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Computational Investigation of Battery Warm Administration Framework with Hexagonal Cell Plans

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Abstract. **Sustainable power sources assume an essential part in moderating the serious effects of energy and natural emergencies. Among these, lithium-particle batteries have arisen as a promising arrangement in the capacity area because of their high mass and volumetric energy density. This study assesses two Battery Warm Administration (BTM) arrangements utilizing Computational Liquid Elements (CFD) reenactments for exact warm demonstrating. The results are looked at considering key boundaries like temperature dissemination inside battery cells and modules. Assess different Battery Warm Administration Frameworks (BTMSs) for hexagonal battery cell plans inside a Battery Module (BM) utilizing CFD. Use assessment results to propose an expense effective, streamlined, and low-upkeep BTMS for further developed BM performance. ANSYS Familiar is utilized to lead CFD Examination (CFDA) for wind current assessment inside the BTMS. Wind stream assessment gives further experiences into upgrading battery cell pressing game plans and carrying out one or the other dynamic or latent Warm Administration (TM) models. Thermal soundness assumes a basic part in guaranteeing the unwavering quality and functional productivity of a battery pack. The study affirms that legitimate warm administration can keep up with the battery module's warm conduct inside ideal circumstances, considerably under greatest functional burdens.**

Keywords: Thermal Management, Equivalent Circuit Model (ECM), Computational Fluid Dynamics (CFD), Parameter Estimation, Electrochemical-Thermal Modeling, ANSYS Simulation

1. INTRODUCTION

1. General Introduction, Needs, and Major Challenges

The surge in renewable energy production has significantly expanded opportunities for various energy storage solutions in today's energy market. Among these, lithium batteries stand out due to their lightweight nature and high energy density, making them a leading choice for storage technologies. Their advantages make them highly desirable for both stationary and automotive applications. However, several challenges persist, including limited lifespan, high costs, safety concerns, and temperature-related issues.

Temperature plays a crucial role in the performance, longevity, and safety of lithium-ion batteries. The optimal operating range for these batteries falls between 15-35°C [1]; deviations from this range may lead to hazardous incidents like thermal runaway while also compromising performance and lifespan. Additionally, temperature variations among cells and modules within a battery pack must be minimized to prevent negative impacts on battery operation and aging.

To effectively manage the heat generated within lithium batteries, an efficient Battery Thermal Management System (BTMS) is essential. Furthermore, in low-temperature conditions, heating mechanisms are necessary to maintain optimal performance. This study focuses on analyzing and comparing different cooling techniques used in the thermal management of lithium battery modules containing 21700 cylindrical cells. Using CFD software Star-CCM+, the study simulates the performance of a 96-cell module, replicating flow distribution, cell properties, and surrounding media [2]. Key parameters such as coolant temperature rise, maximum module temperature, and temperature distribution across individual cells and the entire module are evaluated to draw comparative insights.

1.1. Background

1.1. Li-ion batteries

They comprise Li in the positive electrode as well as an electrolyte, where Li-ions shift from negative to positive electrode while discharging and vice versa while charging. The Li-ion batteries' volumetric and mass-energy density is what gives leverage to them in contrast to other battery technologies, thus making them more significant for various purposes, specifically the automotive industry in which the energy density is important. Pouch, prismatic, and cylindrical are the 3 form factors by which Lithium Batteries are manufactured. Figure 1 displays that the layers are rolled and placed into a cylindrical can in cylindrical cells. Ease of manufacturing and mechanical stability are the merits of this cell format. For this design demands, the prismatic cell is wrapped in packages (Figure 2), which are found mostly in electronic devices like mobile phones. By removing the metal enclosure and allowing stacking, effective packaging is done in pouch cells.

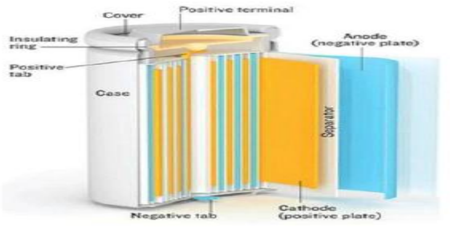

Figure 1. Li-ion cylindrical cell composition [2] Figure 2. Li-ion prismatic cell composition [3]

Figure 3. Li-ion pouch cell composition [3]

2. LITERATURE REVIEW

EVs: A Synthesis of the Present Literature with a Concentration on Economic as well as Environmental Viability: Dr. Robin North, Dr. Gregory Offer, Marcello Contestable, as per the study, for lowering costs and increasing the energy density, the EVs' long-term uptake would heavily rely on progress in battery technology and an appropriate recharging infrastructure's provision. (Marcello Contestable, 2012[1] Potential Requirement for EVs, Charging Station Infrastructure along with its Challenges for the Indian Market: by Kalyan Dash & Praveen Kumar, for managing the load problems locally, India must invest in smaller-scale reinforcements in place of going for a massive change. Home charging must be motivated. Prior to deploying the huge-scale charging infrastructure, appropriate planning of safety, population, place, and traffic density must be done. It was significant to integrate the activities within the energy as well as transport fields. The market would grow through the development goals via several innovative policies along with programs, for example, a financial consumer incentive, namely (i) purchase subsidies, (ii) tax credits, (iii) discounted tolls, (iv) free parking, and (v) access to controlled highway lanes rendered for electrical car drivers. (Dash P. K., 2013) [2] Traditional, Hybrid, or else EVs: Which Technology for an Urban Distribution Centre? by Cathy Macharis, Joeri Van Mierlo, Cedric De Cauwer, Philippe Lebeau, Goods transport had a chief effect on urban association. The EVs' probable amalgamation in urban logistics operations was explored by the researcher. The last mile's prices could be minimized by a fleet with various technologies. Fleet size as well as mixed vehicle routing issues with time windows for EVs were propounded. Considering the variability of EVs' range was the author's major contribution. Frequently, EVs were the most aggressive technology in smaller van segments. Since EVs were required for covering a long distance to be cost-effective, the financial point of view shows that diesel was the most remarkable solution in the larger van segment. In the truck segment, hybrid vehicles were selected since their fixed and running costs were low compared to diesel trucks. (Philippe

3. OBJECTIVE OF THE STUDY

3.1 Objectives

This study primarily focuses on evaluating different Battery Thermal Management Systems (BTMS) for various cell arrangements within a battery module (BM) using Computational Fluid Dynamics (CFD). Additionally, based on the evaluation results, the study aims to propose an optimal, cost-effective, and low-maintenance BTMS to enhance BM performance.

For this analysis, different types of cell arrangements in the BM are considered to determine the most efficient configuration. The specific cell arrangements used in this study are outlined below:

- Hexagonal battery arrangement

The above model will be investigated for the following operating conditions:

(a) Inlet Temperature - 15° C, 20° C and 25° C

(b) Inlet velocity - 1m/s, 3 m/s and 5 m/s

(c) Discharge Rate (DR) - 1 C & 2 C

3.2 Problem Formulation

The battery pack's physical model is designed using NX software. Figure 6 illustrates the cell arrangement along with the boundary conditions.

The battery cells are positioned as follows:

- Outer cells are placed 3 mm away from the case walls.
- A 5 mm gap is maintained from the case walls at both the top and bottom.
- An inter-cell spacing of 2 mm is maintained between individual cells.
- The casing material is assumed to maintain a temperature equivalent to the ambient environment (283 K or 10°C). Additionally, the heat transfer coefficient (h) for free air convection is considered 10 W/m²K.

Regarding flow conditions:

- At the intake, the gauge pressure is set to 0 Pa.
- The airflow velocity at the intake is 1 m/s.

The thermal conductivities of the 18650 batteries are:

- Radial conductivity: 20.06 W/m·K
- Axial conductivity: 3.39 W/m·K

4. METHODOLOGY

4.1 BASIC STEPS TO EXECUTE CFDA

4.1.1 Preprocessing:

- CAD Modeling
- Meshing:
- Type of Solver
- Physical model
- Material Property
- Boundary Condition

4.1.2 Solution:

- Solution Method: It is selected for solving the issue, that is, First and second order.
- Solution Initialization: The solution is initialized for obtaining the primary solution for the issue.
- Run Solution: By providing several iterations for a solution to converge, the solution is run.

4.1.3 Post-processing

Post Processing: To view and interpret the outcome. The outcomes could be viewed in different formats, such as the graph, value, animation, et cetera.

4.2 Analysis criteria

Figure 1 displays the technique to build an optimal air-cooled BTMS; Figure 2 exhibits the steps involved in performing BM's SFD simulation [9,10]. Cells that are connected in parallel and series are encompassed in BM. Utilizing the lumped technique, every single cell is designed, which is regarded as a homogeneous development. For this work, the Sanyo 18650 Lithium-ion cell is considered. Table 1 lists the cell's properties, which are utilized for the calculation of the lumped cell system's efficient thermal properties. The investigational outcomes of power, which is produced by the insulated Sanyo cell, [11] as well as energy source values at various DRs are exhibited in

Table 2. In 1C & 2C simulations, these energy sources are utilized.

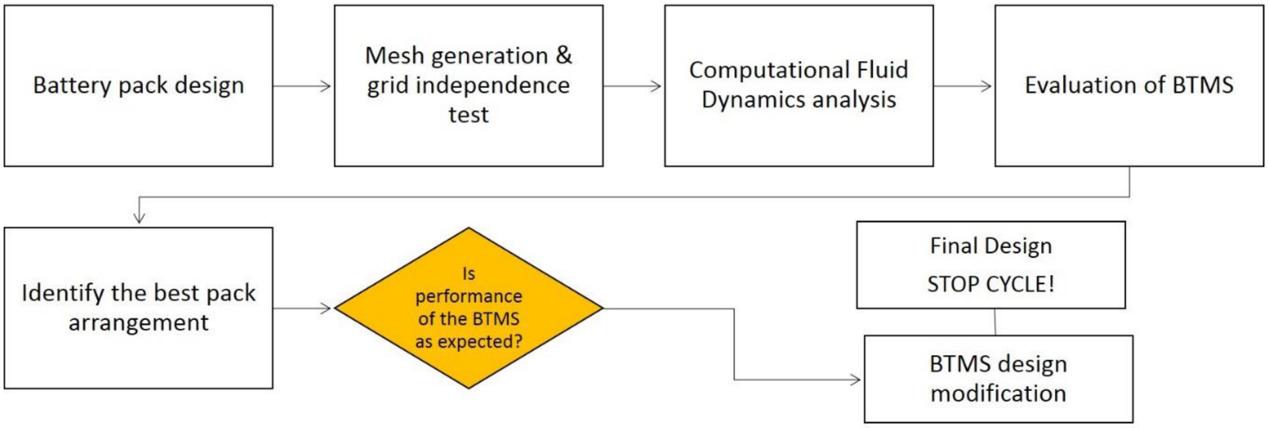

Figure 4: Iterative design technique for developing an optimal air-cooled BTMS

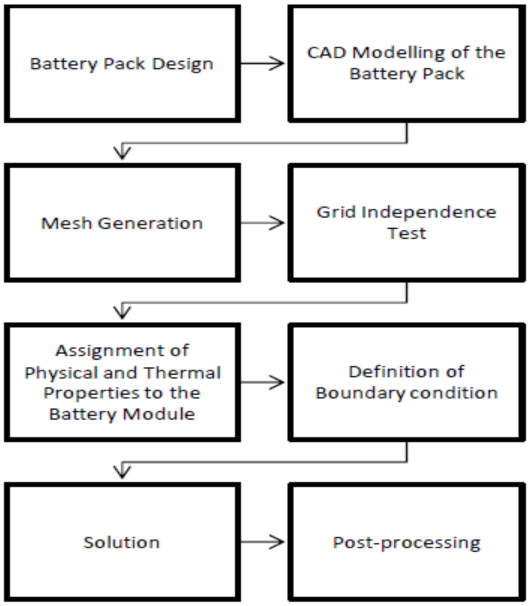

Figure 5: Technique adopted for CFDA of BM

Table 1: Energy source utilized in simulation at 1C and 2C

DR	**Thermal Power** **P (W)**	**Energy Source** **(W/m^3)**
1C	**0.0836**	**5417.01**
2C	**0.5248**	**31728.21**

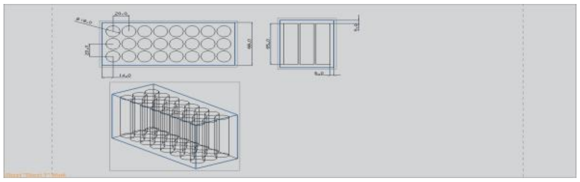

Figure 6: Dimensional detail 1

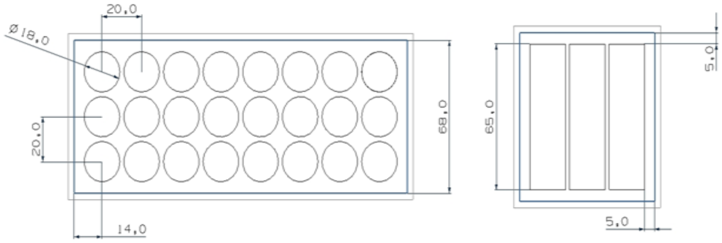

Figure 7: Dimensional detail with isometric wireframe

4.2 Governing equations

The governing equation utilized in the simulation for the BM is described further:

Continuity equation

$\nabla v = 0$ (1) (1)

Momentum conservation equation

$\rho\ \partial v\ \partial t + (v\nabla) = -\nabla p + \mu\nabla 2v$ (2) (2)

Energy Conservation Equation

$\partial E\ \partial t + (v\nabla) = \alpha\nabla 2E$ (3) (3)

4.3. Boundary condition

By considering cells' various arrangements inside the casing as hexagonal battery arrangements, BM's CFDA is done utilizing ANSYS [4]. For such arrangements, cells' Inlet Air Velocity (IAV), temperature, as well as DR are changed. At 1C & 2C, the DR is regarded; at 15°C, 20°C, along with 25°C, the Inlet Air Temperature (IAT) is regarded; at 1 m/s, 3 m/s, as well as 5 m/s, IAV is regarded. For recognizing the optimal cooling arrangement while the Air Inlet (AI) is on the BM's side, the BM's average and maximal temperature are examined. Figure displays the air's outlet and inlet.

5. RESULTS AND DISCUSSION

5.1. Cell arrangement

5.1.1. Hexagonal battery arrangement

Mostly, for every considered inlet temperature and velocity range, BM's maximal temperature and the average temperature in the hexagonal arrangement are like a rectangular arrangement at a low DR (1C) [5]. Table 2 shows the effect of IAT, DR, along with the velocity on BM's average as well as maximal temperature for hexagonal battery arrangement [6-8]. Here, the maximal temperature increases 15% more than a rectangular arrangement at higher DRs (2C & 3C) with 5°C inlet air temperature and 1 m/s IAV.

Table 2: Variation of the average and maximal temperature of the BM with IAV as well as IAT for the hexagonal battery arrangement at various DRs

BATTERY ARRANGEMENT	**INLET VELOCITY (m/s)**	**DISCHARGE RATE**	**INLET TEMP. (°C)**	**AVERAGE TEMP. IN BATTERY (°C)**	**MAXIMUM TEMP. IN BATTERY (°C)**
RECTANGULAR 3X8	5	2C	25	28.95	29.10

HEXAGONAL	5	2C	25	31.42	31.56
STAGGERED	5	2C	25	30.31	30.75

RESULTS OF IMAGES FOR ALL THE CASES

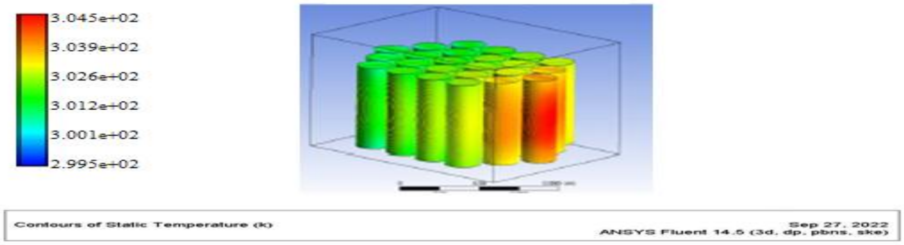

Figure 8: Contour of static Temperature on Battery cell isometric view in (Hexagonal cell arrangement) 2C, 25° C @ 1 m/s

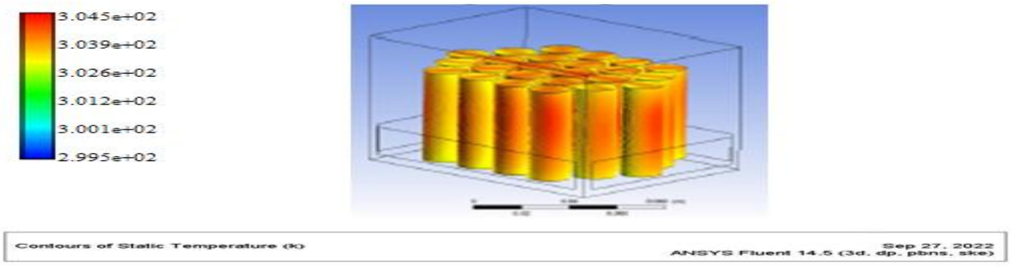

Figure 9: Contour of static Temperature on Battery cell isometric view in (Hexagonal cell arrangement) 2C, 25° C @ 3 m/s

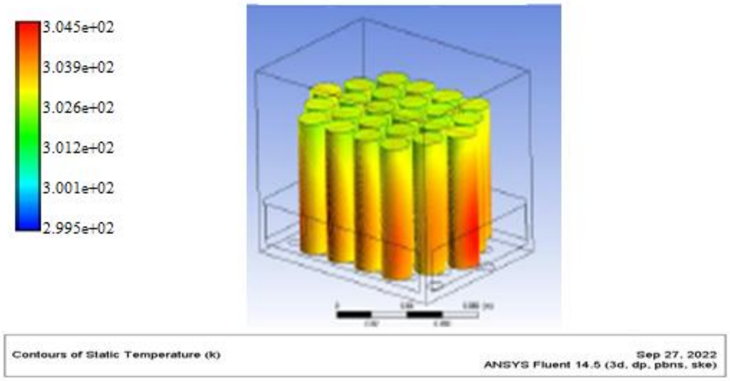

Figure 10: Contour of static Temperature on Battery cell isometric view in (Hexagonal cell arrangement) 2C, 25° C @ 5m/s

Discussion

In the provided images, planar contour visualizations are obtained by creating a plane from the top to the bottom of the cells and adjusting the distance accordingly [6-8]. The CFD simulation results indicate that the temperature gradually increases from the top to the bottom surface of the battery. However, it remains within a safe range, below the critical threshold.

Effect of Inlet Temperature

The inlet temperature's impact is primarily analyzed in the CFD simulation, along with discharge rate (DR) and inlet velocity. The system is tested at inlet temperatures of 15°C, 20°C, and 25°C, which are considered optimal for maintaining cell temperature within a safe atmospheric range.

Effect of Inlet Velocity and Discharge Rate (DR)

Inlet Velocity: According to CFD results, increasing the velocity under stable flow conditions leads to a decrease in the maximum cell temperature.

Discharge Rate (DR): As DR increases from 1C to 2C, the temperature rises on the cell sides, reaching its peak at the top surface of the cells.

Compared to ambient atmospheric temperature, the maximum temperature on the cell remains relatively low, indicating effective thermal management.

6. CONCLUSION

For examining and optimizing the BTMS model, the CFDA of the BM of 18650 Lithium-ion cells is done. A BM, which comprises twenty-four cells, is organized in various arrangements as hexagonal. For the optimal BTMS's various operational conditions, every single arrangement's influence on the maximal and average temperature of the BM at various DRs is noticed. Furthermore, the influence of changing IAT and IAV is investigated. Since the cell's power is elevating, the maximum along with average battery temperature is elevated with the gain in battery discharge. But, for various arrangements, a considerable decrease in the temperature is noticed while decreasing the inlet temperature and elevating the IAV. The maximal BM temperature for the AI on the side arrangement is diminished by approximately 17.4% than common environmental conditions devoid of velocity flow while the IAV is elevated as of 1 m/s - 5 m/s for stable IAT as well as 3×8 rectangular battery arrangement at a 2C DR. Likewise, the module's maximal and average temperature also diminishes with the decrease in the IAT. For sustaining the module temperature in a particular temperature range to get optimal performance for every BM arrangement with AI on the side as well as 1C DR, the 3 m/s air velocity and 20°C IAT are adequate. Nevertheless, a rise in velocity to 5 m/s is preferred for a 3C DR. Maintaining uniform temperature throughout BM along with the length of individual cells is crucial. Therefore, different heat sink arrangements are explored by adjusting the positioning of inlet and exhaust vents for both the hexagonal and 3×8 rectangular configurations.

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