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A REVIEW: STUDIES ON DIFFERENT PERFORMANCE IMPROVEMENT METHODS FOR BATTERY THERMAL MANAGEMENT SYSTEMS FOR LI-ION BATTERY

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Abstract: Every country in the world wants to gain to the title of a developed country rather than a developing or undeveloped country. Without the availability of energy, the objective could not fulfill. This leads to the global issue of environmental pollution due to the excessive use of fossil fuels. The transport sector is the biggest contributor around 24% of direct carbon dioxide emission to the environment after fuel combustion. Concept of electric vehicles (EVs) strongest alternative for internal combustion engines, which may reduce air pollution up to a certain extent. Li-ion batteries gaining popularity due to their numerous advantages like zero-emission, recyclability, good power density in electronic appliances and EVs. Although Li-ion batteries are having positive attribute, it has few limitations of overheating due to excessive heat generation. The Li-ion batteries perform better for the temperature range 15 0C to 40 0C. The operation of batteries below and above the given limits may lead to serious issues like an explosion or short circuit. Therefore it is essential to provide an optimal thermal management system. The paper comprises the effect of temperature on battery performance and battery thermal management systems. Henceforth many of the researchers working extensively on developing an optimized battery thermal management system. Researchers categorized these systems into two basic types i.e. active and passive cooling. Active cooling preferred the use of air and liquid to fulfill the target, while passive cooling utilizes phase change materials (PCM), heat pipes, and nanomaterials. Each of these methods has its limitations and advantages. While choosing a BTMS few factors need to be kept in mind like volumetric constraints, cost of installations, and efficiency of the system.

***Index Terms* – Li-ion Battery, BTMS, Electric Vehicles, PCM, Heat Pipe.**

I. INTRODUCTION

The growth within the transportation trade has raised environmental concerns. This combined with the depleting fuel reserves has resulted in varied countries adopting property energy resources to mitigate the upcoming warming crisis. Currently, the transportation industry contributes extremely to global warming and greenhouse gases (GHG) [1]. In step with the recent report revealed by the United States, Environmental Protection Agency GHG emission contribution from the transportation industry was 28% in 2018. To counter the adverse effects of GHG emissions transportation electrification was introduced, because of that the approximate reduction in GHG is according to be 20%. Moreover, if the electricity from renewable sources is employed in electrical vehicles (EV) then it will increase to 40% [2].

Lithium-ion (Li-ion) battery, in comparison with distinctive batteries, is featured through its immoderate strength density [1, 2], prolonged lifespan, and no memory effect. Today, it is been extensively applied in a massive kind of clinical and engineering applications, which incorporates virtual industries, strength storage, military uses, and to name a few. In particular, it is been diagnosed as one of the promising possible strength belongings for future herbal and hybrid electric-powered vehicles. However, Li-ion cells require a selected thermal surrounding to carry out successfully and efficiently. The perfect running temperature variety is from 25 ◦C to 40 ◦C, beyond this variation, the cells begin to overheat and their overall performance reduces at an improved rate. The overheating of the cells also can bring about a thermal runaway; ensuing in protection hazards. Therefore, lately giant studies have been performed for battery thermal control systems (BTMS) [5, 6, 7].

Comparing number of BTM-cooling systems developed from the last few decades, performance of battery at high grab less attention. Within the literature, solely a couple of studies created some attention-grabbing investigations on this subject [8]. So, competent BTM system for Li-ion battery ought to be equipped with each cooling and heating means. It should guarantee battery to be operated at a perfect thermal state, free from any damages and deterioration resulted from either high- or low-temperature conditions. Its value mentioning that the planned style is applicable at an outsized scale with additional batteries included. Though the present results might not be directly climbable for a few specific battery layouts, they're valuable for style and optimization of an additional comprehensive thermal management system in giant-scale applications, similar to in electrical vehicles and electric energy storage. For future electric vehicles, to fulfill numerous operative conditions we would be need hybrid battery thermal management at large scales. So, the performance of lithium-ion batteries will be optimizing by planning integrated thermal management systems [9-10].

1.1 Background of Battery Thermal Management

The electric performance and aging characteristics of batteries are powerfully joined to the thermal conditions at which they operate hot temperature lead to higher energy density, but, at an equivalent time accelerate the degradation of the battery; temperature reduces the charging/discharging performance of the battery because of the rise of the inner resistance [10]. In addition, conjointly the non-uniform temperature distribution at cell or module level will considerably reduce the performance and accelerate the degradation of the battery [11]. Finally, the shortage of correct temperature management for the electrical storage systems can even compromise their reliability, leading to thermal runaway or perhaps fireplace hazard.
From such associate analysis, the importance of the thermal battery management system (TBMS) is evident and is powerfully supported by an enormous analysis within the field. Indeed, many totally different systems were suggested, that embrace passive and active ways and build use of air, liquid, or refrigerants as a chilling technique similarly as activity materials (PCMs), with a high range of works revealed throughout the last years [12, 13, 14].

II. LITERATURE REVIEW

This chapter is describes literature review especially related to active (like air or liquid cooling) and passive (Phase change material, Heat pipe, spray cooling) cooling techniques for battery thermal management. Role of nano material also revealed with limited aspect.

Batteries are the used to store power in the form of chemical energy. They provide the power to a load by changing hold on energy into power. Batteries are an important part of Associate in nursing device since they are chargeable for powering up the full setup; therefore, they have further care and maintenance. Stored chemical energy gets regenerate into electrical energy once a chemistry reaction takes place within the battery [15]. Batteries will be differentiated into four teams as given within the following subsections. The choice of batteries in the automotive trade is only supported specific demand. Each type of batteries have their specific property; one has high energy density whereas the opposite has a lot of mechanical strength, and so on its conjointly true that one battery is not enough to power the full vehicle, thus multiple batteries are needed and that they ought to be placed in an exceedingly instrumentation in a specific arrangement with another hardware components. This whole setup constitutes a battery pack. To develop a thermally balanced battery pack, it is necessary to review the thermal behavior and structural property of all 3 forms of batteries [16]. Such a study can facilitate to decide which kinds of battery are going to be a higher option for a selected application.

III. Characteristics of Battery

It is essential that different characteristics of a battery such as electrical, thermal, and chemical etc must be reviewed. This insight into the battery characteristics is necessary to solve battery issues and for the development of effective BTMS. The thermal and chemical characteristics are also needed to be analyzed before the designing of the proper thermal management system.

The Li-ion batteries are broadly used in various applications like electric vehicles, laptop [17], etc. due to their characteristics like high energy density. The chemical reaction occurred at positive and negative electrodes permit the batteries to work and produce output. As the material of electrode degraded, it leads to the reeducation in the performance of battery. Chemical characteristics of any battery play an important role while selecting effective thermal management of battery. Different types of Li-ion cells are used in diverse applications based on their properties required in the system. As Lithium Nickel Manganese Cobalt Oxide (NMC) cells gives continuous discharge current up to 20A; these are good performer and extensively used batteries. Disadvantage of low specific power of 2800mAh overcome by satisfying criteria of loading conditions and longer life. Combination of Nickel and Manganese metals with each other eliminates the drawbacks and results in high specific power and excellent stability [18]. So, these metals are most preferred in EV.

Behavior and Performance of Li-ion batteries are directly associated to temperature variation and temperature uniformity in the battery pack in EVs. Too much temperature variation promotes to abnormal charging/ discharging rates [19]. The variation in temperature range of battery pack has close relation to the manufacturing method, cell chemistry, and design of battery cells. Electric vehicles are used in diverse ambient temperature situation globally, in low temperatures and high-temperature regions. The performance of battery is greatly affected by this intense temperature environment. As result of this unwanted chemical compositions may developed and damages to the system. So, thermal characteristics suggest that for effective temperature control is essential as heat production in battery cells is result of internal confrontation and polarization [19]. Hence optimum temperature is a vital characteristic of a controlled battery management system to maintained charge/discharge.

IV. Performance of Battery at Low and High Temperature

A battery needs to work in diverse temperature condition for actual applications. It is noted that performance of battery is reduced for low temperature condition; which will limit their use in cold climates and high-altitude drones such as Canada and Russia. The low temperature can affect batteries in numerous ways together with charge acceptance, energy and power capacity, round-trip efficiency and life cycle [20]. Smart et al. [22] charged Li-ion cell at low temperature and found that it was tough to charge the cell to its power as obtained at normal room temperature and lithium plating might occur at high charging rates. It was reported that both power and energy of Li-ion batteries could be reduced once the temperature fell down to the -10 °C [4]. With a lower temperature of −40 °C, the power and energy density could be delivered only 1.25% and 5%, respectively, as compared with the values obtained at 20 °C. In addition along with poor performance, the aging rate of LIBs will be increased during cycling conditions at low temperature particularly below 0 °C. At a low temperature of −10 °C, Ouyang et al. [23] found that an 11.5 Ah Li-ion cell had a capacity loss of 25% after only being cycled 40 times at a charge rate of 0.5 C. The capacity decrease mainly occurred in the initial stage of cycling conditions and lithium plating was generally considered to be the major degradation mechanism.

For high working temperature (e.g., larger than 55 °C) will increase the impedance of Li-ion battery and weaken its capacity. So, there is substantial reduction in driving range, if this degraded battery is used for an EV. If the temperature increased above 80 °C, Li-ion battery could experience a thermal runaway, which will produce a large quantity of heat at a rapid rate. If no corrective actions taken to dissipate the heat, this process will results in severe accident e.g. fire or explosion. Meanwhile, a rather low operating temperature promotes Li-ion battery to having reduced electrolyte conductivity, slow reaction kinetics and a small diffusion coefficient of lithium [23].

V. Active BTM

BTMS is a very critical and important fundamental part of BTMS (Battery Thermal Management System). The primary goal of BTMS is to maintain the temperature of batteries in the optimal working range and to maintain the temperature uniformity in the battery module. Active cooling or active battery thermal management (BTM) using air is simple and straightforward. Active cooling provides channels through which cold ambient air comes in contact with battery surface. This cold air takes heat away from battery surface. Active cooling using a liquid is additionally admired in EV, for there high convective heat transfer coefficient.

VI. Air Cooling

Air cooling is one of the simplest and least complicated techniques of cooling. It uses air as a working fluid which carries the heat away from battery cell or pack as shown in fig. 6.1.

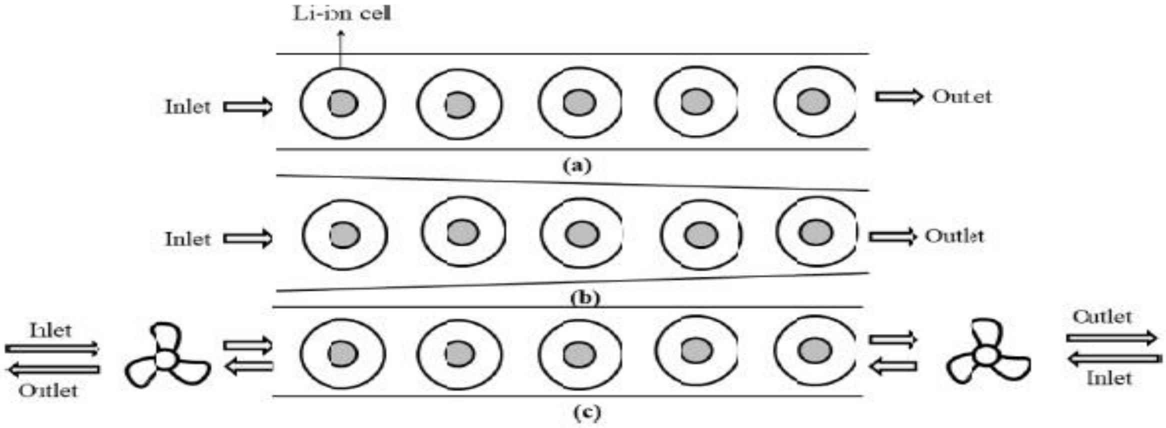

Figure 6.1: Series cooling arrangement (a) Simple channel (b) Wedge channel (c) Simple channel with reciprocating cooling [24].

Arrangement of channels and battery cells studied at various positions helps to enhance results for battery cooling. Low temperature difference between inlet and outlet for wedge channel compared to the series arrangement. The proposed an enhanced air cooling approach in which a simple channel with a reciprocating cooling process was engaged, as shown in Fig. 4(c). In this case, two fans were located at inlet and outlet of the simple channel, and both fans were operated alternatively to generate reciprocating airflow. This strategy resulted in the decrement of parasitic power by 84% and temperature distribution was such that it first greater than before up to the middle of the channel and then reduced towards the outlet [24].

Performance of air cooling at high ambient temperature is not satisfactory and rapid discharge rate conditions for batteries. Another restriction of air-based BTMS is that at a higher discharge rate this cooling strategy will not provide the required temperature drop, hence it will be needed to integrate other additional cooling strategies in the system.

VII. Liquid Cooling

Liquid cooling is considered a potential cooling strategy for battery modules. Liquid coolant (e.g. water or water-glycol mixture) is favored over air coolant under high charging/discharging rates and elevated ambient temperature conditions due to less power consumption and effective management of temperature. Fig. 7.1 shows the schematic diagram with various parts of a liquid cooling system.

Direct and indirect cooling these are the types of liquid cooling. Direct cooling [25] in which the battery pack is fully immersed in distributed dielectric and indirect cooling in which fluid will not be in direct contact of battery cells but the liquid coolant will passes through tubes/cold plates/jacket fond at the surface of battery cells or battery modules. The characteristics of working fluid like high specific heat, thermal conductivity, and high heat transfer coefficient as compare to air cooling results in promotion to liquid cooling.

Though the liquid cooling perform better than air cooling, this method has numerous limitations due to the complex in system design, the addition of extra weight for pump. This leads to the high maintenance and initial setup cost. Irrespective all these limitations liquid cooling system also has brutal safety issues such as seepage of coolant which may extend to severe accidental situations such as short-circuiting of the complete arrangement. These limitations of the liquid cooling system demand the exploration of some technique through which these safety issues can be solved.

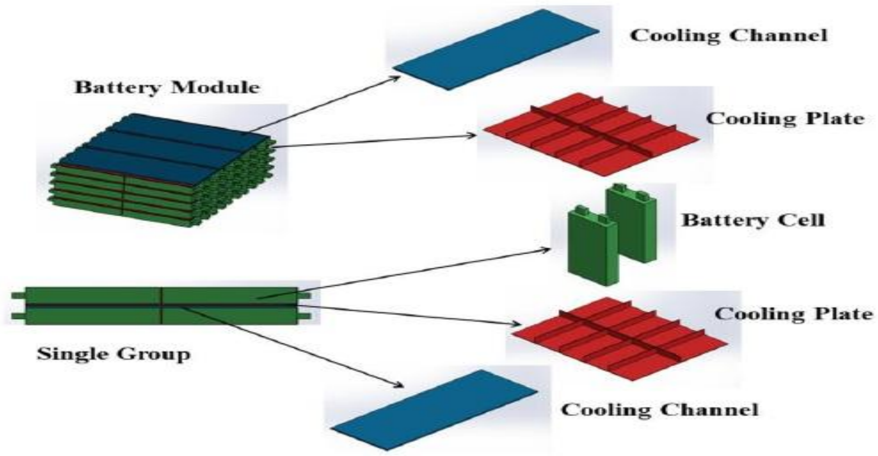

Figure 7.1: Liquid cooling system [25].

VIII. Passive BTM

Passive cooling uses mainly phase change material (PCM), which will not require any outside power inputs. The prime requirements of PCM in passive cooling should have high latent heat and an appropriate melting point close to the recommended operating temperatures of Li-ion battery. As a passive-cooling method, PCM takes battery heat away by its phase change. It is one efficient way to achieve higher efficiency in battery cooling.

PCM based cooling is a substitute to the liquid cooling systems as PCM has a great value of latent energy storing capacity. It differs PCM from other methods because it absorbs more energy without any change into the temperature during phase change. Main uniqueness of a PCM, required for effective thermal management of Li-ion batteries are high value of thermal conductivity, stable and non-explosive nature, non-flammable, easily available at a low cost and low volume expansion during melting.

PCM based cooling is also favorable to use in relieving the battery deterioration during long term cycles as studied by Youfu et al. [26] In this study, apart from the obvious decrease in battery temperature from 51.7 to 47.5°C, the cycle life was also increased to 65.3% as compared with the battery module without PCM as shown in Fig 8.1. Due to its heat carrying capacity PCM cooling systems are widely preferred in battery packs in conjunction with different types of subsidiary systems to improve the thermal performance of the battery pack. Cicconi et al. [27] studied the use of passive PCM and air cooling system for enhancing the thermal performance of BTMS. The results showed that the temperature of the batteries can be reduced up to 40% combining PCM and air cooling.

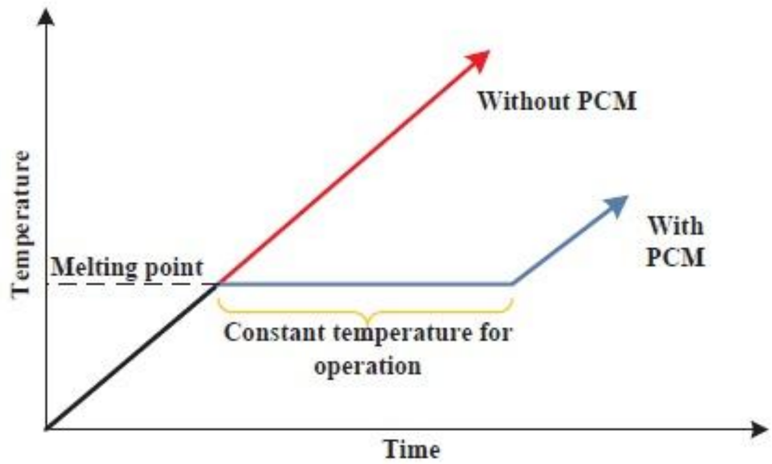

Figure 8.1: Temperature characteristics of PCM material [27].

With the use of PCM material temperature in battery is maintained near to phase change temperature for number of cycles, this leads the PCM a novel solution for thermal management applications as shown in Fig. 8.2. Due this exceptional property, PCM based BTM system has acknowledged extensive attention and exploration in recent years. PCM provides better temperature uniformity and good range of maximum and lower temperature than conventional system [27]. Irrespective of these advantages few challenges are still in front of researchers; leakage of PCM, strength of structure, low thermal conductivity and surface heat transfer.

Although PCM based system can control the battery temperature in normal conditions, accumulated heat should be dissipated in the long run or harsh working cycle conditions when the PCM is completely melted. In addition, composite PCM generally presents low surface heat transfer capability, leading to a reducing of the effectiveness of heat dissipation.

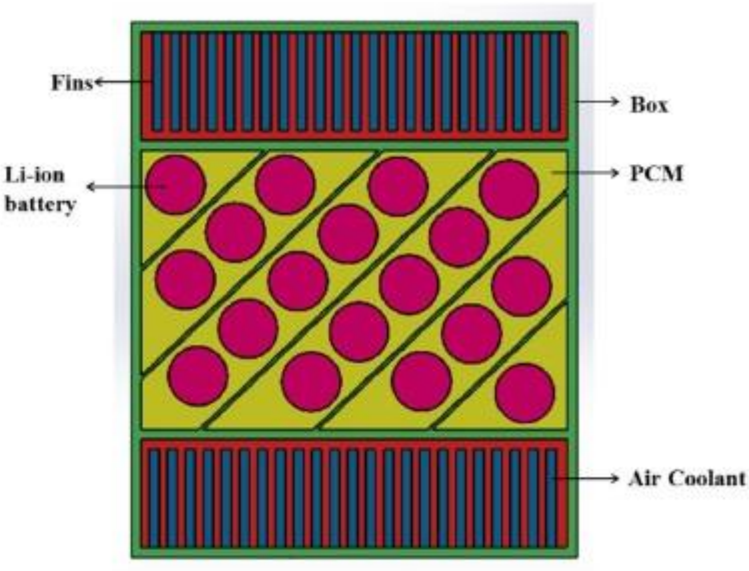

Figure 8.2: PCM based cooling [27].

As the heat pipe have good characteristics of flexible design and compact structure, it would be broadly used in thermal management [28]. There are three sections in a typical HP: evaporator, adiabatic and condenser sections. Evaporator section kept in contact with heat source which leads to vaporization of high temperature fluid. This HTF transferred to condenser section decrease the temperature of fluid as shown in Fig 8.3.

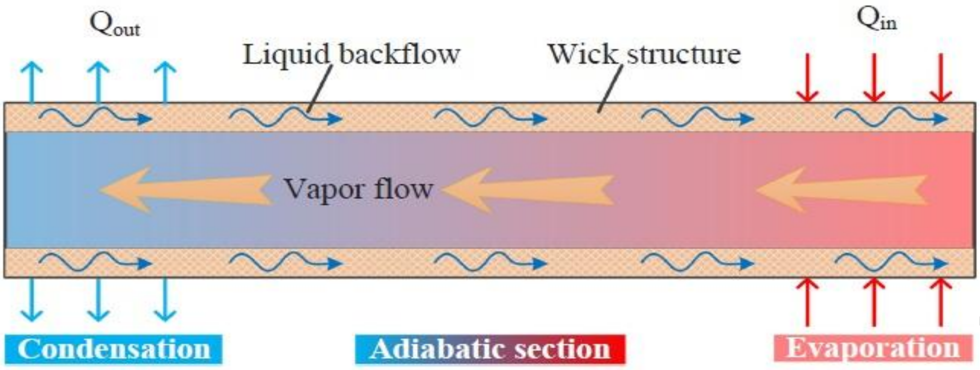

Figure 8.3: Working of heat pipe [28].

In addition the good thermal contact on evaporator section, adequate heat dissipation on the condenser section is another main aspect of a successful execution of HP. Extended surface with finned array is the primary technology to augment the heat transfer area and air is usually utilized as the cooling fluid to remove heat from the fin surface using fans. The system is simple but may causes noisy and bulky operation. Zhao et al. [29] projected a arrangement of HP based BTM system with four condenser cooling approaches, that is, natural convection, air forced convection, thermostat bath and wet cooling. Glycol-water mixture with higher thermal conductivity and specific heat capacity was used as the cooling fluid in contact with the finned array of HP.

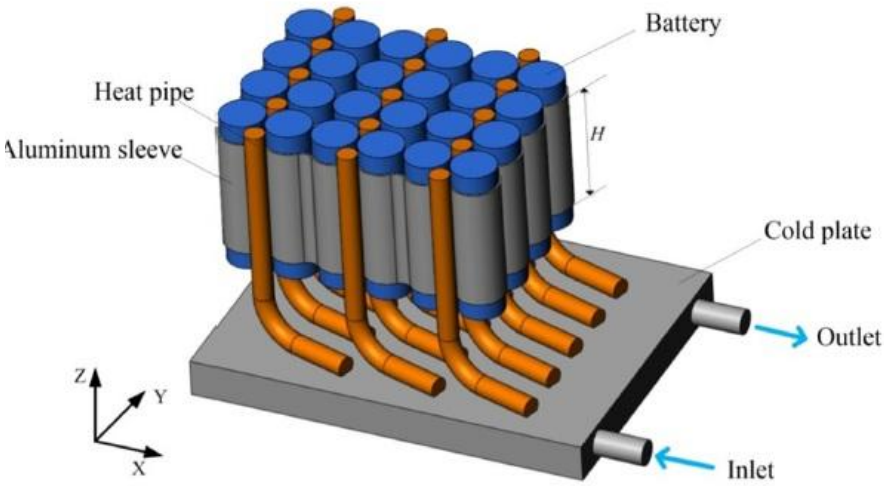

Figure 8.4: Schematic of heat pipe cooling [30].

In this way, the heat dissipation capacity could be improved, thus reducing the temperature with less volumetric flow. Also, the antifreeze performance of glycol-water mixture could make it possible for the practicality of battery heating even under sub-zero climates. Since the tubular heat pipe can have a limited contact area, the circular geometry limits the contact between the heat pipe and the heat source. So, to overcome this limitation to increase the contact area with battery surface flat heat pipe and flat loop heat pipe can be used. The comparative analysis of battery temperatures with and without heat pipe experimentally and show that flat heat pipes could operate well and reduce the temperature and temperature difference successfully.

The Fig. 8.4 shows that structure of the BTMS with arrangements of 24 cells (Type: 18650), heat pipes, aluminum cover and a cold plate [30].

IX. Nano materials for cooling

Low thermal conductivity of liquid coolant is major concern in cooling performance of batteries (e.g., water and ethylene glycol) in comparison with metals. Numerous studies suggested various suitable designs for battery pack on the same. To improve the thermal conductivity few researcher suggested addition of metal of micro sized particles. This is challenging in terms of certain issues such as difficulty in maintenance, complicated design of the system, and high cost initial cost. This optimistic research develops new strategies for proper cooling. Nano particles were introduced to beat these issues. Nano particles can be mixed up with liquid coolant to increase its heat carrying capacity [31]. Nanofluids were prepared by mixing nano particles (Al_2O_3, ZnO, CuO, TiO_2) with base fluids such as water and ethylene glycol.

After reviewing the studies pertaining to the use of nano material in liquid coolant, it can be concluded that for the wider utility of nanofluids along with liquid based coolant more research needs to be done in the area of nanofluids to enhance its thermal performance and heat transfer rate, reducing its initial set up cost, ease of application, simplicity to adapt and prolonged life of thermal management system.

X. Summery

Li-ion batteries were recognized as the mainly suitable for this study due to its advantageous characteristics and broad applicability such as EVs, energy storage devices, etc. among different battery chemistries. The battery characteristics such as electrical, thermal, and chemical were analyzed and an attempt was made to compare the effect of these characteristics on the thermal performance of batteries. Various methods for heat generation and heat dissipation with their mathematical modeling were analyzed for the exact study of thermal characteristics of Li-ion battery. To resolve the thermal issues of BTMS, various strategies such as air, liquid, and PCM-based cooling were analyzed. The advantages, disadvantages, and applicability of the air cooling system based on its thermal efficiency were analyzed. Further areas were identified where work can be done for the improvement of thermal efficiency.

PCM based cooling system can be good alternative for cooling. The different systems such as heat pipe assisted PCM based BTMS, PCM with open-cell metal foam; PCM-cooling plate-based BTMS, etc. were analyzed as the potential application for the use of PCM based cooling system. The low thermal conductivity of pure PCM was identified as the main problem in the application of this cooling strategy. The use of nano material in the liquid coolant and PCM were analyzed for the enhancement of thermal properties. The methods of the addition of nanomaterial in PCM and the potential applicability of composite PCM in BTMS were explored.

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