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A STUDY ON NOISE REDUCTION OF BATTERY PACK COOLING SYSTEM OF EV

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Abstract: Electric vehicles are becoming popular because of the alarming rice in pollution, depletion of fossil fuels and global warming. Lithium batteries are the most popular energy source for the electric vehicle because of their high energy density, good efficiency and long life. Apart from the major advantages, high operating temperature is one of the major disadvantage for lithium ion battery. 20-50^{0}C is the optimal temperature for lithium ion battery operation; battery thermal management system have defined 60^{0}C as the safety temperature by considering different criteria's. BTMS use different methods for cooling; liquid and air cooled. Polyethylene terephthalate (PET) is a popular material used in the automotive sector for interiors. Interiors panels have chance of noise such as squeak and rattle, which occurs because of the elastic deformation caused by frictional force. PET material can be used as duct material for air cooling in the battery, reducing the noise and vibration. This paper gives a overview on the use of PET material for battery cooling and noise reduction.
Keywords: Thermal management, Electric vehicle, Hybrid electric vehicle, battery pack, cooling system

1. Introduction

Global warming has become a problem because of the increasing use of fossil fuel in the IC engine. It has been alarmingly increasing and the only method to solve this issue is by introducing electric vehicle. Replacing the IC engine with electric vehicle to solve the problem of increasing global warming [1,2]. Electric vehicles are being introduced into the vehicle fleet by many countries. 8 billion euro have been sanctioned by the French government to encourage customers [3].4.8 million charging stations are being introduced together with 120,000 switching stations by the Chinese government to meet the demand 36,000,000 electric vehicle until 2020. Lithium ion battery have been an popular energy source for the electric vehicle because of their good efficiency, high energy density and long life. As Lithium ion battery have a lot of advantages, but at the same time 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 are being carried out on the battery thermal management system, the different cooling medium being used such as air, liquid and phase change material. Air cooled system do not have good efficiency and the temperature uniformity is not maintained because of the low thermal conductivity of air.
Polyethylene terephthalate (PET) is a popular material and is being use by many industries and also it is widely used in the world as plastic polymers [4]. It has been observed that the production and consumption of plastic polymers have been increasing day by day. For the year

of 2015 the world production of plastic was 322million tons where as for the year of 2016 it was 335 million tons [5]. Until now the annual usage of plastic is 370million tons, it is expected to rise to 1 billion tons until 2050 [6]. In Turkey, in 2015, 25.8 million tons of plastic waste has occurred. 20% of this was consisted of packaging wastes [7].But, the use of polymeric materials in automotive interior always has a chance of occurrence of noises such as squeak and rattle(S & R). When sliding two materials, because of the frictional force there is an elastic deformation caused, adjacent to the contacting surface producing a squeak sound [8,9,10]. Squeak is produced by the unexpected noise because of the sliding induced friction instabilities. Rattle is also produced by the contact between two materials. Impact of two materials produces in-plane vibration that couple without-of-plane modes that can be heard as noise [11]. Trapp et al. [12] noticed that noise was produced during frictional sliding on the painted steel of different types of material. Sound produced due to the friction was because of the surface roughness of the material. It was also investigated that by increasing hardness and reducing Izod impact strength, impact induced noise was observed for different materials like PA and PP. Therefore, frictional characteristics are related to the S&R for the materials impact strength. Noise reduction could be reduced by reducing the friction coefficient, also improves the impact strength of materials. 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 [13-14]. A promising candidate for the cooling medium in the air-conditioning of EVs, pressurized CO_2 [15] 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

Rekabra Youssrf st al. researched on the design optimisation to improve the environmental aspect of cooling system and weight reduction. Jute fibers as a plant-system, available, cheap, and weightless material is combined with the PCM battery thermal management system. The lithium-ion battery is considered the main power source for EV because of its durability, long cycle life, low self-discharge rate and high capacity. But high temperature, fire risk, and thermal runaway remains as disadvantage in lithium-ion batteries. Nonetheless, the key issue are the heat and extreme temperature for the battery, and these could happen at high current stages during situations such as rapid acceleration or when the battery is full discharged, etc. therefore, an effective battery thermal management system is required to keep uniform temperature distribution among the cells and maintain the temperature within the proper scope. In this study passive cooling strategy such as phase change material with high laten heat is chosen to integrate jute. Since the PCM heat storage strategy is deficient to release and absorb the heat, hence deficient in maintaining the temperature within the desirable range especially for future EVs standards and demands with fast charging. Therefore, combining additional cooling mediums like jute with PCM will contribute to improving thermal performance and lowering the temperature increase. The PCM cooling strategy was built physically with and without jute, then the thermal characteristics of a 50Ah prismatic battery cell were investigated under three scenarios of load profile. Maximum temperature, temperature differences, and distribution with cooling efficiency were analysed [16].

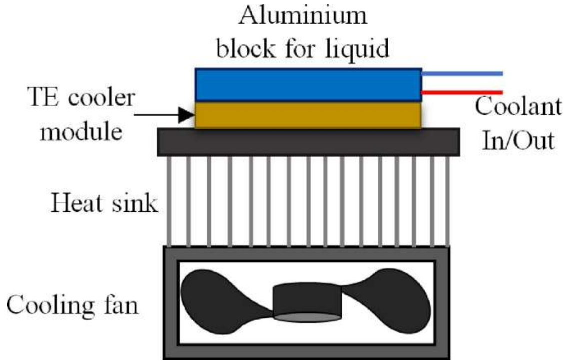


Figure 1: illustration of the used single unit of TEC system for BTMS [16]

Y. Lyu et al. studied on the battery thermal management system. Study was carried out for the purpose of development of the battery thermal management system with the combination of thermoelectric cooling, forced air cooling and liquid cooling. Science batteries play critical role in renewable energy-based application like the performance of EVs and hybrid EVs. BTMS are developed generally to optimized and monitor battery temperature, as it is a critical factor for the battery operating performance. Majorly charge/discharge capacity can be strongly influenced by temperature. This availability will further impact the performance of applications. For instance, the discharge rate will determine the acceleration process of electric and hybrid electric vehicles. The lifespan of batteries also greatly depends on the operating temperature. Under normal operating conditions, of say -30 ^{0}C to 60 ^{0}C, the battery health varies significantly from the optimal battery temperature range. However, studies suggest that working at above 50 ^{0}C can be harmful to the lifespan of batteries [17].

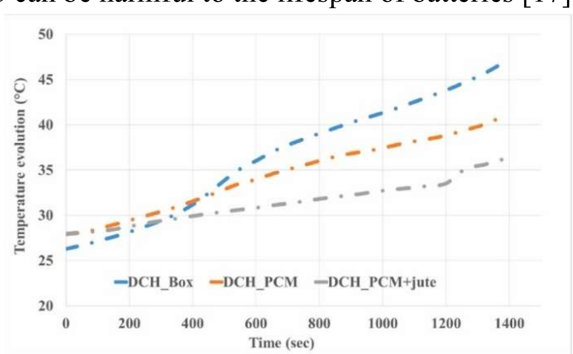


Figure 2: Temperature evolution over time during fast discharge [17]

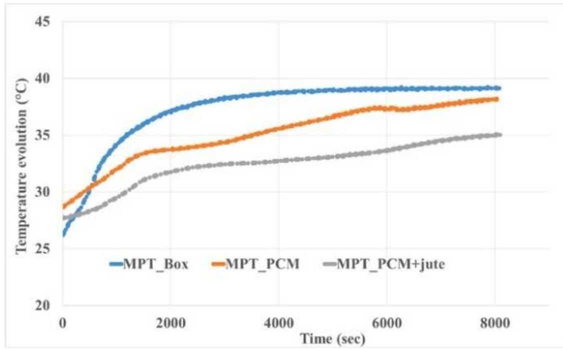


Figure 3: Temperature evolution over time during fast discharge with micro-pulse of charge and discharge currents [17]

Zhonghao Rao et al. proposed on the use of paraffin/ copper foam in the battery thermal management system. The temperature analysis with various conditions of experiment was discussed to evaluate thermal performance

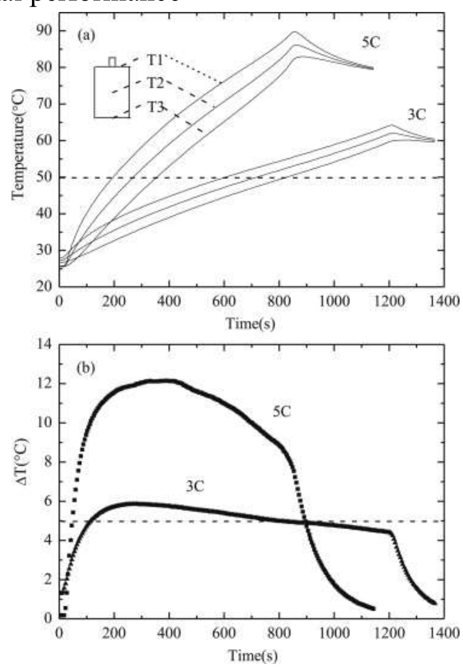


Figure 4: Temperature response of single battery cell without BTM at difference discharge rate [18]

of the BTM system. The experimental result of the battery module using paraffin/copper foam in vehicle system resulted the maximum temperature of 38.94^{0}C and local temperature difference of 2.85 ^{0}C. by seeing this result it can be concluded that the BTM system using parffin/copper foam could work efficiently in electric vehicle. The evaluation of battery discharge included under constant discharge rate and road operating state. Fluctuation of the temperature and local temperature difference of the battery cell and module in the road operating state. The cooling performance of the BTM system under constant discharge rate showed a good result. At different ambient temperature of 29^{0}C and 33^{0}C, BTM had a maximum temperature of 40.89^{0}C and 42.33^{0}C respectively. The paraffin/copper foa could work efficiently for BTM system with EV testing at maximum temperature 38.94^{0}C and local temperature difference of 2.85^{0}C [18]

Zhonghao Rao et al. studied to increase the cycle time of the power batteries and decrease the overall cost of the electric vehicles, the thermal management system equipped with heat pipers was designed according to the heat generated character of power batteries. The experimental result showed that the maximum temperature could be controlled below 50^{0}C when the heat generated rate was lower than 50W. the comprehensive performance of the power battery decreases with the increase of temperature. Temperature above 50^{0}C will lower the charging efficiency or the longevity property of power batteries. Therefore, the maximum temperature of power batteries should be controlled below 50^{0}C. The heat pipes are effective to cool a power battery with heat generation rate less than 50W. The maximum temperature and temperature difference are all under desired range when the input power is changed from 30W to 5W. Coupled with the desired temperature difference, the heat generation rate should not exceed 30W. Applying heat pipes-based power batteries thermal management is an effective method for energy saving in electric vehicles [19].

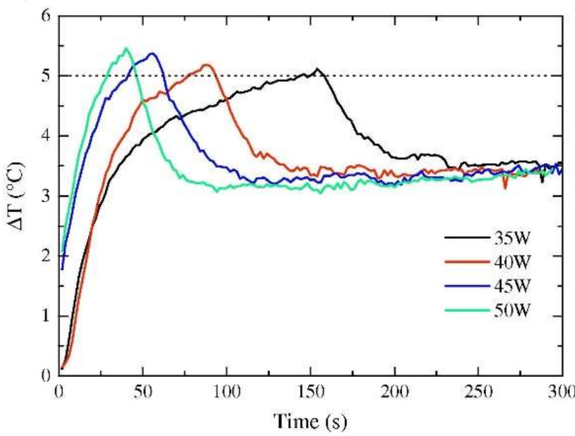


Figure 5: Temperature difference variation with input power from 35 W to 50 W [19]

Ziye Ling et al. researched on passive thermal management system using phase change materials (PCMs) provides an effective solution to the overheating of lithium-ion batteries. But this study shows heat accumulation in PCMs caused by the insufficient cooling of air natural convection leads to the thermal management system failures. Here a hybrid system that integrates PCMs with forced air convection is presented. This combined system successfully prevents heat accumulation and maintains the maximum temperature under 50^{0}C in all cycles. A numerical study is also carried out and validated with experimental data, which gives theoretical insight on thermos-physical changes in this hybrid battery management system. The hybrid system provides a more reliable thermal management performance, Auxiliary forced air convection cools PCM down below its phase change temperature during the charge which prevents heat accumulation. Full recovery of latent heat helps maximize the thermal energy storage capacity of PCM and keep T_{max} under 46^{0}C in all cycles. Forced air convection lowers the battery temperature and accelerates the latent heat and latent heat release, preventing the failure of the PCM-based passive thermal management system. In all cycles discharging at any rates, the average maximum temperature difference in the module is kept below 3^{0}C [20].

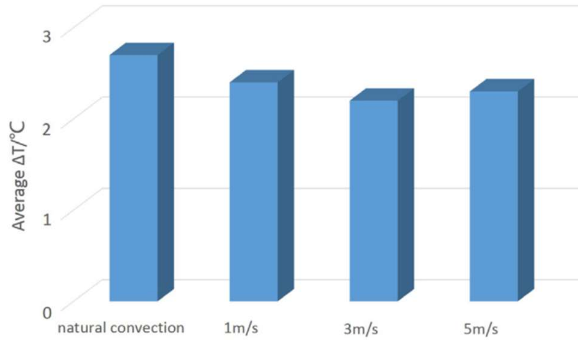


Figure 6: Comparison of historic average maximum temperature difference in thehybrid system with different airspeeds [20]

Jiwen Cen et al. studied on the lithium-ion battery thermal management system was investigated which uses the electric vehicle air conditioning refrigerant to cool the battery pack directly. In this system, a basic finned-tube heat exchanger structure and a special aluminium frame are adapted to design the battery pack thermal management module with lithium-ion batteries of cylindrical shape. The module is then integrated into the electric vehicle air conditioning system using two electronic expansion valves for the automatic control of the packs temperature with self-programmed control software. Experimental results show that the BTM system can control the battery pack's temperature in an appropriate present value easily under extreme ambient temperatures, as high as 40^0C. The temperature difference of the pack is less than 4^0C when its discharge rate is 0.5C, 1C or 1.5C and is within 1.5^0C for typical road driven cycles considered. Through the refrigerant circuit optimization, it can reduce the temperature non-uniformity in side the battery pack [21].

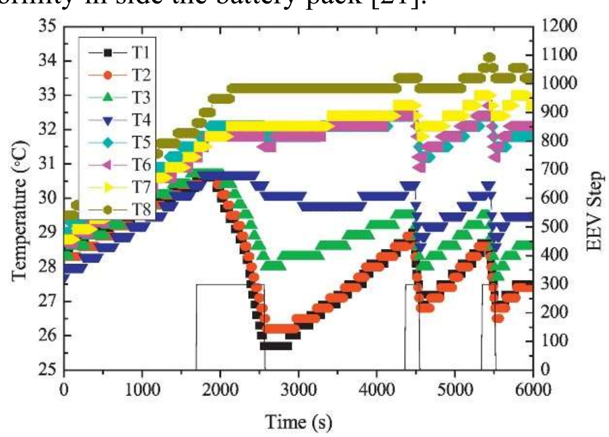


Figure 7: Time-evolution of the pack for a discharge rate of 0.5 C with low refrigerant flow [21]

Ahmad Baroutaji et al. researched on the proton exchange membrane fuel cells produce electricity as a result of electrochemical reaction between hydrogen and oxygen. PEMFCs are clean source of energy. The biproduct of PEMFCs are water and heat. Due to this, PEMFCs can be used to remedy the unfavorable environment impacts of fossil fuel and its role in global warming and pollution. Thermal and water management for the large amount of water and heat produced along with the electricity is very essential to enhance the energy efficiency and improve the durability of the device. Thermal management of PEMFCs can be achieved by employing appropriate cooling strategy depending on the power rating and specific application of the device. The cooling can be either passive or active. Waste heat recovery has also emerged as effective strategy for enhancing the efficiency of the PEMFC thereby reducing operational costs. Due to their significant impact on the cell performance, waste heat recovery systems have gained a great deal of attention in recent years. Therefore, this article aimed to present their recent development, prospects and trends as well as the main challenges. PEMFCs are considered among the promising technologies driving the transformation towards decarbonised and more sustainable societies. However, increasing the energy efficiency of a PEMFC continues to remain a challenge for this technology. Energy prices are increasing globally so there is an urgent necessity for any emerging energy technology, such as PEMFC, to increase efficiency and reduce the cost in order to remain competitive[22].

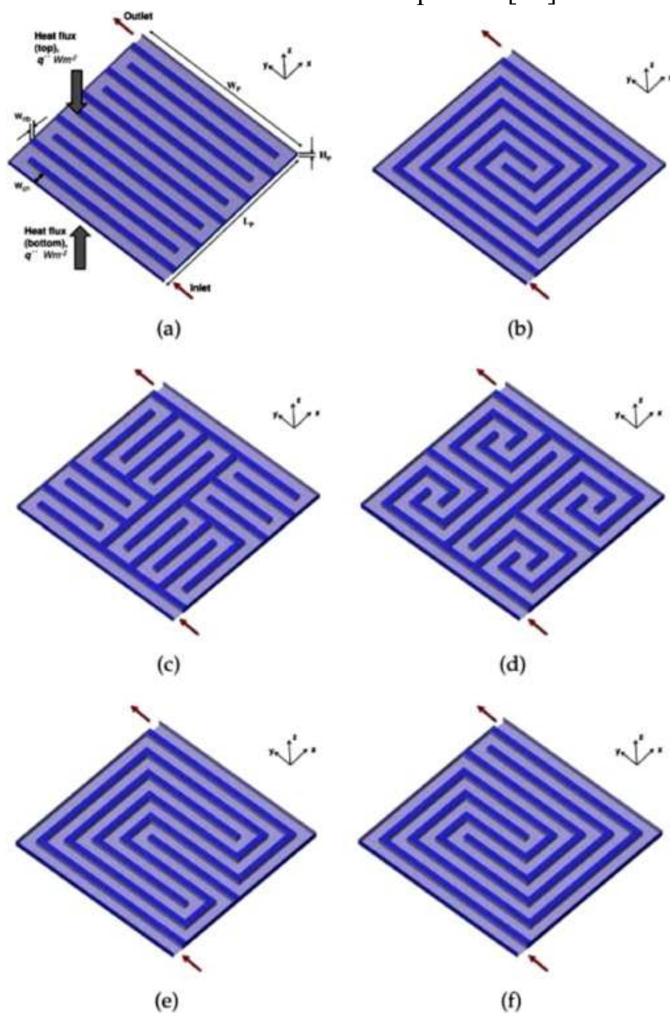


Figure 8: Air-flow cooling channels design [22]

M.N Khan et al. researched on the thermal management of cylindrical Li-ion battery (CLIB) with forced airflow and PCM was carried out. The battery was placed in chambers of different shapes filled with PCM and graphene nanoparticles. In (b), a total of 5 chambers (circular, triangular, hexagonal, rhombic, square) are applied. Cooling experiment is conducted through FEM by flowing air in the same pipe as in (c). When the PCM started to melt, a major percentage of the produced heat was spent for the phase shift, with some heat being transmitted to the air inside the channel. As a result, after the PCM melted, the HTC no longer grew. The triangular chamber was found to have the largest HTC; Higher heat transfer occurred from the triangular chamber to the airflow since the wall had a smaller distance from the CLIB. The lozenge chamber, on the other hand, had the smallest HTC. Moreover, the hexagonal chamber was observed to have a greater HTC than the circular one. A rise in the nanoparticle content of PCM improved thermal management and temperature distribution. The addition of graphene NPs to the PCM enhanced the HTC of the CLIB chamber; heat transfer was found to be 6.6% higher at a graphene NPs volume fraction of 4%. Increased airflow velocity reduced the TOU and TAVE-B while enhancing the heat transfer of the PCM chamber. The triangular chamber had the highest HTC, while the lozenge chamber was observed to have the lowest HTC. The triangular and hexagonal chamber had the largest and smallest PCM melting quantities, respectively, at early operation times. However, the triangular and lozenge chambers where found to have the largest and smallest quantities of PCM melting at longer operational times [23].

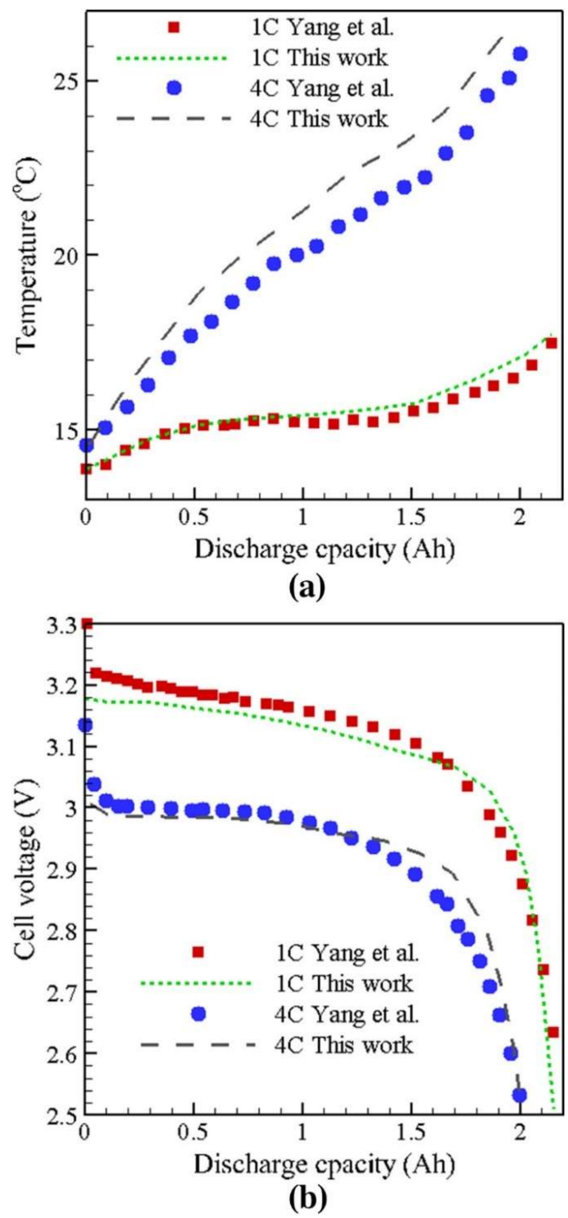


Figure 9: a) Cell voltage and b) TMAX comparison of a 3.7-V Li-ion battery to [23]

B.E Lebrouhi et al. this study is aimed to developing a low cost lumped model for simulating a Li-Ion battery pack with thermal management system under continuous charging/discharging cycles. Based on the literature review, most of proposed studies where PCM is combined with liquid cooling for battery does not consider the system during continuous charging-discharging cycles and they use general time-consuming CFD numerical tools. In addition, using CFD tool for this type of thermal management is not suitable in terms of computational time because of the phase change phenomena treatment and fluid dynamic modelling in the coolant channels. To develop a fast and simple lumbed model for passive and active BTMs. To evaluate the validity of the developed model, obtained numerical result were compared with both experimental and CFD results from the literature. To carry out a detailed parametric study, reducing the liquid coolant inlet temperature is suitable for battery pack system as it leads to absorb a high amount of stored heat in PCM and to maintain battery pack system as it leads to absorm a high amount of stored heat in PCM and to maintain batteries at low level. The maximum battery cells temperature is reduced from 31^0C to 20^0C as the used liquid coolant inlet temperature is reduced from 25^0C to 10^0C. The liquid coolant velocity and the number of coolant tubes are optimised in the BTMS. Increasing the coolant velocity is recommended when the PCM is fully charged for heat dissipation. However, and in the order to optimise the coolant pump energy consumption, a controlling strategy must be adopted to optimise the coolant pump energy consumption, a controlling strategy must be adopted for system coolant pump. The suitable number of coolant pipes in the studied battery pack system is nine tubes. Increasing the number of tubes above this number does not significantly improve the system performance and will lead only to complex the structure and induce difficulties at the manufacturing stage [24].

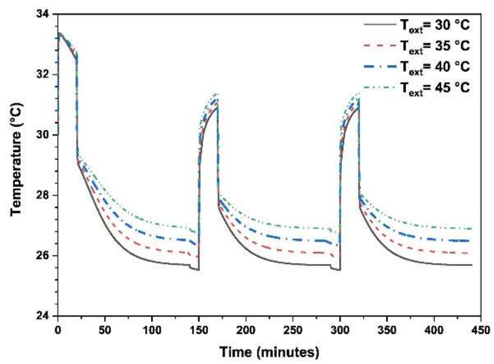
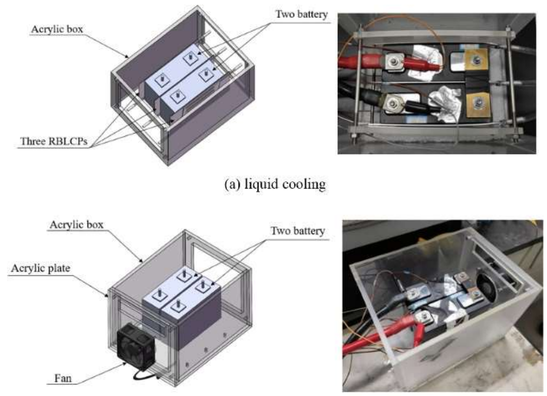


Figure 10: Time-wise variation of the battery temperature: The impact of the exterior temperature during continuous charging/discharging cycles [24]

Abhijeet Mitra et al.studied on the thermal management of the battery used for electric vehicle, cooling performance were experimentally observed at different discharge rates for 18,650LIB cylindrical cells. Indirect liquid cooling with single and dual aluminium serpentine channels were used with different flow configurations. Nanofluids were also prepared during the experimentation while using multi-walled carbon nanotubes. Mixture of ethylene glycol and water were used at three different volume fractions 0.15%, 0.3%, and 0.45%. The results were compared with mixture of ethylene glycol-water and with only water. The maximum temperature drop was observed for 0.45% Vf of MWCNTs for 6.9 °C, 10.2 °C, and 11 °C at 2.1C for single-channel flow, dual-channel with parallel flow and dual-channel with counter-flow configuration, respectively. The best cooling performance was observed for dual-channel with counter-flow configuration in terms of temperature, with a 8.6-13°C drop by working fluids. Temperature of the battery was uniformly maintained when counter flow was used and maximum deviation was 1.5-3°C was observed. 0.45% Vf of pressure drop was also observed for MWCNT of 1.3% and 14% for single and dual channel [25].

ZhaoliangChen et al. investigated the lithium-ion batteries which are used because of its energy storage, stability and energy efficiency in electric vehicle widely. Energy storage system has a limited power density by thermal management. Temperature distribution along the height of the battery was assessed. The thermal management analysis of two 100Ah lithium-ion batteries in series is carried out by using roll bond liquid cooling plate which has significant heat dissipation performance and low manufacturing cost. Comparison of direct channel with



(b) air cooling

Figure 11: Battery module structure [26]

serpentine channel embedded in cavity and rib structure. Contact area and flow rate on the battery thermal was studied. The cell temperature can be controlled by the flow rate under charging and discharging at 1C, in the dominance of large heat exchange area. Large flow rate are required for 2C discharge. Better performance was observed with rib structure. Roll bond liquid cooling plate can control the temperature below 35^{0}C at small pressure drop [26].

Qi Li et al.investigated on the acoustic propagation PE pipeline that were filled with fluid. It was found that the cutoff frequency were 4.6,10.4 and 16.3 kHz, close to experimental results. Sound above a cutoff frequency could propagate axially and an also propagate in the form of vibration [27]. **Muhammad Rafiq Kakar et al.**researched on the use of waste plastic for noise reduction. The cyclic compression test (CCT) and semi-circular bending (SCB) test was used for characterization of high and low temperature performance. The CCT results revealed that the PmB mixture had shown significantly higher resistance compared to the PE mixture. Low temperature PE behaves elastic where as at higher temperature it becomes viscoelastic [28].

Ayşe Özkal et al.produced a new material using nano fibres for noise control in the lower frequency regionabsorption using recycle polyurethane (PU) nanofibers of different durations. Nanofiber spinning was examined and compared with commercial sound absorbers. Nanofibers were produced from 15wt% PU solution for 5,20,60 and 120min were chosen for nanofiber spinning durations. Calculation of noise reduction coefficient was carried out after sound absorption coefficient was measured. Reduction in noise was significant on the basis of composite on the nanofiber spinning duration. It was also observed that a sandwiched structure was better for sound absorption and as it is produced form recycled PU it was environment friendly[29].**Nga H.N.Do et al.**developed material with fly ash and recycled polyethylene terephthalate fiber. The obtained composite aerogels display extremely low density of 0.026–0.062 g/cm3, high porosity of 96.59–98.42%, low thermal conductivity of 34–39 mW/(m·K), flexibility with Young's modulus of 3.98–20.61 kPa, and noise reduction coefficient of 0.18–0.31. Addition of fly-asg reduces the weight of the composite, at the same time ensures safety, high value and cost effectiveness [30].

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. Use of air cooling system in the EV battery pack can lead to a lot of noise. Using PET material in the air cooling duct can help in reducing the noise from the battery pack. In this work, the use of PET material in the duct system of the battery pack was reviewed. The following conclusions were drawn:

1. Polyethylene terephthalate (PET) is one of the most widely used plastic polymers in the world.
2. Use of polymeric materials in automotive interior always has a chance of occurrence of noises such as squeak and rattle.
3. PCM heat storage strategy is deficient to release and absorb the heat, hence deficient in maintaining the temperature within the desirable range especially for future EVs standards and demands with fast charging.
4. working at above 50 ^{0}C can be harmful to the lifespan of batteries.
5. Temperature above 50^{0}C will lower the charging efficiency or the longevity property of power batteries. Therefore, the maximum temperature of power batteries should be controlled below 500C.
6. Auxiliary forced air convection cools PCM down below its phase change temperature during the charge which prevents heat accumulation.
7. new sound-absorbing composite materials in the form of nanofiber web-reinforced nonwovens and sandwich structures were produced by incorporating polyurethane (PU) nanofibers of different durations to recycled polyethylene terephthalate (PET) bottle waste nonwovens in order to execute environmentally friendly noise control in the lower frequency region.

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