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Critical Review on The Various Process Parameters To Enhance Performance of Ali-Ion Battery

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ABSTRACT

The development of an electric vehicle is mainly driven to address the global energy issues and air pollution concerns. Due to its long life cycle and high energy density Li-ion is widely used in EV's coupled with the help of an effective Battery Thermal Management System (BTMS).An EV can compete against an Internal Combustion Engine (ICE) vehicle in terms of driving range. This review paper givesdetailed explanation on the progress of BTMS in the field of battery arrangement, parameters required for structural optimization of a battery pack, cooling techniques such as air cooling technique with series, parallel and series-parallel configuration, liquid based cooling involving direct and indirect based configurations.

KEY WORDS: Battery, BTMS, CFD, Cells, Cooling

INTRODUCTION

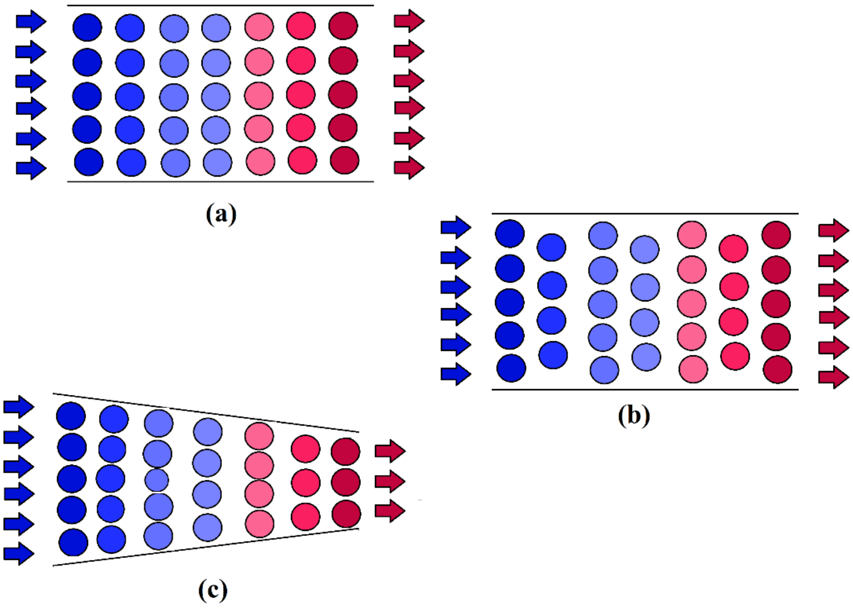
The global oil consumption per day has grown by 1.9million barrels out of which $^{2}/_{3}{}^{rd}$ of the pollution is credited to transportation sector as per the report given by BP energy outlook 2016[1]. Therefore automakers are under immense pressure to focus R&D on electric vehicles (EV), hybrid and plug-in hybrid vehicles (HEV &PHEV) that help in reducing emissions of GHG's and harmful pollutants. Anderson et al.[2] reported that the utilization of EV's in transportation sector can reduce emission of GHG by about 40% if they are powered by renewable sources of electricity. If renewable sources are used for the generation of electricity Endo et al. [3] predicted that the CO_2 emission will be reduced by $^{2}/_{3}{}^{rd}$ by 2050. The governments across the world are starting initiatives by introducing policies that help in promoting EVs that helps in zero emissions and energy savings. Globally by 2014 around 315,000 EVs were sold, this represents 50% of sales done in 2013. By 2015this number rose to 550,000 and in 2016 the EV sales have touched to about 774,000 which is 40% of sales done in the year 2015[4, 5].The performance of a EV is as good as the selection of the battery which can meet the driving parameters of aninternal combustion engine (ICE) vehicle that it is intended to replace in first place such as energy storage system, low self-discharge rate, high specific power and energy, long life cycle. The EV's generally have faster acceleration when compared to ICE. For vehicle applications rechargeable Li-ion is very well suited as it gives nearly twice the amount of energy density of 400Wh/L and specific energy 150W h/kg, which is relative to the Nickel-metal hydride (NiMH) that have ruled the HEV market with energy density of 240Wh/L and specific energy 75W h/kg. The operating temperature range for Li-ion battery is around -20 to 60^{o}C.But the optimal performance is only obtained when the temperature is narrowed down to between 15 to 35^{o}C. Hence there is a need for effective Battery Thermal Management System (BTMS) to maintain required temperature range and minimize effects of temperature on the batteries. The temperature change inside a battery is unavoidable due to the effects of operational conditions heat is released by a chain of chemical reactions during discharging and charging.

According to the cooling medium BTMS is divided into liquid cooling, air cooling, heat pipe cooling and phase change material (PCM) cooling. The air cooling is the most simple in structure to construct and low cost, however low on thermal conductivity, cooling capacity and low specific heat. The phase change material helps in absorbing the heat generated by the battery by phase transition and releases the heat absorbed under cold conditions. However the phase change materialoffers low thermal conductivity. Research studies showed that these limitations can be overcome by adding metal additives to PCM. In BTMS heat pipe cooling also known as heat exchangers are used because of their flexible geometry, compact structure and lightweight. Another prominent feature of heat pipe is that no external power is required. They work by transferring the working fluid to be evaporated from the evaporator to the condenser and then by using capillary wick back to the evaporator. In comparison to the cooling strategies liquid cooling does show some efficient cooling due to its high specific heat capacity of liquid and high thermal conductivity. This system also employs a compact structure thereby making it to easier to use it in automobiles where space restraints plays a major role. Thereby making it highly practicable to use in EV's.

The key limitations that restricts the use of li-ion batteries in EV's is the high cost of the battery, degradation with rise in temperature, safety concerns, limited life cycle. Ongoing research work is being done in the field of thermal related issues of li-ion batteries innumerous conditions and development of battery thermal management system (BTMS).

DESIGN OF BATTERY ARRANGEMENT

In an EV the performance of the battery is mostly influenced upon the design and arrangement of the overall structure. For air and liquid cooling techniques the battery configurations such as parallel, series andseries-parallel can be employed. The different types of battery configurations has been summarized by Xia et al.[6] Of these configurations series-parallel is the better option as it combines the benefits offered by the series and parallel by making the batter pack more compact, shortening the length of the battery pack, uniformity in battery temperature by lowering the coolant pressure. In hybrid configuration the number of inlet channels for the coolant is reduced thereby reducing the cooling system complexity in terms of designing when compared to parallel configurations.The trapezoidal structure can be used in series-parallel configuration from. Fig 1(c). the number of batteries in each row can be reduced by using staggered arrangement, while enhancing the coolant speed by greatly improving the performance. The comparative studies is done by Yang et al. [7]between aligned and staggered cell arrangements. Fig 1 (a) and (b). Shows the power consumption, temperature rise and uniformity, cooling power index of these two cell arrangements at by altering the longitudinal gap and transverse spacing. The results showed that for longitudinal spacing there has been an increase in cooling efficiency but it is quite opposite in case of transverse gaps. Thereby indicating that the cooling index changes in opposite to longitudinal gap.



(a)

(b)

(c)

Fig .1 .Series parallel configuration of a) aligned b) staggered and c) trapezoidal configuration

CFD simulations were carried out in alignment configuration by incorporating the reciprocating air cooling technique byMahamud and park et al. [8]the results showed that for a reciprocating time period of 120s the temperature difference of a battery can be reduced by around 4^{o}C while the maximum temperature difference is around 1.5^{o}C. This is due to boundary layer disturbance by reversal of periodic flow and redistribution of heat. Wang and Ma et al. [9] carried out experiment by constructing actively controlled and uncontrolled reciprocating air flow for effective battery cooling. The numerical simulations and experimental data used by Wang et al. [10] to form the optimal cooling strategy required for the parasitic power consumption and the maximum temperature rise.From fig. 2(a) because of heat absorption by the coolant, there is rise in coolant temperature. Therefore the battery temperature near the outlet is higher than the entrance. Fig 2(b) and (c) shows the improvements to the configuration of the battery design. Fig 2 (b) shows a trapezoidal design that allows to increase the coolant along the flow direction by having same mass flow rate at the inlet by increasing the heat transfer co-efficient at the surface. Thereby improving the heat transfer rate. Fig 2(c) is a reciprocating structure having two fans identical to each other placed at the exit and the entrance. They generate a reciprocating air flow whenever they are turned on and off. By employing this technique hysteresis control is achieved and parasitic power is reduced by 84%.

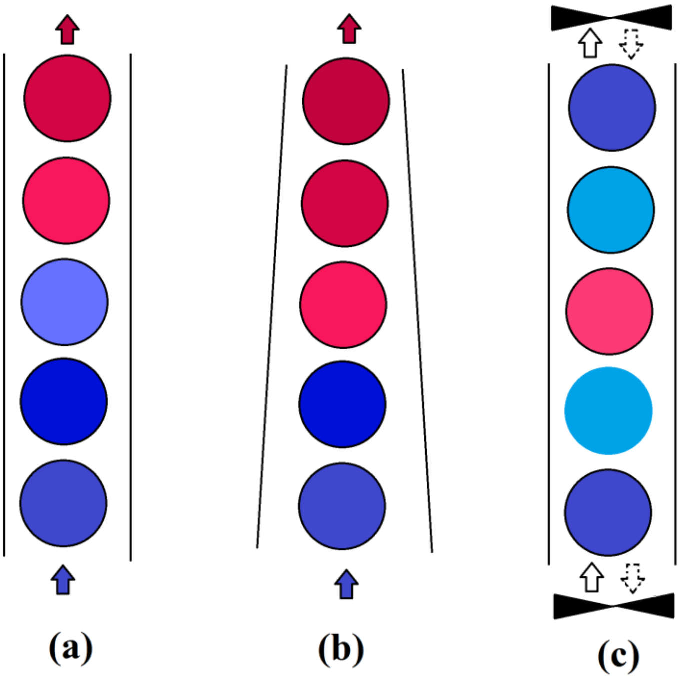
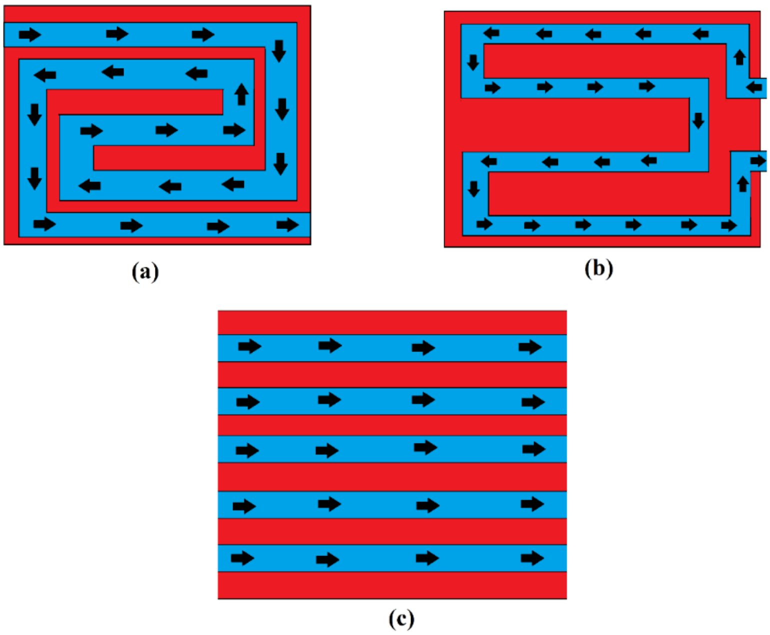


Fig. 1. Series cooling configurations. (a) Simple channel; (b) wedged or trapezoidal channel shape; (c) reciprocating cooling by using fans.

PARAMETERS FOR STRUCTURAL OPTIMIZATION OF A BATTERY PACK

The selection of coolant medium determines the type of battery pack or structure needed to be designed. In case of direct cooling the battery pack has to be relatively simple. While for indirect cooling auxiliary devices for heat transfer such as jacket, cooling plate and tube are required and needed to be designed accordingly, thereby making it complex to design. The inlet and outlet channel diameters of coolant flow for a battery are designed as per the needed requirements. For direct cooling system the battery pack is completely immersed into the coolant thereby making efficient heat transfer between the battery and the coolant. The major drawback of this cooling system is that the weight of the battery pack is heavy due to immersion of coolant into battery pack. To solve this issue Hirano et al. [11] used boiling water along with two separator configurations of type A and type B. The type B separator works as an artery and is covered by using a microfiber cloth of high capillary pressure on the surface of battery and is sandwiched by plastic separators for vapour gas path mimicking just like arteries. The vapour gas is also allowed to flow on to the top of the battery and into the plastic separator through the arteries. The experimental result showed that type B has required only half the coolant to achieve the same performance at 20C charging and discharging as given by type A when completely immersed.

When it comes to indirect cooling usually a cooling plate is used as a separator for soft cell or prismatic cell. While cooling jacket is ideal for cylindrical cell. The cooling performance depends on parameters such as position of the cooling plate, channel shape, path geometry, number of channels and diametersof inlet and outlet. The path geometry for coolant flow can be a U-turn type [12-15], multichannel type [16-18] or serpentine type [19,22-21] as shown in Fig 3 a. Jarrett et al. [12,21]performed CFD analysis by optimizing the performance of coolant channel elements that have been taken into consideration are temperature uniformity, pressure drop and average temperature. By increasing the width of the serpentine belt the results showed increase in average temperature and reduced pressure.From fig.3(a) Comparative studies between serpentine flow, serpentine-parallel flow and flow without distribution channels were given by Wie et al. [22] showed good operational results in terms of pressure drop, coolant flow rate and electrolyte temperature for serpentine-parallel flow. From Fig. 3 (b). shows the structural and working conditions for a cooling plate of U-turn type were optimized to perform experiments and simulation by Yuan et al. [23]The results more uniformity in temperature distribution between the batteries when inlet and outlet are in same direction. The structures of serpentine and U-turn channel are very similar to each other.Fig 3 c. shows a multi-channel cooling plate, the muti-channels are mainly used for high coefficient of heat and heat transfer.



(a) (b) (c)

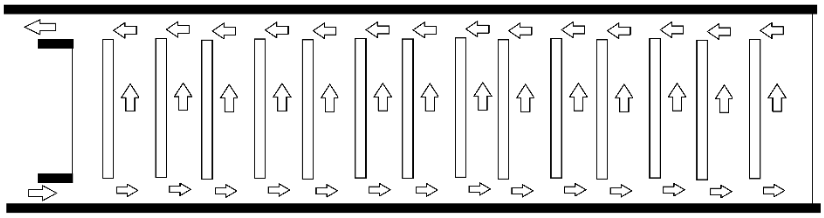
Fig. 3. Types of coolant flow: a) serpentine channel flow; b) U-turn channel flow; c) multi-channel flow

A lot of research studies are being done in the field of multi-channels such as mass flow rate, number of channels, channel diameter and shape,mass flow rate, direction of inflow and cooling performance based on ambient temperature. Qian et al. [24], Hua et al. [25] and Wang et al. [26]pointed that the effect of cooling performance is little by inlet flow direction. Qian carried out numerical simulations by designing a cooling plate with 5 channels. By increasing the mass flow rate to definite value there has been a decrease in temperature rise but further increase in flow rate hasn’t shown any consistent reduction in battery temperature rather than energy losses due to pumping. Xie et al. [20]performed work by increasing the width of the channel from 3-6mm thereby reducing the pressure drop to 55%. Therefore pumping loss can be reduced by increase in width. Zhang et al. [27] studied on the channel shape aspects on three different of shapes circular, rectangular and trapezoid by keeping the area of cross-section similar to all three shapes. The results showed that the trapezoidal shape has attainedthe finest cooling performance while the battery module having circular channel has maximum pressure drop at similar flow rate. The configuration of channel outlet was studied by Jin et al.[28] by introducing straight channel with oblique cuts across the straight fins as it lead to boundary layer re-initialization. The results showed that coefficient of heat transfer is higher for oblique channel when compared with straight channel. Bai et al. [29] worked on the cooling plate height and thickness. By keeping the battery spacing and mass flow rate as constant and varying the height from 2-7 cm. It is found that increase in height can reduce the coolant pressure drop. But when the height exceeds 5cm there is a minimum temperature difference. Tong et al. [30] worked up on the cooling plate thickness by varying it from 0.5-4mm. It is observed that increase in thickness can help in temperature reduction between the two batteries particularly at high discharge rates. When the thickness is at 2mm or more there is not much significant effect on the battery.

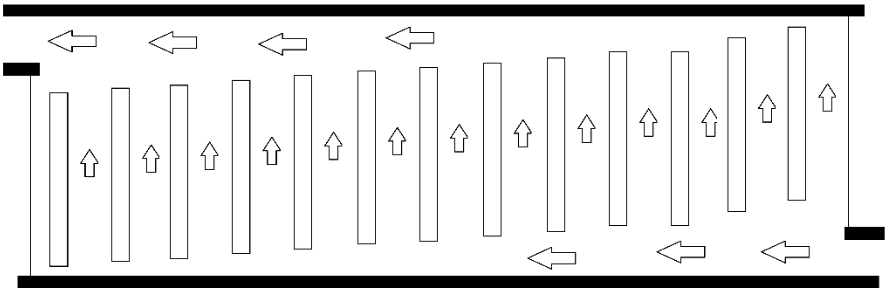
In order to have superior heat dissipation area a cylindrical battery having a jacket as an auxiliary device is wrapped around it in order to have superior heat dissipation area. A mini channel cylindrical tank with coolant flow from inlet located at the bottom to the distributor was designed by Zhao et al. [27]the distributor helps in maintaining a homogenized pressure flow at the bottom inlet to the exit at upper end where the collector is meant to collect the heat absorbed from the coolant. When compared with the heat transfer by natural convection the cylindrical battery cooling with jacket cooling showed good results in eliminating the temperature difference when channel number is more than 8.Rao et al. [31] studied on cooling effect of battery inside an aluminium cylindrical block.on the basis of performance of heat transfer. The results showed that uniformity in battery temperature is more effective for a system with variable area of contact than a system with constant contact area.Zhang et al. [32] improved the cooling system by sandwiching a flexible graphite between the batteries and cooling plate. The results showed there is 7-2^{o}C reduction in temperature between the batteries. Yeow et al. [33]combined the aluminium fin with cooling plate. The fin acting as a bridge between the cooling plate and battery. Chiu et al. [34] studied the effects of pressure drop on heat sink with micropin fins and heat transfer efficiency of liquid coolant. Wang et al. [35] studied the intensities of diverse air flows on to the coolant by introducing forced gas cooling system with a cooling plate. Bai et al. [29] investigated on the effects of Phase change materials (PCM) in combination with cool plate to improve the temperature uniformity.

AIR BASED COOLING

In BTMS of EV's air is used as cooling medium mainly because it's simplicity to construct and maintain. Several studies have done on optimizing the airflow channel as the distribution of airflow has an direct effect on the batteries, thereby improving the cooling performance.The air based cooling is widely used vehicles such as Toyota Prius, Nissan leaf. The cooling performances are classified into parallel, series and series-parallel configurations.Park et al.[36] studied on cooling performance by optimizing airflow configuration without any changes to the existing battery system. The results showed by extending the tapered manifold by 10-20mm the harmful gases can be released as it also acts as a pressure relief valve. Xu and He et al. [37] studied heat dissipation effects by comparing longitudinal and horizontal battery layout. The results showed a horizontal layout with shorter air flow by adding bottom duct thereby increasing heat dissipation with the increase in area of contact in comparison longitudinal battery layout. Sun and Dixon et al. [38]investigated the cooling efficiency for a tapered Z-type and U-type from Fig.4 (a) and (b). The results showed tapered Z-type ducts mitigated the changes in cell temperature by reducing the air flow rate in cooling channel and overall pressure drop in comparison to U-type.



(a)



(b)

Fig.4.Schematic parallel configurations. (a) U-parallel configuration;Z-parallel configuration

Chen et al. [39] studied airflow distribution by using flow resistance network model. The results showed optimization of 41% reduction in maximum temperature difference between the batteries with fixed air inflow and with constant heat generation. Xie et al. [40]studied the effects angles of air/outlet. The results showed best thermal performance for air inlet and outlet angles of 2.5^o for an evenly distributed battery system with reduction in temperature by 12.82%. Hong et al. [41] studied the cooling performance on the outlet wall duct by changing the position and size. Fan et al. [42]studied 3-D thermal analysis by changing the gaps in a cell and air flow rate. Wang et al. [43] investigated thermal performance of cell layouts in rectangular arrays of (1×24, 3×8, 5×5) rectangular arrays. Yang et al. [7]investigated on the thermal performance of a 6×10 cell arrangement in staggered and aligned arrangement. The results showed maximum temperature rise is directly proportional to staggered arrays for longitudinal spacing while for aligned arrangementit is inversely proportional with longitudinal and transverse interval of 34mm and 32mm.Mahamud et al. [8]studied on aligned battery configuration by introducing reciprocating air cooling system and carried out two dimensional CFD simulationsfor a unidirectional flow. The results showed a temperature reduction of around 4^{o}C.

LIQUID BASED COOLING

Liquid cooling is considered to be one of the efficient cooling technique when compared with air based cooling techniques. The only drawback is that liquid cooling is prone to electrical short circuit if there are any leakages. Therefore automobile manufactures have adopted indirect cooling techniques in vehicles such as Tesla and GM. Water and ethylene glycol mixture is usually used as a medium for heat transfer. For indirect liquid cooling an additional thermal resistance is around 10^{-4} K W^{-1} due to electrical insulation coat and metal tube. While for direct cooling the thermal resistance for air is 10^{2}-10^{1} K W^{1} and 10^{3}-10^{2} K W^{1} for liquid [44-45]. The indirect cooling system can be classified as jacket cooling, tube cooling and cold plate cooling with micro channels by using fins. The EV manufacturer Tesla adopted the use of wavy tubes [46-47]. The configuration of series cooling when compared with jacket design is safer based on mechanical and electrical evaluation. The fluid connections between the tube and manifold by enclosing at outside the battery module. Thereby eliminating the potential leakage and thus enhancing heat transfer between the cooling tube and the cells. From Fig. 7.Shows a cooling jacket cross-sectional view that consists of inlet, outlet, hallow closure and segregation walls. The segregation walls are unified into the closure and guides the liquid coolant. In parallel cooling configuration uniformity of temperature can be attained. Zhao et al. [48]suggested a parallel cooling configuration of novel kind on liquid cooled mini-channel cylinder from the Fig. 5.The results showed the effects of flow direction, mass flow rate, and size of the entrance on heat dissipation performance lead to a maximum controllable temperature of up to +40°C with a discharge rate of 5C.

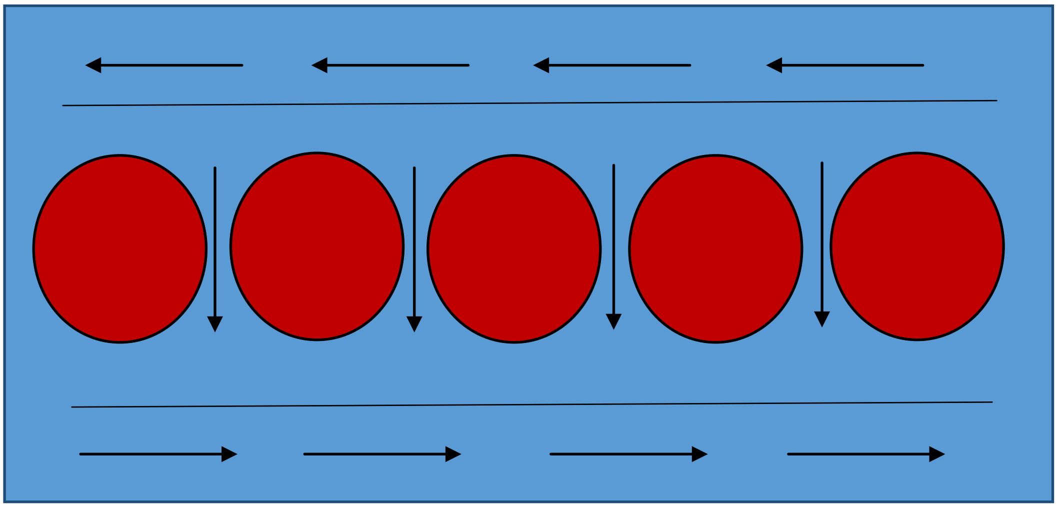


Fig. 5. Indirect liquid cooling for a cylindrical cell by using cooling jacket

Huo et al. [49] studied the effects of ambient temperature rise and distribution of a battery at discharge process by designing a straight mini channel cod plate. The results showed boundary layer development due to heat transfer by convection thereby resulting in maximum temperature elevation along the flow direction. Panchal et al. [18] performed experimental investigation of a serpentine channel the coolant path flow is similar to that of an EV Chevrolet Volt. The results showed with increase in temperature of 5°C and 35°C by increasing the boundary conditions, the discharge rates were increased in a range of 1C to 4C. An et al. [50]performed work on cooling effect on voltage and temperature distribution on a prismatic battery pack by suggesting a BTMS on min-channel boiling liquid. The cell temperature and temperature were maintained at 40°C and 4°C in order to get optimal results. The results also showed that with the increase in flow rate the voltage of cell is reduced and also the temperature and voltage uniformity of a battery module can deteriorate at high rates of discharge.

CONCLUSION

Extensive research in field of electrolytes and electrode materials paved the way for the application of Li-ion battery in EV. However the advancements in BTMS is somehow overlooked. The working parameters of a battery such as life span, operating temperature, thermal runaway and power degradation are greatly affected by the performance of BTMS. It also helps in maintaining the optimal temperature range of -20-60^{o}C with no more than 5^{o}C temperature difference. An effective BTMS helps in battery layout of series, parallel and series-parallel configuration. Of all the configurations series-parallel has a more cooling performance and is beneficial for large battery pack with a compact size. The design and structural parameters of cooling plate inside a battery pack also plays a huge role for effective functioning of a BTMS.And among all the approaches air and liquid cooling methods are commonly adopted for commercial use in an EV.

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