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A STUDY ON THE USE OF PET MATERIAL FOR THE COOLING SYSTEM OF ELECTRICAL VEHICLE BATTERY

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Abstract:

Controlling the temperature of a battery pack within an optimal range and ensuring uniform temperature distribution are the key to improving battery life. With the elevating energy density of batteries, more efficient and energy-saving thermal management system is urgently required for improving electric vehicle (EV) performance in terms of safety and long-term durability. In this work, a novel hybrid thermal management system towards a high-voltage battery pack for EVs is developed. Both passive and active components are integrated into the cooling plate to provide a synergistic function. battery pack incorporated with electrical, mechanical and thermal management components was designed, manufactured and integrated. As the core hardware, a pack-level cooling plate set was innovatively designed by integrating with phase change material (PCM). The radiators that are used in fuel cell-based electric vehicles are at least twice the size of IC engine radiators. This leads to vehicle overloading and an increase in fuel consumption. This paper gives a review of the thermal management system used for the battery of the electric vehicle and the use of PET material in the intake of the cooling system.

Keywords: Thermal management, Electric vehicle, Hybrid electric vehicle, battery pack, cooling system

1. Introduction

Global warming has been increasing at an alarming rate and the only method to curb this problem is to introduce electric vehicle by replacing the existing IC engine vehicles [1,2]. All the nations are taking steps to introduce the electric vehicle into the fleet. 8 billion euro have been sanctioned by the French government to encourage customers [3]. Chinese government planned to setup 4.8 million charging stations and 120 thousand switching stations to meet the demand of 3.6 million EV by 2020. The most popular energy source for the electric vehicles is the Lithium ion battery, because of their good efficiency, high energy density and long life. Though there are a lot of advantages of Li-ion battery, but it has a major disadvantage of high operating temperature. The optimal temperature for the operation of Li-ion battery is 20-50^{0}C, discovered by different researchers. The safety temperature by Battery thermal management system have been 60^{0}C, considered to be an important criterion. A lot of research have been conducted on the different types of BTMS and the different types of cooling medium used by them, such as liquid cooled, air cooled and phase change material. Air cooling system are not considered because of its low efficiency and bad temperature uniformity because of low thermal conductivity of air.

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Phase change material are referred as the paraffin wax, and are used for the regulation of temperature for the BTMS, and was found to be suitable. Different materials like expanded graphite, nanomaterials and metal foam have been added by many researchers for improving the thermal conductivity and rigidity. It was also seen that the addition of 30% expanded graphite to the paraffin was improved the stability and thermal performance of the paraffin wax [4]. With the addition of metal foam in the PCM material for the stable composition, thermal conductivity increased by 7.51compard to pure PCM material in BTMS. As well as impregnating the expanded graphite and metal foam, nanomaterial was also considered to improve PCM performance [5]. Lv et al. [6] introduced nano-silica in the PCM material to improve the mechanical property and thermal performance, which also helps in preventing the volume change and leakage. The maximum temperatures under the composite PCM were, respectively, 1.6, 2.4, 4.5, 5.3, and 5.9 ^{0}C lower than the pure PCM at the end of the 1st, 2nd, 4th, 6th and 8th cycle, while the temperature difference kept stable at 6.22 ^{0}C. PCM could be used in the heat pipes because of its improved thermal conductivity by exploring the fast phase change of liquid vapour.

BTMS based on heat pipes were also investigated, it could be seen that on the flat heat pipes the maximum temperature could be reduced significantly, aswell as the maximum temperature difference [7]. Indirect liquid cooling has been popular among BMW, Tesla, NIO and other because of their practicality [8]. In indirect cooling by liquid, a cooling plate is used to cool the battery pack, cooling plate is cooled by pumping coolant through the mini tunnels, helping in transferring heat. The cooling plate are placed below the battery or in between the battery cells. For improving the thermal performance, factors like number of channels, flow direction, ambient temperature and mass flow rate were explored [9][10], to achieve the best performance.

With the demand for fast charging and high demand, heat generated by the battery have been accumulated in the battery case, which decreases the capacity of the Li-ion battery and increases the thermal runaway. Many research have been carried out to prevent thermal run away, explosion and fire. To prevent thermal runaway many researches have been carried out [11][12]. A promising candidate for the cooling medium in the air-conditioning of EVs, pressurized CO_2 [13] was also considered for cooling over heating batteries and hindering the thermal runaway at the initial stage. The presents a review on the cooling of the battery used in the electric.

2. Literature Review

S. Wiriyasart et al.researched on the electric vehicle battery cooling modules. Battery thermal management system was required because temperature management of the battery, as high power density leads to significant rise in battery temperature which can affect the energy storage, life, durability and efficiency of the battery. Maintaining a proper temperature of the battery requires a good cooling method for the battery module of the electric vehicle. Pressure drop and temperature distribution using nanofluids flow was analysed in the corrugated mini channel of cooling module of a electric vehicle. Battery module of an electric vehicle consisted of 444 cylindrical lithium-ion cell batteries (18650 type). The direction of flow of coolant,

coolant type and mass flow rate decide the temperature distribution. Heat dissipation increases first during upstream and then during downstream it weakened. Compared to conventional cooling model II had reduced the battery temperature by 27.59%. The best cooling performance of the proposed module (Model II) is obtained with nanofluids as coolant showed 28.65% reduced the maximum temperature as compared with the conventional cooling module (Model I)[14].**Anthony Jarrett et al.**researched on the thermal management of the high-energy battery used in the electric vehicle. Thermal management system also helps in avoiding excessive power diversion from the primary vehicle function. Cooling plates can be used by the battery cell stack, which are fabricated by using metal fabrication which uses internal channels and coolant could be pumped through the channels. The coolant pumped through the channels transfers the heat that are generated by the battery cells through the cooling plates. Modelling of a serpentine channel was characterised by the help of CFD. The inlet channel had been designed in such a way that it widens out at the outlet, this helps in balancing the coolant velocity, heat transfer area, and fluid–solid temperature gradient to equalize the heat transfer from all areas of the plate as shown in Figure 1. Investigation of the convergence behaviour, and it could be varied by factor. Space and restricted boundary are the principal limitations of the design [15].

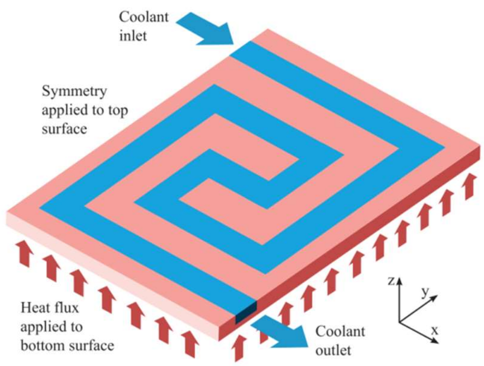


Figure 1: Schematic of CFD analysis model[15]

Q. Wang et al.researched on the thermal behaviour of the battery for electrical vehicles. lifecycle, efficiency, durability and energy storage of the battery are effected by the thermal behaviour of the battery. Experimental characterisation of the battery cooling heat pipe and heat covering range of the battery was investigated. Two battery of 2.5 to 40 W/cell with different heat source had been constructed. Results showed that the method was able to keep the battery under safe temperature of 40^0C, for under 10 W/cell battery. Battery between 20-40 W/cell batter the method was able to maintain the temperature below 70^0 C. Sintered copper-water heat pipes was tested for sub zero temperature by testing it for 14Hr and exposing it to 15-20^0C as shown in Figure 2. It was observed that heat pipe performs well even after prolonged exposure in sub-zero temperature [16].

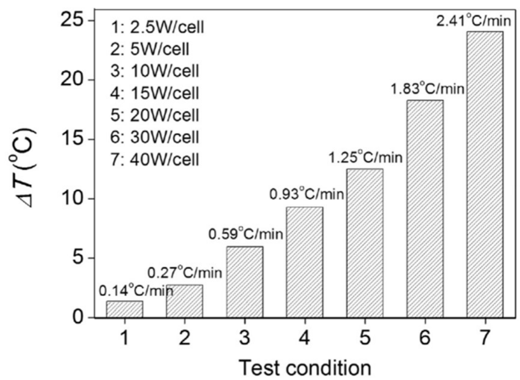
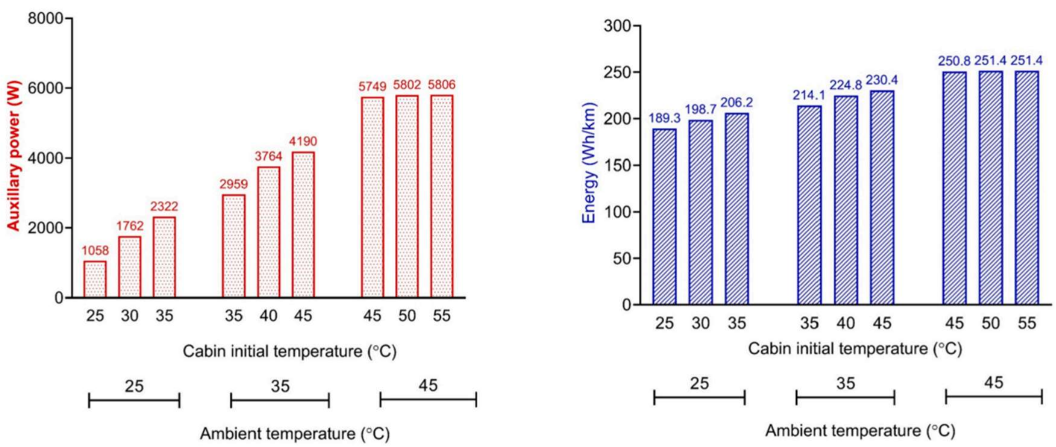


Figure 2: Average temperature drop rate in 10 min under 7 conditions[16]

Gürsel S¸ efkat et al.enhanced the overall energy efficiency of the hybrid fuel cell vehicle by the use of fuzzy logic algorithm. It was also required to balance the energy consumption by gradient decent optimization of the battery and the fuel cell, and lastly control of the fuel flow using waste heat from the hydrogen vessels. To control the temperature of the battery pack, fuzzy logic controller was used. Numerical simulations were validated with the experiment for energy consumption and temperature change of the vessel of HEV under actual conditions. With the use of fuzzy logic, total energy consumption decreased by 9.1% at 18^0 C which included fuel system, thermal management and propulsion system. It was also observed that the energy efficiency increased by 7% for -10^0C ambient temperature and 11% for 35^0C ambient temperature. Algorithm provided better thermal management and use of waste heat from the hydrogen vessels[17].**Paolo Di Giorgio et al.** researched on the fuel cell and electric vehicles battery thermal management system by introducing metal hydride tank with the battery pack. The rationale behind this solution is to use the exothermic absorption and endothermic desorption processes of hydrogen in metal hydrides for heating and cooling the battery pack, respectively, thus ensuring an optimal thermal management control. Experimental results showed that the system is efficient to control the temperature variation within the battery, in the condition of constant current discharge. The hydrogen desorption of 30-40%, this helped in reducing the temperature of the battery pack by 15^0C. The developed system was able to provide 4hrs of thermal management under real driving conditions. High gravimetric and volumetric energy densities have been achieved by the energy storage system, with theoretically 182 Wh/kg and 530 Wh/L, respectively [18].**Jie Wang et al.**studied on the vehicles with power source from a single fuel cell. There were problems like recovery of braking energy and slow response as the current market trend is dominated by the fuel cell hybrid vehicles. Fuel cell, supercapacitor and battery topology were proposed, and a double-delay deep deterministic policy gradient for the energy management was designed for this topological structure. Life loss of battery, fuel cell and consumption of fuel cell hydrogen optimization were the main goal. For this supercapacitors were used for coordinating power output of the fuel cell and battery. Using the algorithm improved the service life of the power system [19].

Vinayak Kulkarni et al.simulated battery electric vehicle which included the battery, cabin and the power electronic models. System-level outputs were obtained from the model which included system COP, and auxiliary power. Component level outputs were also obtained which included cabin temperature, power electronics, battery temperature and power electronic temperature. Both the system and component level were validated. With the help of energy conscious action 1336 to 4297kWh of energy could be saved in the overall life of the vehicle. Change in ambient temperature from 25^0C to 50^0C, there were increase in energy consumption by 35%, 6 times increase in auxiliary power and 39% drop in COP as shown in Figure 3. The model was compared with different modes to check the energy consumption.Drivetrain model parameters like vehicle mass, motor and transmission efficiency, and road gradeability are varied to estimate their effect on battery electric vehicle energy consumption. Battery thermal management were simulated with two different types of cooling loop and the terminal voltage and temperature of the cell were measured. Temperature drop of 5^0C was observed when cabin exit air is blown to the battery radiator [20].



(a) (b)

Figure 3: Effect of initial cabin temperature on auxiliary power and energy[20]

Adil Wazeer et al. researched on the battery of the hybrid and electric vehicle. A lot of heat is generated because of charging and discharging. The temperature of the battery is very important for a proper efficiency and reliability. Thermal management system is being used extensively for the temperature management of the battery;therefore, Phase Change Materials have attracted a lot of attention in the recent time. Recently a lot of attention has been received by the Phase Change Material in the recent time because of its lightweight, improved energy efficiency, less intricacy and better thermal homogeneity. PCM could be used in active and passive system for the electric vehicles. PCM enhances the thermal conductivity. With the help of expanded graphite matrix, metal fin, thermally conductive particles and metal foam applied with phase change material enhances the heat transfer. Air cooling could be used with the melted PCM as an hybrid PCM[21]. **Abdul Hai Alami et al.**researched on the phase change material which are used to prolong the life cycle of the battery pack of electric and hybrid electric vehicle. PCM material employed for the battery thermal management system. Using the PCM material for cooling system, leads to the management of appropriate temperature distribution with the help of desired cooling effect. PCM material has the highest thermal conductivity and better performance which helps in dissipating battery heat and also helps in maintaining better battery temperature. The advantage and disadvantage of different thermal management system using battery thermal management system have been studied. To avoid the low thermal conductivity of PCM and to reduce the maximum temperature hence increase the system lifetime; hybrid battery thermal management systems based-PCM integrated with air/liquid, heat pipes, fines, and nanoparticles. Using the thermal management system based of PCM material used in the electric vehicle and hybrid electric vehicle cooling system; showed improving results in the thermal management[22].

Nadiya Philip et al.studied on the fuel cell cooling system, as the world has been evolving from the IC engines to the alternative fuels like the fuel cell, providing lesser emissions and better performance. Radiators used in Fuel cell vehicles are twice the size of the radiators used in IC engine vehicles as shown in Figure 4. increase in size of the radiator leads to the increase in fuel consumption and overloading of the vehicle. Using phase change material the radiator size can be reduced and same amount of thermal energy can be stored. Pinch analysis based in mathematical approach is used to for the resizing the thermal management system. Use of paraffin wax of 13Kg reduced the minimum radiator size by 5.5 times om Toyota Mirai. High curb weight of the vehicle resulted in higher power requirement and resulted in higher temperature generation. Lower drag area can also reduce the size of the radiator. Even the reduction in the higher allowable temperature will lesser the minimum size of the radiator. Roadway-related parameters have the highest impact on radiator area requirements. For every 1° rise in the slope of the road, there is a need for an additional 0.5 m^2 of the minimum radiator area and 7.50 to 8.50 kg of PCM[23].

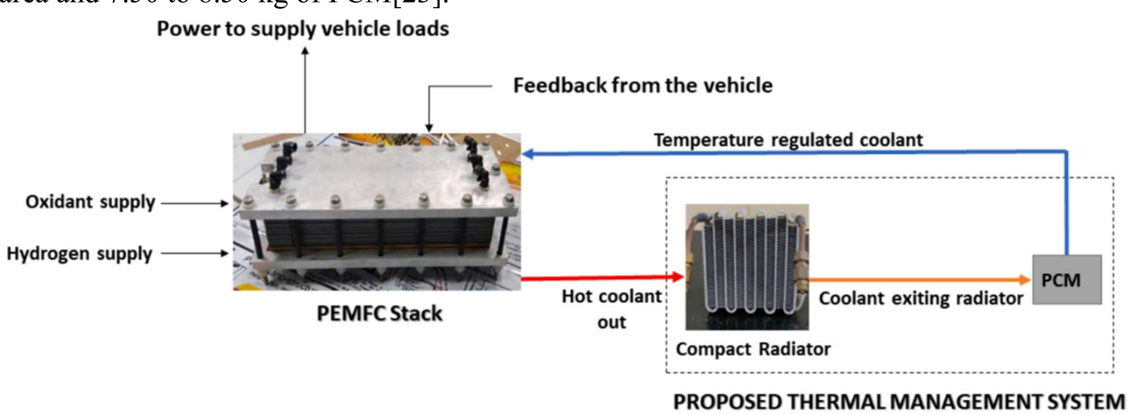


Figure 4: Illustration of the proposed system[23]

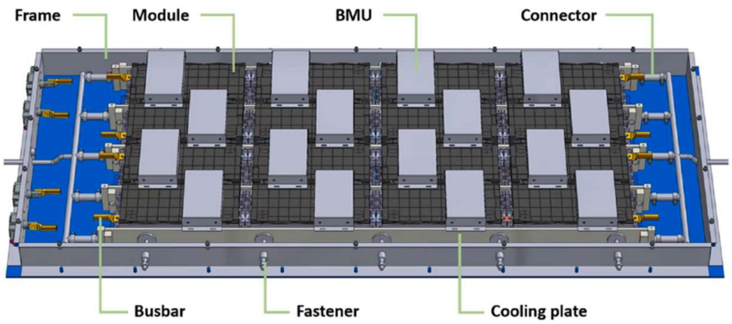


Figure 5: Breakdown structure of the key components in the pack[26]

Arvind J. Bhosale et al.studied on the electric vehicle system, and found that the design of the electric vehicle is incomplete without the temperature control system of the battery. Thermal management system helps in maintaining the temperature of the battery as well as the it helps in enhancing the temperature uniformity. Cooling strategy for BTMS were analysed, which were natural, forced air cooling, liquid cooling and mini channel cooling. Potential benefit was found with forced air cooling system, including easy integration, minimum maintenance, cost efficient but the cooling efficiency was lower than liquid cooled BTMS system [27].**Sinan Gocmen et al.**research on electric vehicle using Z-type manifold in natural convection cooling for the desired operational temperature. Flow resistance are generated for elevated battery for uniform which yields flow rate sweeping the surface of each cell to be the same. Maximum temperature decreases from12K to 0.3K. Temperature uniformity are essential for ageing and electrical resistance of the cells. Heat transfer is improved with different fin design as shown in Figure 5. Peak temperature can be controlled and kept under operational temperature which are extremely important for the electrical vehicles[28].

Peng Qin et al. researched in the thermal issues of the lithium-ion battery being used in the electric vehicle. In the research a rapid cooling and thermal management was proposed which was based on $C_6F_{12}O$ spray cooling in a closed loop system for a 18650 cylindrical battery pack arranged in 4X4. With the help of $C_6F_{12}O$ spray cooling the performance of lithium-ion batteries thermal management systems was improved. At 6cm spray height and 2.05 g/s flow rate, heat was dissipated by 30% with liquid film; 70% heat was dissipated with direct spray method. When rapid cooling and blank experiment were compared, maximum temperature was reduced by 517.1^0C of the thermal runaway. With the help of $C_6F_{12}O$ spray cooling, thermal runaway is removed effectively [29].

You Lyu et al. researched on the solid-state thermoelectric refrigeration and use of heat pump for the thermal management of battery pack in the EV and HEV for hot and cold weathers. By changing the polarity the operating modes can be changed. Battery pack design were proposed with copper battery holders, battery cells, acrylic battery container and liquid cooling medium. BTMS was included with thermoelectric cooling and a combination of air and liquid circulation. Heat generated by the battery pack were transported by the heat sink to the cold end and then were dissipated to the surroundings. System performance were evaluated and experimentally validated. The system was 20^0C lower for 40V test with only liquid cooling.

Batter pack did not exceed 30^0C for 30V power supply for 5000s period. Battery was within 60^0C under continuous discharge condition for 50V input for a period of 3000s [30].

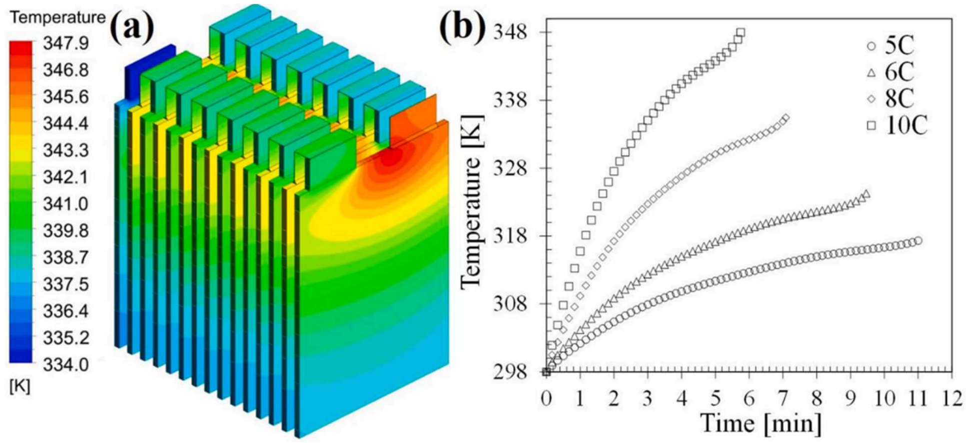


Figure 6: (a) Temperature distribution in a 15S1P battery pack at 10C without forced-convection and (b) maximum temperature in the pack for 5C, 6C, 8C and 10C [28]

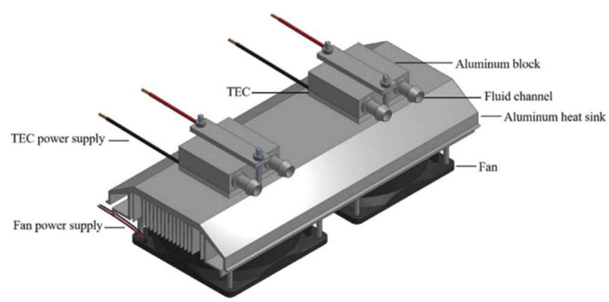


Figure 7: Structure of the TEC sub-system[30]

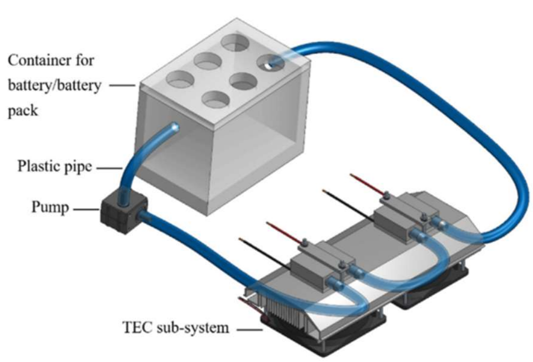


Figure 8: Illustration of the coolant flow path[30]

B.E. Lebrouhi et al.aimed for the development of the thermal management system for Li-ion battery pack for continuous charge and discharge cycle. the system is composed of 24 Li-ion battery with PCM material with liquid coolant circulation with aluminium tubes. Simulation of 3C discharge/0.5-C charging was carried out and the results were compared wth CFD and experimental results. The battery temperature were reduced by 38^0C by combing PCM material and liquid cooling compared to natural convection and PCM thermal management respectively. Increase in number of pipes will increase the performance of the system. The maximum cell temp. reduced by 11^0C as inlet temperature of liquid reduced by 15^0C as shown in Figure 9[31].

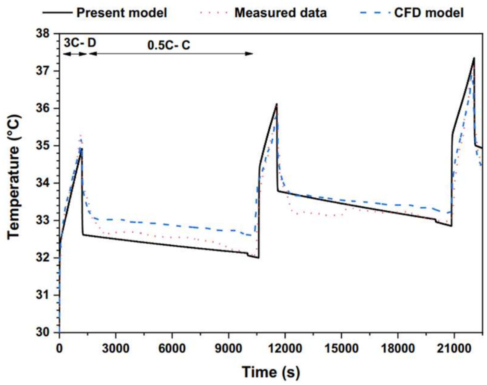


Figure 9: Comparison between Present model, Experimental and CFD results[31]

Jinglei Hao et al. researched on the use of polyethylene terephthalate (PET) material to be used for lithium ion battery. Mechanical/thermal and electrochemical performance of polyethylene terephthalate with fibrous material were analysed. PET fibrous membrane were prepared by electrospinning method. Mechanical/thermal, electrochemical properties were evaluated also stress–strain test, differential scanning calorimetry (DSC), thermal gravimetric analysis, and charge–discharge techniques. Result from the experiment showed that the membrane had high tensile strength with excellent thermal stability. Lithium ion cells assembled with PET material showed better electrochemical stability and good discharge capacity. PET material used for separator for lithium ion battery shows better performance and can be used in electric vehicles [32].

3. Conclusion

Controlling the temperature of a battery pack within an optimal range and ensuring uniform temperature distribution are the key to improving battery life. With the elevating energy density of batteries, more efficient and energy-saving thermal management system is urgently required for improving electric vehicle (EV) performance in terms of safety and long-term durability. In this work, a novel hybrid thermal management system towards a high-voltage battery pack for EVs is developed. Following conclusions could be drawn:

- The direction of flow of coolant, coolant type and mass flow rate decide the temperature distribution. Heat dissipation increases first during upstream and then during downstream it weakened.
- The design for temperature uniformity has a narrow inlet channel widening towards the outlet; this balances the effects of coolant velocity, heat transfer area, and fluid–solid temperature gradient to equalize the heat transfer from all areas of the plate.
- Adopting efficient cooling systems for electric vehicles is necessity to enhance battery safety, increase life of the battery, and minimize the detrimental effects of high surface temperatures on battery cell.

- Combining both PCM and liquid cooling for battery thermal management leads to reduce the maximal battery temperature by about 38 ◦C and 4 ◦C compared to natural convection thermal management mode and to passive PCM thermal management mode, respectively.
- At high cost of pumping power and low porosity the result demonstrated improved thermal performance of mini-channel with embedded AF over the plain mini-channel. The insignificant superiority of better thermal performance of cooling configuration with embedded SPF over AF was established with higher fluid flow velocities.
- Lithium ion cells assembled with PET material showed better electrochemical stability and good discharge capacity. PET material used for separator for lithium ion battery shows better performance and can be used in electric vehicles

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