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A REVIEW ON DIFFERENT THERMAL MANAGEMENT SYSTEMS USED FOR COOLING OF LITHIUM ION BATTERY

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Abstract - *Modern developments in the electric vehicles has made use of high power density packed battery a necessity. However the high heat generated within the battery leads to serious thermal management issues. High temperature of the battery cell may affect its functioning and life span. Thus this requires a proper thermal management system to dissipate out the generated heat. This research work presents a brief analysis of different battery thermal management techniques.*

Key Words: *BTMS, Thermal Management, Li-ion cell, Li-battery, EV, HEV*

I. INTRODUCTION

We are in the era where clean and green source of energy is preferable. Electric and hybrid electric vehicles using Lithium ion battery is considered to be a successor over vehicles using traditional internal combustion engines. But these lithium ion batteries have certain operational limitations. Among all its limitations, significant increase in the battery temperature at a high galvanostatic discharge is of a major concern. This high temperature of the battery due to the heat generated within it affects the performance of battery and damage its functioning over a span of time. Thus this heat has to be efficiently removed from the battery by effective thermal management system.

1.1 Battery Thermal Management System

Battery thermal management (including cooling and heating) is essential for electrically powered vehicles to maintain an adequate cell temperature in all weather conditions. The thermal imbalance between the cells has a major impact on the short and long term performance of vehicle battery systems. According to Arrhenius' law of battery electrochemistry, the reaction of batteries increases exponentially with the temperature of the battery cells [1]. As a result, warmer cells break down faster than cooler ones, and these few overheated cells shorten the life of an entire battery. Due to overheating, the capacity of the cell quickly decreases. Manufacturers must ensure that a package can be used for eight to ten years without modification. In this case, an overheated cell is a challenge for the manufacturer. For example, the lifespan of the Li-ion cell is reduced by about two months with each degree of temperature rise in an operating temperature range from 30° C to 40° C [2]. The Li-ion battery system should keep the highest cell temperature below 40° C for a full life and the cell temperature difference below 5° C.

The thermal management system must operate the package and the cell in the desired temperature range in order to achieve optimal performance and service life. It must reduce the uneven temperature distribution in a module pack to avoid degradation. The thermal management system must also rule out the potential risks associated with the uncontrolled temperature. It must keep the cell temperature in the optimal zone with air, liquid (direct and indirect), insulation material, phase change material, passive (ambient air) or in an operating temperature range (HX, cooler, air conditioning) etc. to ventilate batteries that may produce dangerous gases. It should provide a control strategy for security operations. The generation of heat in the cell depends on the electrochemistry of the battery and the manufacturers provide the optimal operating temperature range for the operating conditions. The thermal management of the battery depends on the requirements of the life of the system, the cost of the guarantee, the space requirement and the performance, etc.

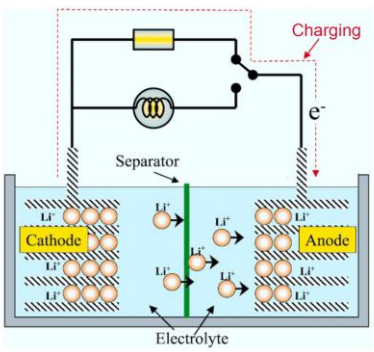
1.2 Lithium-ion Battery

Lithium-ion battery has brought a revolutionary change in the energy storage technology. Due to its high potential, its high energy density and capacity, this type of battery has already improved our lifespan and will undoubtedly continue to do so in the coming years. However, battery development is generally very intimidating and difficult, and perhaps especially when it comes to lithium batteries. “Battery” was introduced by Alessandro Volta at around 1800, since then considerable efforts have been invested in the development of batteries [3]. Many scientists and engineers working in science, industry and even independently of each other have contributed to this development and realized that finding solutions for efficient batteries is a very difficult task. Development has therefore been relatively slow, and very few efficient battery configurations have been successfully designed over the years. For example, we are still dependent on the lead-acid battery which was discovered in the mid-19th century. Indeed, these challenges could be overcome, and the lithium-ion battery would become a reality that has fundamentally changed our world.

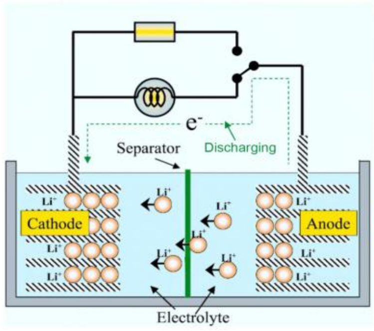
Lithium ion battery consists of three main components, cathode (positive electrode), anode (negative electrode) and a separator dipped in electrolyte, as shown in figure 1.1 and 1.2. Normally negative electrode is electron donor which is electropositive in nature such as lithium metal whereas Positive electrode is electron acceptor which is strongly electronegative (such as $LiMO_2$ compounds, M = Co, Ni, Mn, etc.). Aluminium and copper foil are coated with cathode and anode. Aluminium and copper are current collectors. A porous polymer separator is immersed in electrolyte and is sandwiched between the anode and cathode. It prevents shorting of the two electrodes. Li-ions intercalates and Deintercalates in cycles and move through the electrolyte as charge carriers in the internal circuit as shown. Redox reactions occur at the electrodes due to the intercalation and DE intercalation of Li-ions, which generate electrons that move through the external circuit to form the current.

Anode during its discharging becomes electrochemically oxidized and releases electron. This electron moves through outer circuit to the anode which accepts the electron. Also, the Li^+ ion moves from anode to cathode through the electrolyte known as intercalation. Whereas, during charging process, the anode is electrochemically reduced and accepts electrons. Li^+ ion moves from cathode to anode known as deintercalation. Role of electrolyte is to act as a medium for the transfer of ions between the two electrodes.

In general, lithium salt dissolved in organic solvent is used as electrolyte in lithium ion batteries. Main requirements for the electrolyte are that it should (i) be a good Li-ion conductor and electronic insulator, (ii) has stability over the operating voltage window, (iii) has chemical compatibility with cell components and electrodes, (iv) has thermal stability and (v) not have any charge accumulation and concentration polarization.



(a)



(b)

Figure 1.1: (a) Charging of Lithium-ion battery (b) Discharging of Lithium-ion battery

II. LITERATURE REVIEW

Zhuqian Zhang et al. [4] demonstrated the effective use of a passive thermal management system. In his research work he enhanced the thermal conductivity of the phase change material using copper metal foam. He compared the performance characteristics of the copper foam based phase change thermal management system with air system having normal air cooling and system having pure PCM. According to his research work the composite PCM can significantly reduce the battery surface temperature as compared to the other two methods.

S. Wiriyasart et al. [5] using 444 cylinder lithium-ion battery presented a computational analysis approach to charachterise the temperature distribution and pressure drop using nano fluids flowing corrugated mini channels of the EV battery module. He found the temperature distribution to be most sensitive to the flow direction of the coolant, mass flow rate and the coolant type. He obtained the best cooling performance with the nano fluids as the coolant. Nano fluids as the coolant provides cooling capacity better than water as the coolant.

Y. Lyu et al. [6] experimentally investigated the cooling performance of an advance battery thermal management system which he referred as thermoelectric cooling system. It is a combination of liquid coolant cooling and forced air cooling. The liquid coolant is in direct contact with the battery and acts as the medium to remove the generated heat directly from the battery. Reasonable amount of heat dissipation enhancement was detected.

Jinlong He et al. [7] in his research work used self-assembled monolayers (SAMs) which act as a vibrational mediator to improve thermal conductance between the electrode, lithium cobalt oxide and a solid state electrolyte polyethylene oxide (PEO). According to the research SAMs are designed to form hierarchical hydrogen bond network with PEO. According to the molecular dynamic simulations the interfaces show enhanced thermal conductance.

Z. Lu et al. [8] explored the air cooling capability of the temperature uniformity and hotspot reduction for a compact battery pack which was subjected to various air flow paths and different air flow rates. According to his observations improvement in effective heat transfer areas between the air coolants the battery surfaces is able to lower the maximum temperature generated within the battery cell.

Rui Huang et al. [9]] in his research work investigated numerically and experimentally the thermal performance of the battery module. He performed the experimental testing on the heat generation model and determined the thermophysical parameters of the PCM. It was found that higher thermal conductivity and latent heat lead to better thermal management system.

Lip Huat Saw et al. [10] in his research work studied the battery module comprised of three pieces of lithium-ion pouch cell arranged beside each other and attached to the aluminium foam heat sink to extract the generated heat. He detected that 10 PPI aluminium foam with 0.918 porosity offered the highest thermal performance and the lowest resistance to the flow of heat.

Noreffendy Tamaldin et al. [11] conducted research on a combination of active and passive cooling systems where air cooling is used for battery module, water cooling for the controllers and water jacket for electric motor. He conducted the DFMEA to identify the potential failures and their causes and to make the desired improvements in the battery module, controller and electric module accordingly.

Nandy Putra et al. [12] constructed a passive cooling system with a heat pipe and PCM and investigated the performance with the help of a battery simulator. He has done a comparative analysis of Beeswax and Rubitherm as the phase change material for cooling of the battery and to maintain the battery temperature in the optimal working zone.

Yuan Li et al. [13] performed analysis on a hybrid cathode lithium ion battery using $LiFePO_4$/Graphene. The experimental results showed the temperature distribution, hottest area and the working voltage matched exactly to the mathematical model. The results concluded that the increase in the temperature could be restricted through reducing contact resistances using LPF/G.

III. OUTCOMES

This literature survey was performed to generate a brief understanding of the different methods available for battery thermal management of lithium-ion battery. There are different methods used such as using phase change materials (PCM), PCM fused with any conductive foam, use of nano fluids, using liquid coolants, using pulsating air flow etc. The outcomes can be summarized in the following points.

1. Normal air cooling is the simplest, less bulky and the most suitable method for the cooling of lithium-ion batteries. This method is based on natural convection current which is develop due to the density difference of the ambient air. The major drawback observed is the generation of heat spots due to low thermal conductivity of air.

2. Forced air cooling is used to increase the heat transfer rate by using phenomena of forced convection. But due to the high velocity of flow usually flow separation zones are observed where local heat spots is generated which may be detrimental to the lithium-ion battery.

3. PCM such as paraffin etc. has a low thermal conductivity this makes the use of PCM inappropriate thus by fusing any conductive foam (such as copper foam) with the PCM its thermal conductivity can be drastically increased it also provides better temperature uniformity as compared to the air cooling or normal PCM. This composite PCM makes the battery more bulky.

4. Liquid coolant with high thermal conductivity can be used in direct contact with the battery module to dissipate out the heat with natural or forced convection. Arrangements has to be made to make the assembly leak proof. Liquid coolant also requires parasitic energy consumption for its circulation through a pump.

5. Use of Nano fluids offers larger surface area and molecular collisions. With the increase in the Nano fluid concentration the molecular momentum transfer also increases which ultimately increases the heat transfer rate.

IV. CONCLUSION

The observations and the discussions on different methods of battery thermal management with a comparative analysis of their individual advantages and limitations is summarized in the following table:

Cooling Method	Advantages	Limitations
Air cooling	Simplest assembly	Low thermal conductivity
Forced air cooling	Increased heat transfer	Parasitic energy consumption
PCM	Passive cooling	Low thermal conductivity
Composite PCM	High thermal conductivity	Makes the assembly bulky
Liquid cooling	High heat dissipation	Requires leak proof assembly
Cooling with	Optimum	Complexity of

Nano fluids	cooling in limited space	its design
Aluminum foam cooling plates	Porosity provides better thermal performance	Requires selection of optimum porosity
Electrochemical-thermal coupled cooling	Reduced contact resistance and peak temperature	Isolated heat spots

V. REFERENCES

1. Rajib Mahamud, Chanwoo Park, Reciprocating air flow for Li-ion battery thermal management to improve temperature uniformity, Journal of Power Sources Pages 5685-5696.

2. Z. Rao, S. Wang, M. Wu, Z. Lin, F. Li, Experimental investigation on thermal management of electric vehicle battery with heat pipe, Energy Convers. Manage. 65 (2013) 92–97.

3. M. Piccolino, Trends Neurosci. 23(2000) 147-151.

4. Zhuqian Zhang, Yi Li, Experimental study of passive thermal management system using copper foam-paraffin composite for lithium-ion batteries, Energy Procedia 142 (2017) 2403-2408.

5. S. Wiriyasart, C. Hommalee, S. Sirikasemsuk, R. Prurapark, P. Naphon, Thermal management system with nanofluids for electric vehicle battery cooling modules, Case Studies in Thermal Engineering 18 (2020) 100583.

6. Y. Lyu, A.R.M. Siddiqui, S.H. Majid, M. Biglarbegian, S.A.Gadsden, S. Mahmud, Electric vehicle battery thermal management system with thermoelectric cooling, Energy Reports 5 (2019) 822-827.

7. Jinlong He, Lin Zhang, Ling Liu, Improving thermal conduction across cathode/ electrolyte interfaces in solid state lithium-ion batteries by hierarchal hydrogen-bond network, Materials and Design 194 (2020) 108927.

8. Z. Lu, X.Z. Meng, L.C. Wei, W.Y. Hu, L.Y. Zang, L.W. Jin, Thermal management of densely packed EV battery with forced air cooling strategies, Energy Procedia 88 (2016) 682-288.

9. Rui Huang, Zhi Li, Wenhua Hong, Qichao Wu, Xiaoli Yu, Experimental and numerical study of PCM thermophysical parameters on lithium-ion battery thermal management, Energy Reports

10. Lip Huat Saw, Ming Chian Yew, Ming Kun Yew, Wen Tong Chong, Numerical analysis on aluminium foam cooling plate for lithium-ion batteries, Energy Procedia 105 (2017) 4751-4756.

11. Noreffendy Tamaldin, Ahmed Kamal Mat Yamin, Mohd Fadzli Bin Abdollah, Hilmi Amiruddin, Mohd Azman Abdullah, Design optimization of thermal management system for electric vehicle utilizing CFD analysis, DFMEA and CES, Procedia Engineering 68 (2013) 305-312.

12. Nandy Putra, Adjie Fahrizal Sandi, Bambang Arianatara, Nasruddin Abdullah, Teuku Meurah Indra Mahlia, Case Studies in Thermal Engineering 21 (2020) 100655.

13. Yuan Li, Fei Qi, Hao Guo, Zhiping Guo, Meiying Li, Wenliang Wu, Characteristic investigation of an electrochemical-thermal coupled model for a $LiFePO_4$/Graphene hybrid cathode lithium-ion battery, Case Studies in Thermal Engineering 13 (2019) 100387.