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Design & Experimental Analysis of Heat Management Optimization & Vibration Isolation Battery Enclosure in Electric Vehicles

Desai Dhairyashil Shashikant [1] , Dr. Shriram Shastri Chavali [2] , Dr. Dilip. P. Deshmukh [3]

[1] P.G.Student, M.Tech (Design Engineering) , [2 & 3] Professor & Assistant Professor
Mechanical Engineering Department, D.Y. Patil University, School of Engineering & Technology, Ambi, Pune, Maharashtra, India
(Corresponding Author Email- d.skdesai@gmail.com)

Abstract**-**The Li-ion battery operation life is strongly dependent on the operating temperature and the temperature variation that occurs within each individual cell. Liquid- cooling is very effective in removing substantial amounts of heat with relatively low flow rates. On the other hand, air- cooling is simpler, lighter, and easier to maintain. However, forachieving similar cooling performance, a much higher volumetric air flow rate is required due to its lower heat capacity. This paper describes the fundamental differences between air-cooling and liquid-cooling applications in terms of basic flow and heat transfer parameters for Li-ion battery packsin terms of QITD (inlet temperature difference). For air- cooling concepts with high QITD, one must focus on heat transfer devices with relatively high heat transfer coefficients (100–150 W/m2/K) at air flow rates of 300–400 m3/h, low flow induced noise, and low-pressure drops. This can be achieved by using tabulators, such as delta winglets. The results show that the design concepts based on delta winglets can achieve QITD of greater than 150 W/K.

I. INTRODUCTION-Battery temperature greatly affects performance, safety, and the life of lithium-ion batteries in plug-in and pure electric vehicles under various driving conditions. Automakers and battery suppliers are paying attention to the thermal management of lithium-ion batteries to reduce elevated temperature excursions that could impact the life and safety of lithium-ion batteries. The operating temperatures for optimal battery performance and hence longer battery life occur in a very narrow temperature bandwidth which depends on the environments and the vehicle operations

The goal of a battery thermal management system is to maintain a battery pack at an optimum average temperature that operates in surrounding environments ranging from -40°C to 50°C(- 40°F to 122°F) and to minimize the temperature difference in cells. Lithium-ion batteries operate best at temperatures between 25°C and 35°C (77–95°F), which is currently difficult or expensive to maintain over the wide rangeof environmental conditions during normal vehicle operation. Active cooling and heating of the battery pack is a challenge due to constraints on cost, power, weight, and volume. Advanced cooling systems are required to remove heat from the energy storage system as well as maintaining cell temperatures uniformity [4–7]. Examples include active heat sinks, air jet impingement, microchannel cooling, heat pipes, immersion cooling, and spray cooling [8–16]. These systems can be far superior in heat removal rates but also pose problems that are more challenging to the designers and engineers.

Currently, the automotive industry relies on liquid cooling for pure electric vehicle battery packs. Liquid cooling is not an ideal solution due to various drawbacks such as potential leaks, weight, and its complexity. The ideal solution is air-cooling. However, air-cooling systems are not as effective as liquid-cooling due to lower heat capacity for air. Thus, the challenge is to achieve a novel air-cooling system which meets all the requirements. To evaluate these cooling concepts and compare their cooling per formances, one needs to understand the basic flow and heat transfer quantities associated with the cooling performance in terms of inlet temperature difference (QITD).

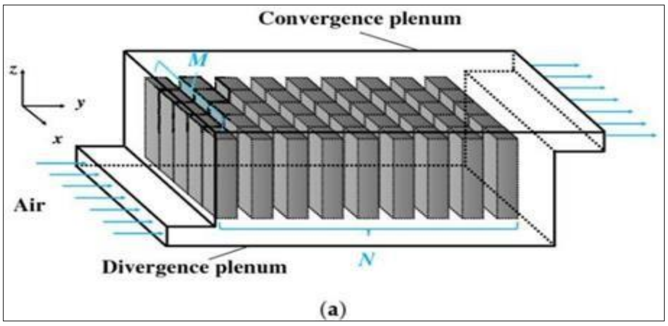
II. BATEERY THERMAL MANAGEMENT SYSTEM

The basic types of BTMS are listed below.

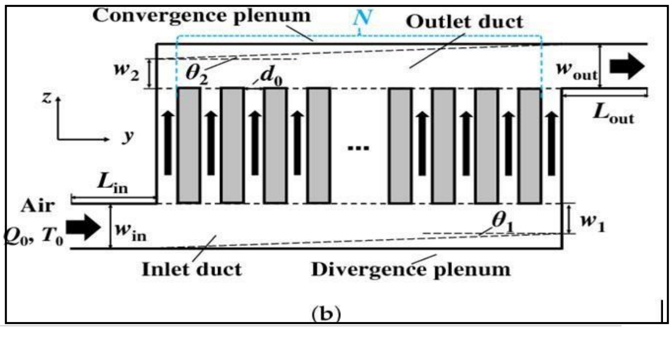
1. Air cooling
2. Liquid cooling
3. Direct refrigerant cooling
4. Phase change material cooling
5. Thermoelectric cooling
6. Heat pipe cooling

Air cooling:

Air systems use air as the thermal medium. The intake air could be direct either from the atmosphere or from the cabin and could also be conditioned air after a heater or evaporator of



(a)



an air conditioner. The former is called a passive air system and

Figure.1. Air cooling system [6].

the latter is an active air system. Active systems can offer additional cooling or heating power. A passive system canoffer some hundreds of watts cooling or heating power and active system power is limited to 1 kW [5]. Because in both cases the air is supplied by a blower, they are also called forced air systems.

Note that the air system offers full functions of heating, cooling, and ventilation. There is no need to build an additionalventilator, but it must be noted that the exhaust air cannot be returned to the cabin again. In some cases, a heat recovery unit (air-air heat exchanger) is mounted after the battery pack to recovery the heat from the exhaust air. It can prevent the mixture of exhaust air with intake air and at the same time provide extra saving potential.

Liquid cooling:

It is a cooling system in which water is used as the coolant for the purpose of cooling the battery. Liquid cooling is the most commonly used cooling system due to its convenient design and good cooling performance. Dielectric liquid cooling ordirect-contact liquid which can contact the battery cells directly, such as mineral oil. The other is conducting liquid or indirect-contact liquid which can only contact the battery cells indirectly, such as a mixture of ethylene glycol and water. Depending on the different liquids, different layouts are designed. For direct-contact liquid, the normal layout is to submerge modules in mineral oil. For indirect-contact liquid, a possible layout can be either a jacket around the battery module, discrete tubing around each module, placing the battery modules on a cooling/heating plate or combining the battery module with cooling/heating fins and plates [7]. Between these two groups, indirect contact systems are preferred to achieve better isolation between the battery module and surroundings and thus better safety performance. The studies on the liquid cooling system have always been fixated at the development of the physical design of the coolingplate and its channels and by targeting the parameters like; coolant pressure drop across the channels of the cooling plates and cell core temperature different designs are fabricated.

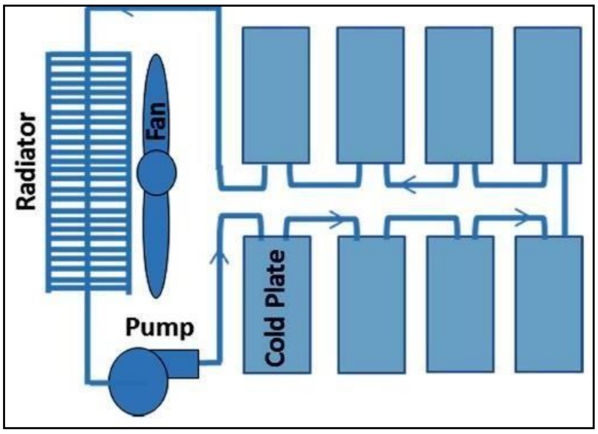


Figure.2. Liquid cooling system (Smith *et al.* 2015).

According to the previous research on the geometric development of the cooling plate, the highest cooling performance was achieved by channelled cooling and it also showed the minimum power consumption as compared to other methods. But channelled cooling is not ideal for temperature consistency due to the comparatively long path of flow.

The path of the heat transfer from the bottom of the battery to the cooling plate highly contribute to the thermal resistance of the battery pack structure, several modified pack designs are devised to enhance the cooling performance such as Thickened cooling fin design, Sandwich cooling plate design and the Interspersed cooling plate design. To optimize the structural design of the practical and large scale battery thermal management system for electric vehicles. A thermal model for the indirect fin-cooling battery pack is developed, type D-2 was proposed as an alternative design for BTMS. It improved the ratio of equivalent heat conductance to the system volume by 64% and the total pressure drop is increased by 19% and the 5.4°C maximum temperature difference was reduced by [8].

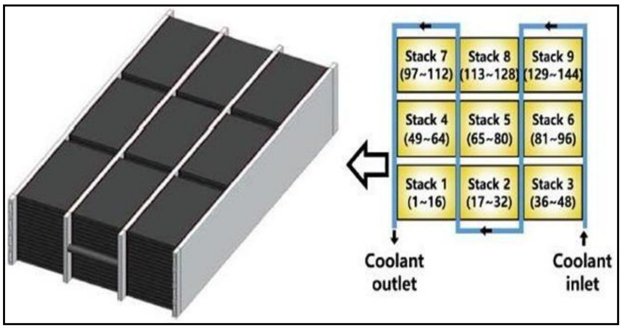


Figure.2.1. Type D-2 Proposed design (Chung *et al.* 2019).

Related Work-[1] Rao and S.Wang, A review of power battery thermal energy management, *Renewable & Sustainable Energy Reviews* 15 4554-4571

It has been observed that the EVs, HEVs and FCEVs are effective to reduce GHG and pollutants emission and save energy. The high energy power batteries, such as Ni-MH as a short and medium term selection, Li-ion batteries as medium-term and fuel cells as long-term selection can be seen as the best choice of the future for application in clean vehicles.

[2] Z Wan, J D Eng, B Li, Y Xu, X Wang and Y Tang, 2015 thermal performance of a miniature loop heat pipe using water-copper nanofluid *Applied Thermal Engineering* 78 712-719

The start-up and transient operation of the mLHP indicates that both the start uptime and the transient stage are reduced, and the evaporator wall temperature and the total thermal resistance decrease by 12.8% and 21.7%, respectively, when substituting the nanofluid with 1.0 wt% nano particles in place of deionized water alone at a heat input power of 100w. The evaporation heat transfer coefficient of the mLHP when using the nano fluid increases by 19.5% for the same operating condition.

[3] Zhao, R Zhang, S Liu and Gu J 2015 A review of thermal performance improving methods of lithium- ion

battery electrode modification and TMS *Journal of Power Sources* 299 557-577

- The heat generation and dissipation of Li-Ion battery are analysed.
- The hazardous effects of an above normal operating temperature are examined.
- The techniques in electrode modification and battery thermal management are reviewed.
- Various battery parameters and optimization methods are discussed.
- Future research endeavours in battery thermal management systems are provided

III. THEORETICAL CALCULATIONS

Air Cooling

The air cooling method uses the convection heat transfer method in which the working fluid is air. Forced convection occurs since the air is directed across the battery pack using a fan. The equation for convection is:

$\square_{\square\square\square\square}=As\,\bar{h}\,(Ts-T\infty)$

Where As is the surface area. $\bar{h}$ is the heat transfer coefficient. Ts is the surface temperature. T∞ is the air temperature. The surface area of the battery pack is 0.10 m2 (0.5x0.2m). The heat transfer coefficient of air is assumed to be varying between $\bar{h}$ = 100w/(km)^2 and $\bar{h}$ =1000w/ (km) ^2 . The surface temperature of the battery pack is 55°C due to internal heat generation. The temperature of the air is 20°C (room temperature).

$\square_{\square\square\square\square}$=(0.10m2)(100w/(m^2 k)) (55-20°C)=350 w/(m^2 k)

$\square_{\square\square\square\square}$=(0.10m2)(1000w/(m^2 k))(55-20°C)=3,500 w/(m^2 k)

Below shows a visual representation of the change in heat rate by varying the heat transfer coefficient of air from 100 to 1000 w/(m^2 k)

Liquid Cooling

The direct-liquid cooling method also uses the convection heat transfer method in which the working fluid is dielectric mineral oil. The equation for convection:

$\square_{\square\square\square\square}=A_s\,\bar{h}\,(T_s-T_\infty)$

Where A_s is the surface area. $\bar{h}$ is the heat transfer coefficient. T_s is the surface temperature. T_∞ is the dielectric mineral oil temperature. The surface area of the battery pack is the heat 0.5mx0.2m=0.10 m^2. transfer coefficient of dielectric mineral

oil is assumed as $1200\,\frac{\square}{\square\square^{2}}$. The surface temperature of the battery pack is 55°C and the temperature of the dielectric mineral oil is 20°C.

$\square_{\square\square\square\square}$ =(0.10 m^2) (1200 $\frac{\square}{\square\square^{2}}$) (55-20°C)=4,200 W

Indirect-liquid cooling method is not considered for calculation due to its potential of leaking problems discovered in paststudies [9].

IV. FEA CHAPTER

The Finite Element Method (FEM) is a numerical technique to find approximate solutions of partial differential equations. It was originated from the need of solving complex elasticity and structural analysis problems in Civil, Mechanical and Aerospace engineering. In a structural simulation, FEM helps in producing stiffness and strength visualizations. It also helps to minimize material weight and its cost of the structures.

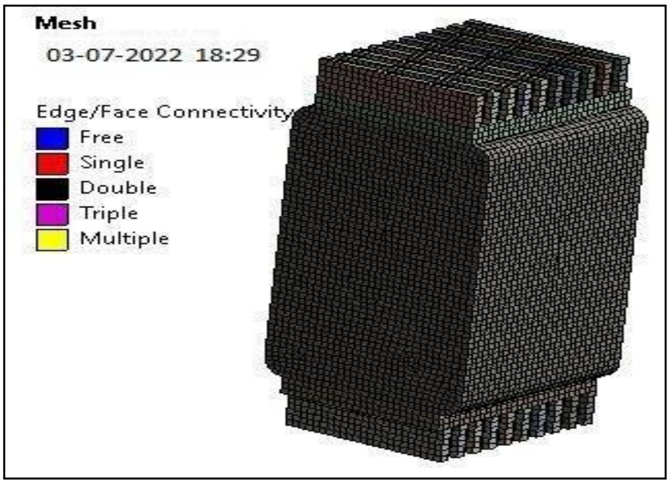
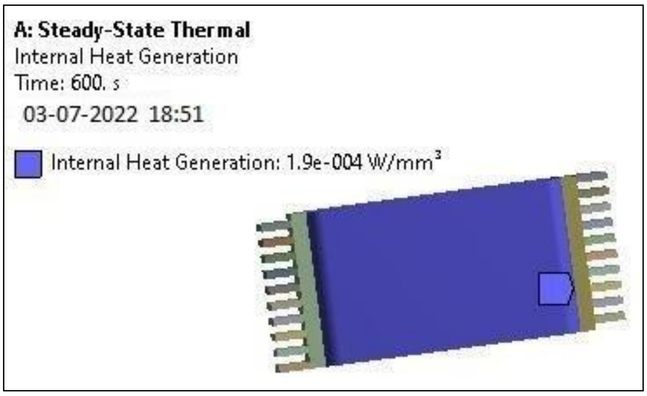


Figure: Meshing of Air Cooling Model (Isometric View)



A: Steady-State Thermal
Internal Heat Generation
Time: 600. s
03-07-2022 18:51

🟦 Internal Heat Generation: 1.9e-004 W/mm^3

Figure: Internal Heat Generation of Air Cooling Model

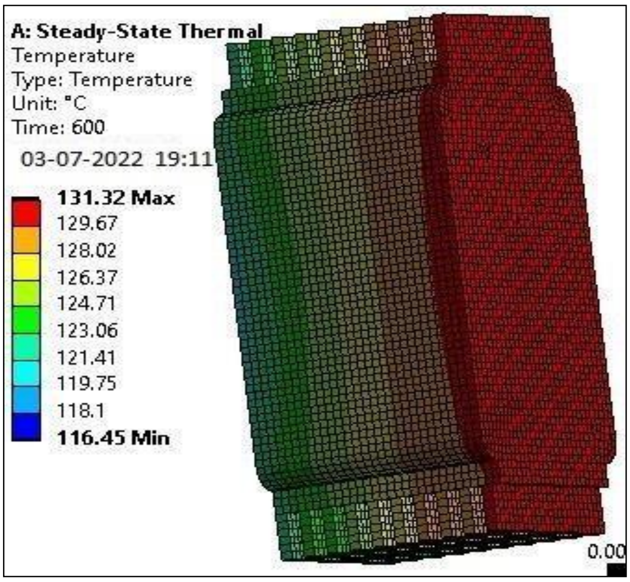


Figure: Temperature Solution of Natural Air Cooling

Cooling Method	Lowest temp.	Max temp.	Average Temperature
Air Cooling	17.58	62.43	32.03
Liquid Cooling	24.74	29.60	25.44
High Velocity Copper Heat Pipe Cooling	22.73	27.46	23.16

Table: Power Battery Temperature Data of Three Cooling Methods under 1C

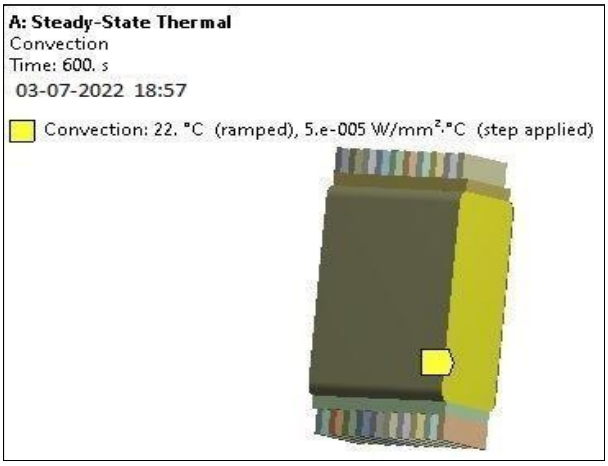


Figure: Convection of Air Cooling Method

CONCLUSION

The use of lithium-ion batteries in electric vehicles provides an environmentally friendly solution to powering automobiles. Zero greenhouse emissions are achieved with lithium-ion batteries opposed to smog from internal combustion engines. However, thermal management of the batteries opposes an issue when internal heat is generated during charging and discharging. To overcome this problem, automobile manufacturers have used air cooling and liquid cooling methods to decrease the temperature of lithium- ion batteries. Research studies show the advantages and disadvantages of these cooling methods along with analyzing the fin cooling method.

This thesis reviewed the history of lithium-ion batteries as well as past studies of cooling methods. A battery pack with a size of 500x300x200 millimeters was proposed for analysis. Theoretical calculations of air, liquid, and fin cooling methods concluded that the liquid cooling method provided the highest heat transfer rate of 4,200 watts. The calculations were based on an initial temperature of 55°C and a final temperature of 20°C.The air and liquid cooling method achieved heat transfer via convection. The fin cooling method achieved heat transfer via conduction.

The next step of the analysis was to use ANSYS software to simulate the cooling methods of lithium-ion batteries. The analysis system used within the software was Steady-State Thermal. A geometry of the battery pack was created and then meshed to divide it into numerous sections. Initial temperature, internal heat generation, and convection rates were assigned to the system. The simulation time was assigned as 600 seconds. The air cooling method simulated 20°C air across the top of the battery pack.

The fin cooling method simulated 20°C air on the fin and on the sides of the geometry method. The liquid cooling method simulated 20°C dielectric mineral oil across the geometry pack.

Furthermore, a design improvement was analyzed which modified the battery pack. The proposed design added four air inlets to the front and back of the battery pack to aid with removal of heat. The geometry of this model was also meshed and analyzed in ANSYS to obtain temperature contours.

The initial temperature, internal heat generation rate, and convection rate stayed the same.

The simulation concluded that the modified battery pack experienced the lowest maximum temperature of 32.526°C, which was the lowest of all methods. This simulation proved that the air cooling method can be ideal if additional air inlets are provided.

A proposition for future work is to analyze recycling of the heat removed from the lithium-ion battery to provide cabin heating of the vehicle. This method allows the vehicle's Heating, Ventilation, and Air conditioning system to consume less power from the lithium-ion battery when cabin heating is required.

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[4] www.Bhorzvanmotors.com