Lithium-ion Cylinder Battery Power Cooling: A Review

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July 1, 2021

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Abstract. Electric vehicles (EV) are an environmentally friendly source of energy. One of the EV applications uses Lithium-ion (Li-ion) battery cells. In practice, li-ion operation generates heat that will later pack on battery performance. Therefore, this paper review will discuss battery thermal management system (BTMS). There are several methods of BTMS, but this paper review will only discuss BTMS air-cooled and liquid-cooled. Both will be done in comparison and search of the best. The results showed that the liquid-cooled BTMS was superior in uniform temperature distribution but more complex and fluid leakage could occur. In comparison, the air-cooled BTMS has the advantage that the system is more straightforward, but the temperature distribution between batteries is not good.

INTRODUCTION

Rising living standards and economic growth are affecting the increasing need for energy. Today, energy sources still come from fossil fuels in the form of oil, gas, and coal. It is aware of affecting environmental pollution and greenhouse gas emissions. The step that can be taken in men over is finding other energy sources that are environmentally friendly and can meet energy needs. The electrification of electric power stations has been promoted as a potential alternative to reduce greenhouse gas emissions. Especially in electric vehicles (EV) applications, more than 20% will reduce greenhouse gas emissions. If electricity for EVs is generated from renewable energy, it can be reduced by more than 40% [1].

EV application uses Lithium-ion (Li-ion) battery cells as energy storage. Generally, battery cells are connected in series and parallel in the battery box. Because of the small space inside the battery box, the battery ventilation effect is not good. Battery power generates a large amount of heat during operation, which causes sharpness to increase the battery pack's temperature. It has been determined that the appropriate working temperature range for the battery is 20–45°C [2]. Furthermore, there is a risk of a thermal runaway at high temperatures as a serious safety issue for Li-ion batteries that cause fires and battery explosions.

Thus, it takes the innovation of a system that can be used to cool down the battery. The cooling is to remove overheating of the storm. This review paper compares the thermal management system of air-cooled batteries with the thermal system management of water-cooled batteries. This aims to be able to find which method is the best and efficient in cooling the battery.

BATTERY THERMAL MANAGEMENT SYSTEM (BTMS): WORKING PROCESS

BTMS consists of a combination of hardware and software. It is used fundamentally to maintain the battery cells' temperature in the package at the optimal range [4]. BTMS helps improve life span and ensure safe and secure battery operation [44–47]. In particular, filling/emptying capacity can be significantly influenced by its nature. To ensure uniform and adequate cooling, BTMS consists of algorithm-related controllers and controllers that adjust different cell temperatures and operating states. Depending on electrochemical-physical characteristics and appropriate reactions, the optimal operating range of the battery is different. Since battery performance depends on individual cells' performance, the cooling scheme must be activated when the battery performs a high charge and discharge rate[5].

BTMS generally consists of cooling, heating, and insulation components. The intensity, direction of cooling and heating will depend on the application's needs to keep the temperature at a uniform range. A provision must be made for ventilation if the battery can produce harmful gases [6]. Figure 1 illustrates the general structure of BTMS [7].

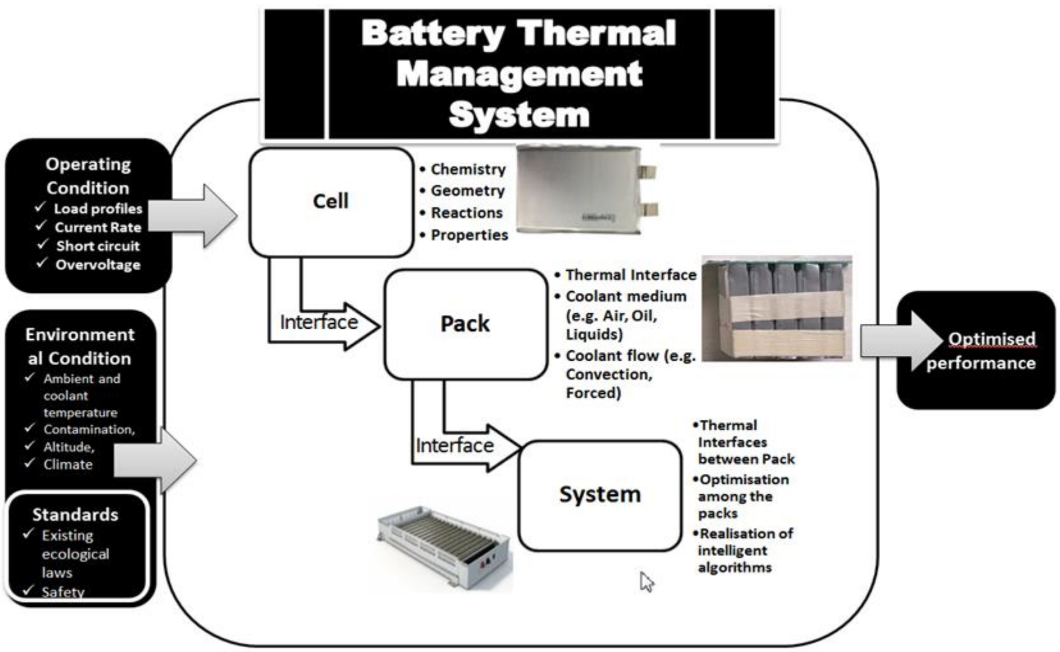


FIGURE 1. The general structure of BTMS [7]

LIQUID-COOLED BTMS

A liquid cooling system is considered an effective cooling method, which can control the battery's maximum temperature and the temperature difference between battery cells within a reasonable range and extend the life of the cycle. Tong et al. [8] numerically studied lithium battery packs-prismatic ions, which use BTMS-based water coolers between cold plates for battery modules with a series of stacks. The increase in the cooling flow rate increases the average temperature and uniformity temperature or the plate wall thickness. Zhao [9] presented the battery thermal management system's design with a separate flat aluminium tube surrounding the prismatic cell, containing small channels in each pack that the water flow passes through to improve heat transfer efficiency (Figure 2). Results have shown very little consumption. When the number of microchannels is not less than four and the inflow rate is controlled at 1103 kg/s, the battery module's maximum temperature can be managed below 40°C. As the number of microchannels in the LCC increases, the maximum temperature decreases gradually, but the channel amount should not exceed 8. Yang et al. made some improvements in the design by using only one fluid inducting port. Water enters through one inbound channel and then divides it into many branches leading to different mini channels. That makes the n flow rate of water in the outer track lower than in the central channel. Di know that the amount of heat generated is significant in the electrode, thus minimising the temperature. If only two small channels are used, the proposed system's maximum temperature can be controlled during disposal.

The techniques mentioned above aim to maximize cooling effectiveness and minimize heterogeneity and temperature fluctuations. However, only a trim heat sink coolant configuration is suitable for mass-produced EV using BTMS from cylinder batteries due to complex structure and high cost. Also, the battery box generally contains thousands of cylinder batteries, and approximately the same heat transfer speed must be guaranteed for each battery, making it challenging to install heat exchangers. Therefore, Tang et al. [11] make a multi-channel corrugated tube for cooling liquid module lithium-ion cylinder battery (Figure 3). The corrugated pipe wraps the battery and removes heat through conduction heat. The effect of corrugated contact angle and mass flow level thermal behaviour of the battery module is analyzed. Maximum temperature and temperature differences are monitored to measure heat transfer capacity. As a result, the effect decreases due to the same amount of corrugated contact angle or increased mass flow rate. The corrugated tube reaches its limit in cooling the battery module.

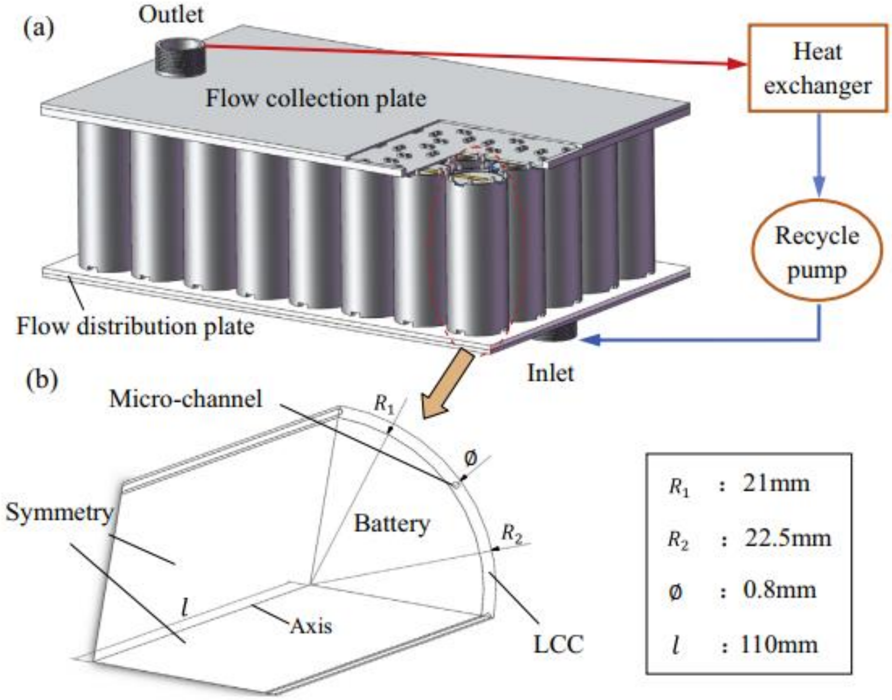


FIGURE 2. Cylindrical Li-ion battery scheme and computing domain [9]

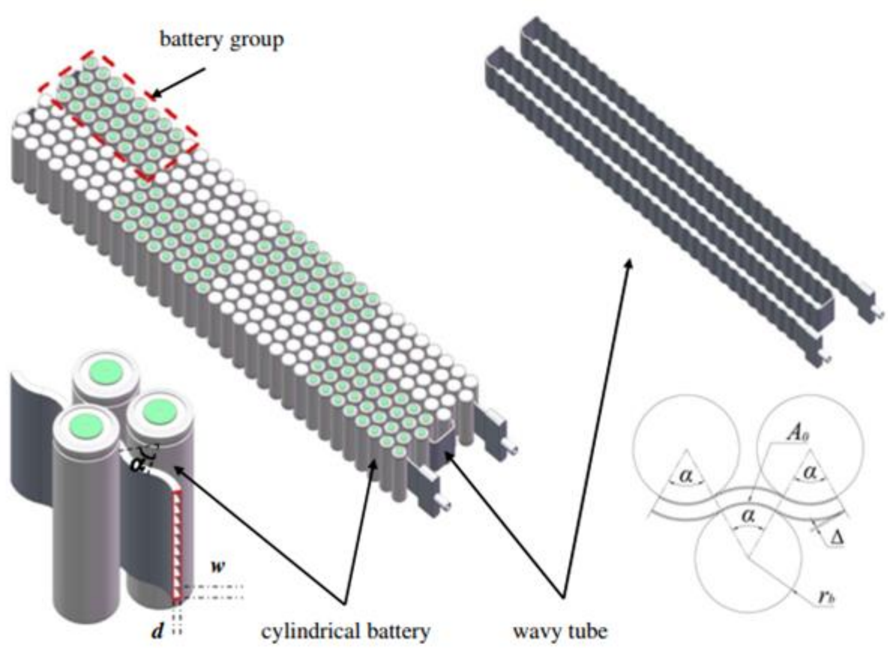
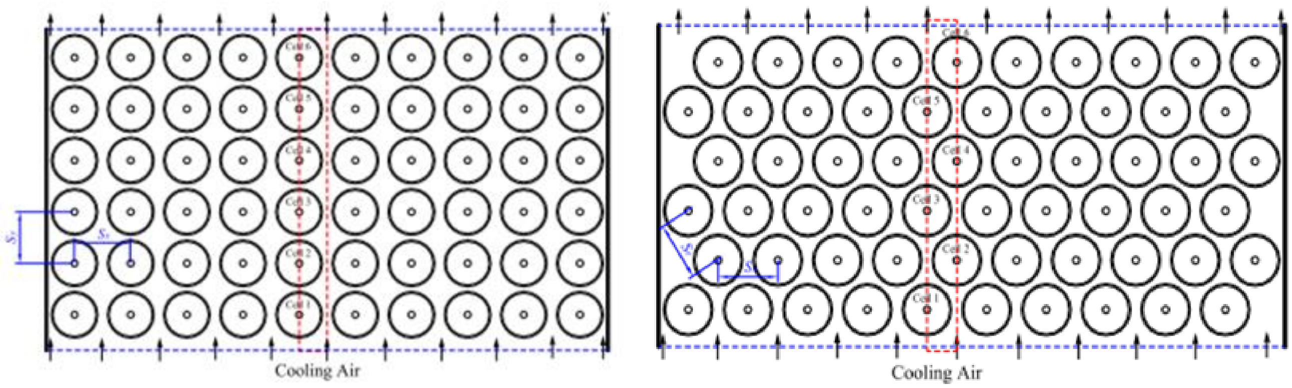


FIGURE 3. Battery module structure [11]

AIR-COOLED BTMS

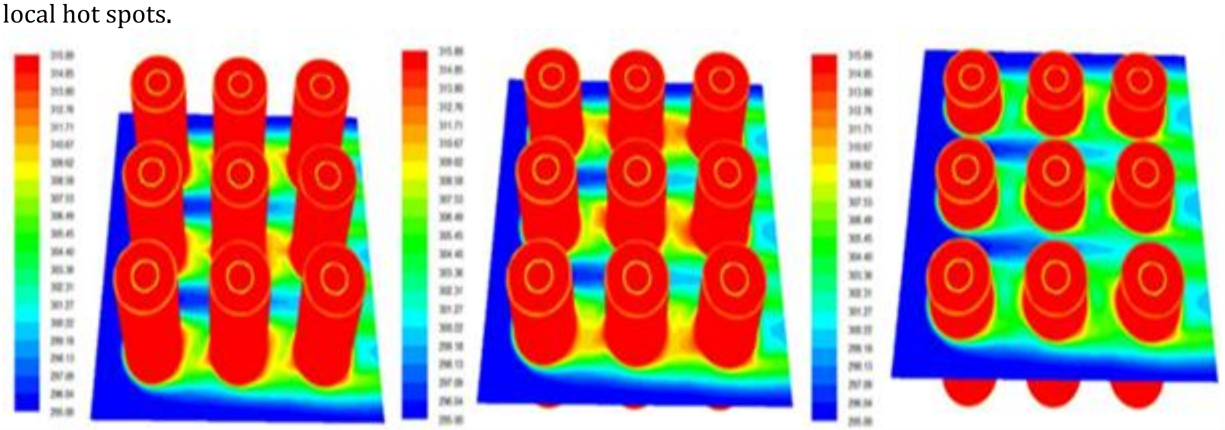
The air-cooled battery thermal management system can be performed from external air directly or from the cab or the air conditioning. Extensive studies have been reported on the forced air cooling of cylinder cells used in battery packs. The cylinder cell is set in an inline configuration in the battery module [12]. In such cases, BTMS considers controlled and limited flow to keep the cell temperature below the preset threshold and to minimize the non-uniform cell temperature. Ravindra et al. [13] investigated the new BTMS method based on the limited flow Li-ion battery submodule and compared it to conventional open flow rectangular modules. Yang et al. [12] governing airflow developed for lithium-ion battery packs. Parametric analysis is performed on a cylinder battery pack with forced-air cooling in a cross-flow configuration. Distribution temperature, maximum temperature rise, fan power, and cooling index are investigated to determine the cooling design differences (Figure 4). Based on the results of the analysis, a practical design of the cooling system is the arrangement of the battery pack that is aligned; longitudinal intervals and transverse intervals are given to 34 mm and 32 mm, respectively.



(a) (b)

FIGURE 4. The air conditioning system scheme for battery packs is arranged in: (a) aligned and (b) zig-zag [14]

The three-dimensional numerical investigation has been performed by Jilte and Kumar [15] transient module Li-ion batteries' thermal behaviour. A user-defined function (UDF) is used to formulate heat generation in battery cells. The results are visualized in terms of thermal transient three-dimensional battery cell response. An in-depth analysis of hot spots has been presented based on thermal regimes and flow fields. Variations in air temperature are found in the transverse directional lines (Figure 5). Increased temperature from supplied cooling conditions (22°C) to maximum local temperature ~26.37°C in certain zones and ensuring local hot spots.



(a) H - 25 mm (b) H - 50 mm (c) H - 75 mm

FIGURE 5. Contour temperature of cooling media (air) inside the battery module (a) H at t = 500 s (air speed = 0.1 m/s, $T\infty$ = 22°C) [15]

OVERALL DISCUSSION

Among the various BTMS for Li-ion batteries, most researchers agree that BTMS uses air conditioning in operation requires low cost and easy cooling availability. Advances in air cooling have centred on optimizing geometric layouts and operating parameters. Still, this cooling method is not enough to handle temperature rise due to the lower air heat removal coefficient. Furthermore, BTMS uses liquid cooling to improve system structure, channel geometry and coolant heat transfer coefficient. A liquid-cooled BTMS requires the addition of components such as pumps, blowers, valves, cooling lines, channels will increase the system's weight and the utilization of BTMS space. BTMS, both air-cooled and water-cooled, have their advantages and disadvantages. Table 1 presents the advantages and disadvantages of air-cooled and liquid BTMS with its development.

TABLE 1. Advantages and disadvantages of air-cooled BTMS and its development [16].

Method	Excess	Weakness	Development
Air cooled	The system design is relatively simple, easy to apply, adjust to different battery types, and has no liquid leakage problems.	1. Low heat capacity, small thermal conductivity, more negligible average temperature effect between batteries. 2. Systems with high cooling need air in large quantities, requiring large pipe size and quantity. 3. Natural convection cooling is only effective for batteries with low energy density. 4. The active air conditioning system is equipped with a fan to improve heat transfer, but with increased cost and noise.	1. Effective action increases system air-cooling efficiency to increase air volume, increase flow rate, increase channel size, and optimize cell position. 2. Thoroughly consider the practical work of the environment and electric vehicles. System air conditioning is suitable for electric vehicle battery packs with low energy density and low target comfort requirements, such as vehicles with short work tasks and crew vehicles.
Liquid cooled	Liquids have a higher specific heat capacity, density flow rate, and more capable heat transfer rate. Temperature distribution can reach uniform.	1. The layout is complicated, the system large and heavy, high cost. 2. High sealing requirements for battery packs and sealing coatings are required to improve heat transfer resistance and reduce the cooling efficiency.	1. Control of fluid flow rate circulating in the liquid pump can reduce energy consumption and improve working efficiency. Combining a cooling cycle system with an automatic control system is key to the development of this technology. 2. Nanofluids, molten metals, and boiling liquids should be further studied to reduce water cooling systems cost.

CONCLUSION

The work of this review discussed BTMS in air cooled and liquid cooled. Liquid-cooled BTMS is a highly effective cooling technique, and the sealing cover must be selected correctly to avoid fluid leakage while designing. Microchannel integration can significantly improve cooling performance while avoiding excess packing and complex design. BTMS that uses an air-cooled system has a simple, safe and consistent design. However, it has lower heat capacity and thermal efficiency and limited capabilities under the thermal management system. Air-cooled BTMS utilizes an airflow channel in which the battery pack provides effective battery cooling due to airflow conditions within the track and its specific heat capacity. Although battery cooling technology has been extensively improved in previous years, it still takes a lot of time and effort from scientists, designers, and manufacturers to enhance thermal performance and battery heat dissipation rates to achieve maximum EV and HEV performance.

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