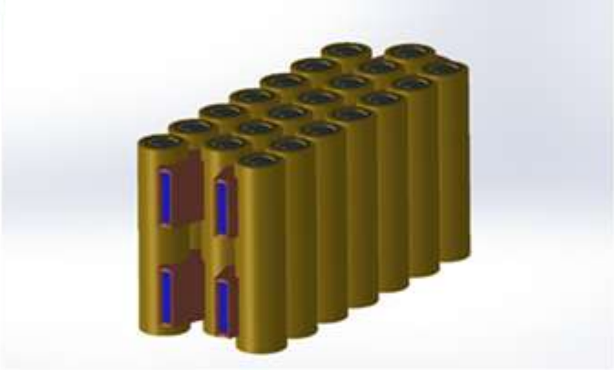


Figure 1 (d)

IV. MESHING AND BOUNDARY CONDITIONS

By using the feature of named selection, name all the part bodies such as batteries, heat pipe, flow domain, battery interface, heat pipe interface, inlets and outlets.Mesh is generated with default element size of 9.0434mm in linear element order. The following methods are used to generate mesh.

1. Patch conforming method is applied to the entire body. This technique involves dividing the model into small patches and creating a mesh for each patch separately. The resulting mesh is then combined to create a complete mesh for the model. The advantage of this method is that it allows for greater control over the mesh density and quality in different parts of the model.
2. Face Meshing is applied on the face of the fluid inlet and outlet zone. Face meshing is the process of creating a mesh directly on the surfaces of a solid model. This technique is used when the surface geometry is complex or irregular, making it difficult to generate a good-quality mesh using other methods. Face meshing can be performed using a variety of algorithms, including sweep, quad-dominant, and Delaunay.
3. Multizone method is applied on the entire fluid domain with body sizing of 2mm.Multizone meshing involves dividing the model into multiple regions and creating a separate mesh for each region. This technique is often used when the model has complex internal features, such as holes or channels that cannot be meshed using other methods. Multizone meshing allows for greater control over the mesh density and quality in different parts of the model, which will make this method perfect for fluid zone regions.
4. Body Sizing: Body sizing involves defining a mesh size or element size for the entire model or specific regions of the model. This technique is often used when a uniform mesh density is desired or when the model has a simple geometry that can be meshed using other methods. Body sizing allows for quick and easy mesh generation, but may not provide the same level of control over mesh quality as other methods.

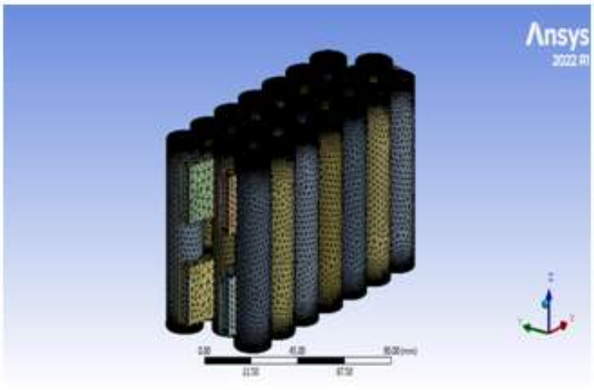


Figure 1(e)

Figure 1(f)

Interfaces are used to connect different regions or components within a simulation model. They allow the transfer of heat. There are 2 interfaces in designed module. They are heat pipe interface and battery interfaces. Walls are boundaries that define behaviour of a specific surface in a simulation. Two heat wall defined are battery wall and heat pipe wall. Attributes defined in battery wall are heat generation rate (42400 W/$m^{3)}$ and Wall thickness (0.00015 m).And heat pipe wall generate zero heat and it's having Wall thickness (0.00102 m).Inlet velocity of heat pipe is defined as 0.2 m/s.As shown in Table 2.

V. THERMAL ANALYSIS & RESULT

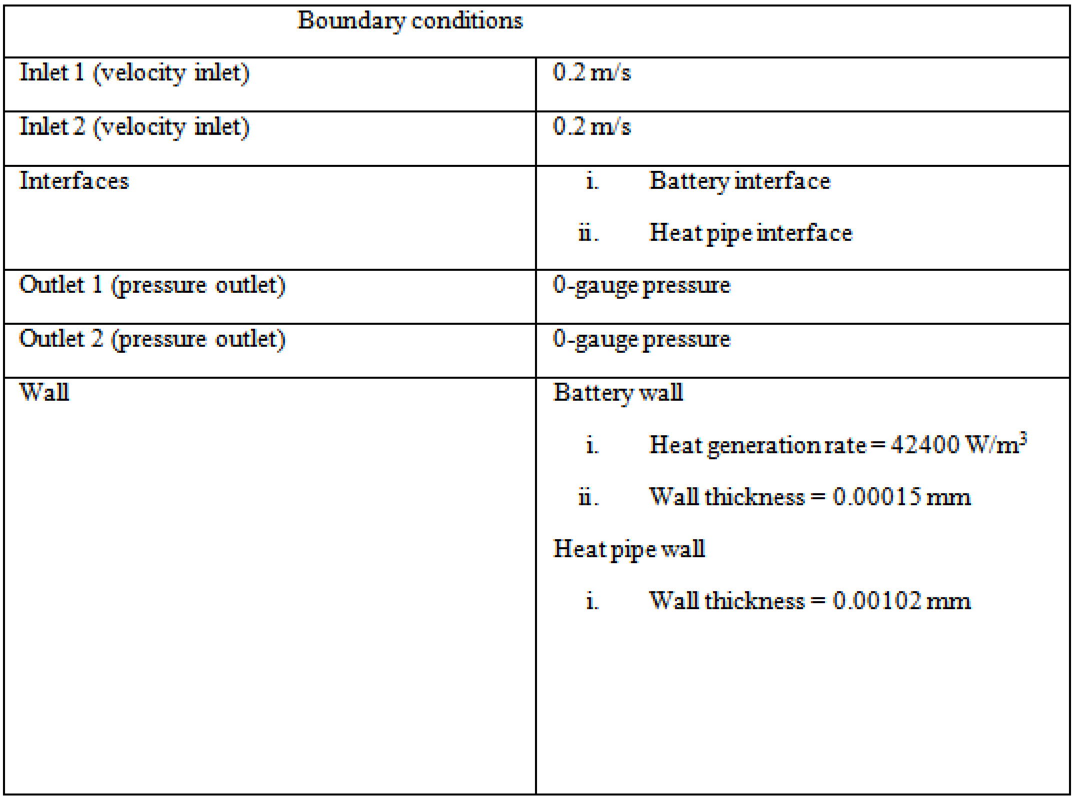
The solution uses the PISO method. So, The PISO (Pressure Implicit with Splitting of Operators) is a numerical method commonly used in Computational Fluid Dynamics (CFD) simulations to solve the Navier-Stokes equations. Standard initialization is computed from all zones. Run calculations parameters of 250 iterations in one reporting interval and one profile update interval.

Figure 1(g) Shown below is surface temperature contour of U-tube module.Set up is same as U tube Staggered module. The Standard initialization is from inlet. Run calculations parameters of 250 iterations in one reporting interval and one profile update interval. Surface temperature contour on zig zag staggered module is shown below Figure 1(h).

At 800 iterations and changing multizone from 2mm to 1mm.Battery interface temperature becomes stable. And Area – Weighted Average of temperature on battery interface become 399.04K ,as shown in Figure1(h) represents U tube and Figure 1(i) represents Zig Zag module.

Following Result as shown in Table 7-1 can be verified by conducting thermal analysis on both U tube Staggered and Zig zag module. Properties like battery interface temperature and heat pipe- battery interactions will be known through thermal analysis. Other parameters like heat pipe temperature is also available. But our main concern is on battery interface temperature.

Table 2 – Boundary conditions



Boundary conditions	
Inlet 1 (velocity inlet)	0.2 m/s
Inlet 2 (velocity inlet)	0.2 m/s
Interfaces	i. Battery interface ii. Heat pipe interface
Outlet 1 (pressure outlet)	0-gauge pressure
Outlet 2 (pressure outlet)	0-gauge pressure
Wall	Battery wall i. Heat generation rate = 42400 W/m^3 ii. Wall thickness = 0.00015 mm Heat pipe wall i. Wall thickness = 0.00102 mm

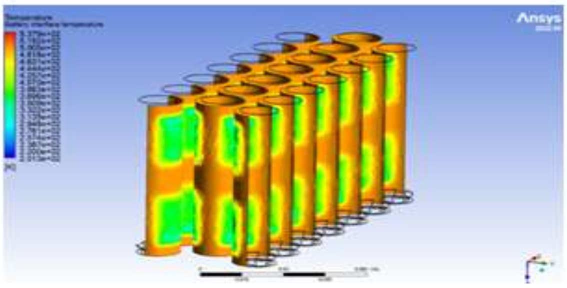


Figure 1(g)

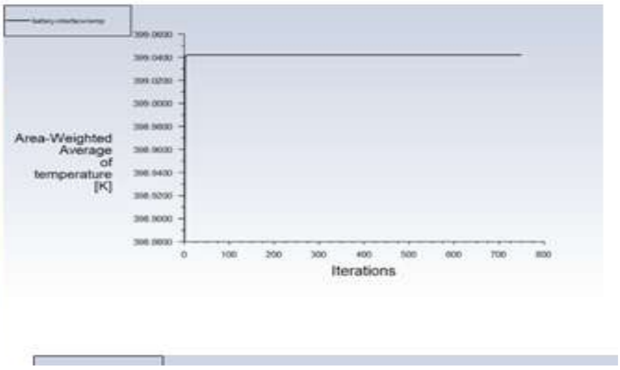


Figure 1(h)

Table 4 - Results

	Zig Zag Module	U tube Module
Battery Interface Temperature	398.88K	399.04 K
Heat pipe – battery interfaces	66	56

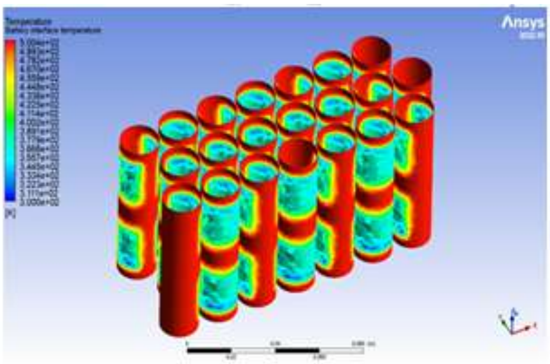


Figure 1(i)

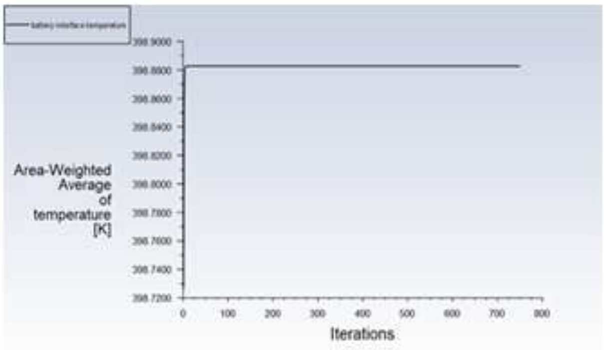


Figure 1 (j)

VI. CONCLUSION

In conclusion, to prevent thermal issues and optimize performance, it is important to effectively control battery temperature within specified limits. The temperature range in which a battery operates has a large impact on both its power output and cycle life. Therefore, maintaining proper temperature conditions is essential to maximize battery efficiency and life.

Two module designs were studied, the Staggered module and the Zig Zag module, to analyze and compare their cooling capabilities. The analysis showed that the Zig Zag module provides good cooling performance. This discovery is particularly valuable because efficient cooling is essential to the overall functionality and reliability of batteries.

One notable advantage of the Zig Zag module is its ability to provide more uniform cooling throughout the volume. This even distribution of cooling ensures that all areas of the battery receive proper temperature control, reducing the possibility of hot spots or temperature imbalances. As a result, batteries are less susceptible to thermal stress that can negatively affect performance and longevity.

In addition, the Zig Zag module exhibits better volume coverage, which means it can effectively cool a larger portion of the battery compared to the Staggered module. This extended coverage can improve thermal management of the entire battery, reducing the risk of overheating and related complications.By maintaining optimal temperature levels, Zig Zag modules help improve battery stability, reliability and overall performance.

Given these findings, it is recommended to prioritize the implementation of the Zig Zag module in battery systems where efficient cooling is a critical requirement. The Zig Zag module's ability to provide uniform cooling and extended volume coverage makes it an ideal choice for applications that require reliable and high-performance batteries.

FUTURE SCOPE

As the demand for electric vehicles (EVs) continues to rise, there is a growing need for efficient and reliable battery cooling systems. Two promising technologies that have gained attention in recent years are Zig Zag heat pipe battery cooling and U-tube battery cooling. These innovative cooling methods offer several advantages over traditional cooling techniques and hold significant future potential in the field of EV battery thermal management.

The future scope of Zig Zag heat pipe battery cooling lies in its ability to provide enhanced thermal performance and improved heat transfer efficiency. The Zig Zag configuration allows for better utilization of available space, making it suitable for compact battery designs in electric vehicles. Moreover, it offers flexibility in adapting to different battery sizes and configurations, making it a promising solution for future EV models. Similarly, U-tube battery cooling also presents a compelling future scope for EV battery thermal management. This cooling technique employs a series of U-shaped tubes that circulate a cooling medium around the battery cells.

In conclusion, both Zig Zag heat pipe battery cooling and U-tube battery cooling offer promising future prospects for EV battery thermal management. These innovative technologies address the challenges associated with temperature regulation in electric vehicle batteries, ensuring improved performance, efficiency, and durability. As research and development efforts continue, we can expect further advancements in these cooling methods, making them key components in the future of electric vehicle technology.

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