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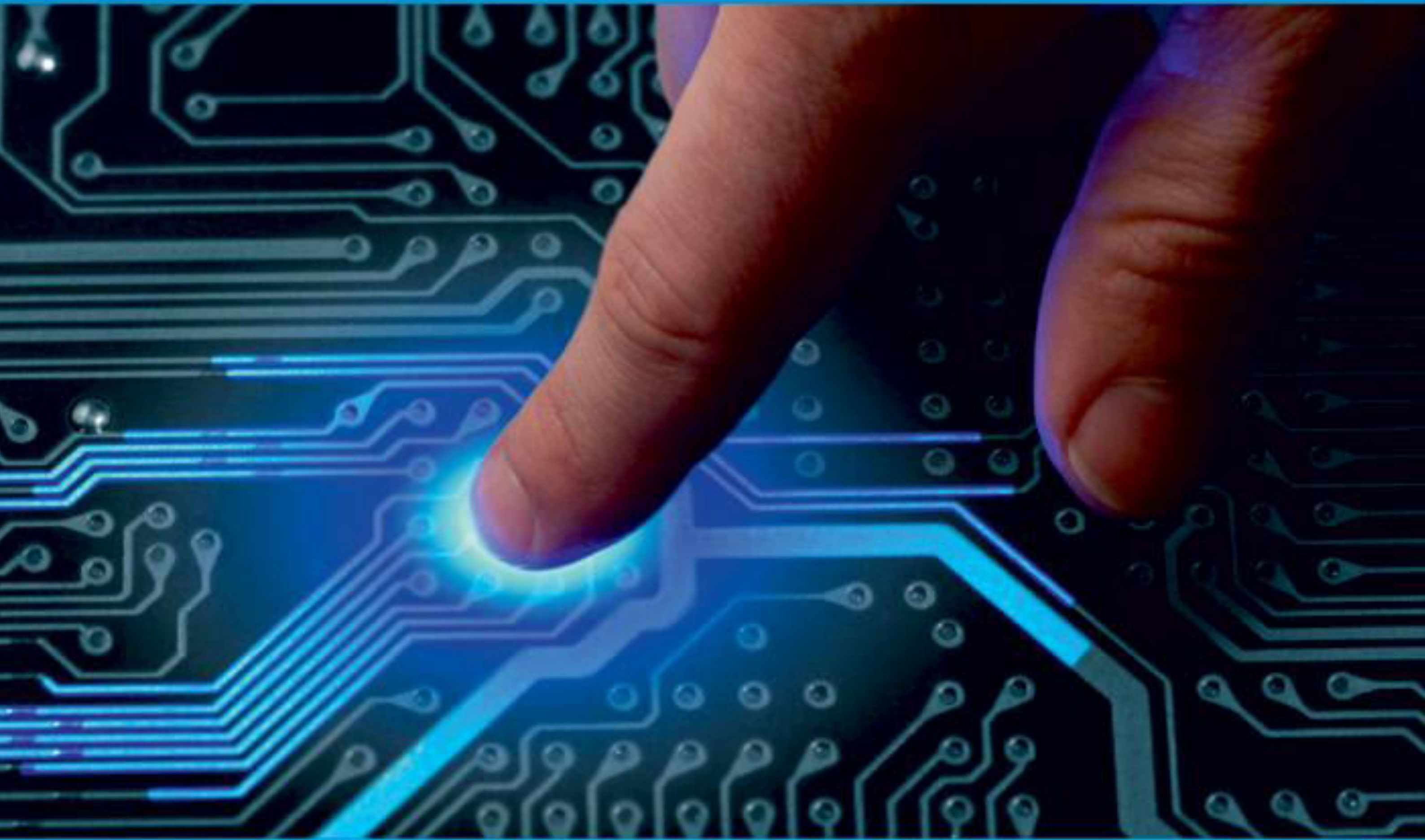

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Study of Different Liquid Coolant and Cooling Strategies in Thermal Management System of Electric Vehicle: A Review

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ABSTRACT: Lithium ion batteries are mostly employed in consumer electronics goods in the modern world. It provides better power density, service life and energy density as compared to other batteries in market. However, in order to attain that high capacity when this battery is utilised in an electric car, numerous cells must be connected in series and parallel, it leads to problems with regard to durability and safety. Battery system is being well-structured and small in order to fit easily into the chassis, however this type of configuration causes issues with thermal system within the battery pack. Extremely hot or cold settings can damage lithium ion cells and result in fire, circuits, and other problems. Thermal runways develop when temperatures go above a specific point and dendrites develop at low temperatures, leading to short circuits. Maintaining batteries within their proper temperature range is therefore always recommended. There are few thermal management techniques, however liquid cooling is among the most dependable and effective. Different coolants and building styles can be used for liquid cooling. Therefore, in this review we will examine the specifics of the cooling system in the system of thermal management including study of coolant, classification, performance and design of liquid cooling system.

KEYWORDS: Battery, coolant, thermal management

I. INTRODUCTION

Regular use of traditional vehicles results in significant oil resource consumption and emission . To fulfil the emission standard, a number of publications suggested numerous emission manage strategies and novel clean fuels . Out of all alternatives, electricity powered vehicles are viewed as a replacement for the conventional cars. Electric vehicles have a far simpler chassis than conventional cars and offer zero tailpipe emissions, silent operation, and high efficiency which is best for the environment . Now a days Lithium ion batteries are frequently employed as energy source due of their greater power capacity and specific energy. The large format preferred for electric vehicle and smaller format for electronic devices .

Honda and Toyota have introduced the Prius, Insight, and Civic hybrid cars since 1997. customers have given these cars excellent reviews. With the launching of the Tesla Model 3, electric car with a 100% lithium-ion battery that could travel more than 358 miles, the industry reached a new high point in 2022. As a result of their high density and energy, lithium ion batteries have been widely adopted by the world's top automakers for use in energy storage systems in electric vehicles and plug-in hybrid electric vehicles.

The ideal range of temperature for health is 25 to 40 °C. The lithium battery must run perfectly to give adequate acceleration in all operation conditions and cover the driving range, while the temperature variation between battery cells should be kept to a minimum. One battery pack typically consists of hundreds of cells, which may be linked in parallel or series. Different places generate heat in different ways, which causes heat to be distributed unevenly. As a result, the battery's consistency is reduced, the performance of the battery pack as a whole is impacted, and the battery pack eventually fails before it should.

However, LIBs are highly sensitive towards their thermal impacts in terms of performance and durability, which can result in battery deterioration in the absence of effective thermal management.

There are two types of heat generating models: electrochemical thermal and electro thermal coupling models. According to Zhang et al simulations of a one-dimensional model of the battery's temperature field, the battery's ability

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to generate heat from joules, electrochemical reactions, and contact resistance are three of its most important heat sources .

The discharging and charging processes, which produce heat, are typically linked to internal temperature rise, according to various researchers. When building a cooling system, it's critical to understand how heat is produced and to determine how it is distributed throughout the battery. In addition, it's important to consider the processes of heat transfer and heat dissipation. One of the main safety problems the battery faces is thermal runaway. Thermal runaway will happen after the temperature of the battery reaches 80 °C if the temperature is continuously rising and the heat cannot be dispersed in a timely manner. An electrolyte fire or battery explosion can happen from failing to extinguish or reduce the internal heat produced by the battery, which could cause relatively significant levels of temperature growth . The battery's ability to discharge power will be reduced by the low temperature. Lithium plating will happen when charging at a high pace and low temperature, which can significantly shorten battery life and create safety issues.

Electric car accidents have become more common in recent years and have been trending upward for the past two years. Similar accidents will occur more frequently as there are more electric vehicles on the road. The importance of battery safety will rise to the top. This paper provided an overview and discussion of the liquid-cooling category of the battery thermal management system (BTMS). Additionally, it highlights the uses of different coolants, along with their benefits and drawbacks.

Battery thermal management system

Lithium-ion batteries produce heat throughout the charging and discharging process, which makes it essential to use a BTMS to distribute the heat generation throughout the battery and extend the battery's lifespan. It is essential to use BTMS in order to make the battery pack function properly and safely, as well as to provide good charging and discharging performance. The BTMS must be able to operate securely, be economically feasible, and deliver the required heat transfer in a modern vehicle's constrained space.

In accordance with where the heat is removed, BTMS are categorised as internal or external systems. Cooling methods can be either active or passive and involve built-in appliances. Passive means that only the ambient environment is utilised, and that an internal cooling device is needed to increase temperature uniformity. Depending on the cooling medium, the BTMS can be classified as cooling with air, liquid, heat pipes, or phase change materials .

The benefits of an air conditioning system are its easy structure, light weight, low cost, and others. The cooling capacity of air cooling is however restricted, the cooling performance is not as good, and the ability to lower the maximum temperature and maintain the temperature uniformity of the battery pack are poor due to the low thermal conductivity and low specific heat capacity of air. According to studies, altering the design of the flow channel, adding exhaust fans, or adding fins to the system can increase cooling performance.

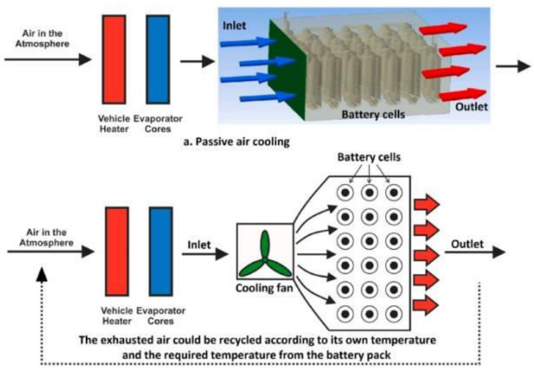

Fig: Air Cooling

Another kind of cooling material is phase change material (PCM). The heat produced by batteries during phase shifting can be absorbed due to the latent heat of PCM. This cooling system has a straightforward structure, is lightweight, and can guarantee temperature homogeneity between batteries. However, the low thermal conductivity of the phase transition material results in the system's limited ability to conduct heat . Recent research has demonstrated that by incorporating metal additions into PCM, the cooling system's thermal conductivity can be successfully improved .

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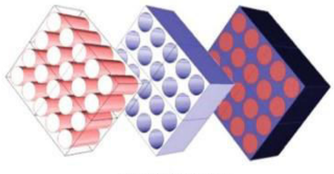

Fig: PCM Cooling

Due to their lightweight, compact design, and flexible geometry, heat pipes are effective heat exchangers that can be employed in BTMS. The fact that they don't require an external power source is an additional noteworthy benefit. The working fluid is evaporated from the evaporator to the condenser and transferred back to the evaporator by capillary wick in a heat pipe that transfers heat through latent heat. Heat pipes, however, are still in the early stages of research, and studies typically pair heat pipes with other cooling systems to improve cooling performance .

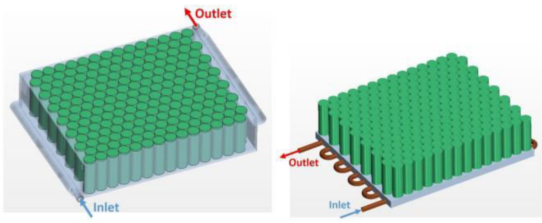

Fig: Heat pipe

Due to liquid's high thermal conductivity and high specific heat capacity, liquid cooling is more effective than conventional cooling techniques. The liquid cooling system, on the other hand, has a more compact structure that takes up less space and enables placement in tighter spaces. These elements make liquid cooling a desirable and highly realisable strategy. Tesla and General Motors have already used it in the realm of electric vehicles with positive results .

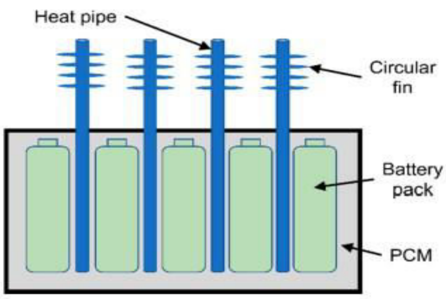

Fig: Liquid Cooling

Liquid thermal management system

Lithium-ion batteries typically use a cold block as an intermediary to prevent direct contact between the cell and the cooling fluid. It is commonly known that fluid has a higher and more efficient heat capacity than air, which improves the temperature of the batteries. A rate of 5 C was attained during the charging procedure after numerous trials .

Smith et al. looked at a 25 Ah battery being charged at a rate of 10 C, which resulted in a 40 W heat dissipation per cell. Both the distance and the battery failure, which have been the subject of much research, have not been taken into account. Refrigeration units, prismatic cells extract heat from the geothermal level, neighbouring cells, and the

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cell's border.

While Nieto et al. assessed the chilled cylinder cells in a narrow channel casing, they failed to take into consideration the constraints of cell analysis or the separation between cells. Jarrett and Kim found this to be the case via their investigation of a serpentine-channel cold plate, where they found the optimal pressure and maximum temperature. Even though the performance coefficient was rather high, the system was not very efficient when the temperature was altered.

Jarrett and Kim looked into the serpentine-channel cold plate to better grasp the effect and establish the boundary conditions. 48 They found that temperature is the most vulnerable factor, but the temperatures and flow rates of the battery were too low to be considered.

Type of the liquid-cooling system

The classification of liquid-cooling systems varies depending on a variety of variables. The cooling system is divided into passive and active cooling at the strategy level. The cooling system might be direct or indirect, as was before explained. When the battery is linked to the liquid, direct cooling occurs. Indoor or outdoor cooling is classed according to where the liquid system is located.

Internal and external cooling system

This system requires a cooling mechanism. Submerging the battery in a coolant creates two heat-removing systems, one on the inside and one on the outside. The internal cooling system comes in two different designs. In the first configuration, a narrow channel evaporator is housed inside a thick collector. The alternative design used a pair of tiny channel evaporator collectors. A small and compact channel shouldn't reduce battery power if any of the above two designs is used. The float controls the flow of liquid in passive interior design, which eliminates the need for mechanical pumps. As a result of the liquid's phase change and even heat transmission in the saturated state, the battery's heat distribution is constant and uniform. Mohammadian et al. advocated using electrolysis as a coolant and placing small rectangular tubes in the negative and positive electrodes.

Internal architecture for cooling and more conventional means of cooling the outside air are contrasted. Coefficient performance and cooling efficiency were compared between the internal and exterior systems using numerical analysis. The batteries' built-in cooling system both reduces their maximum internal temperature and standardises it throughout the pack. The results showed that using the same amount of energy (0.024 W) as the SD method, the inside temperature reduced five times. Band-hauer and Mohammadian found that an internal system that controls both battery and battery pack temperature was preferable to an exterior cooling system. Internal cooling adds weight, making the product more difficult to construct and hence more expensive. The usage of hundreds of batteries in the battery pack architecture undoubtedly drives up production costs.

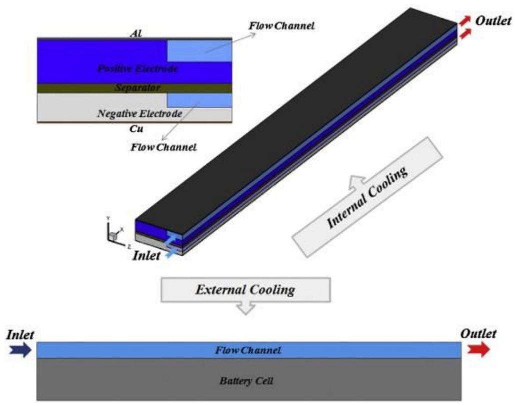

Fig: Internal and external Cooling

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Passive and active cooling system

Heat is transferred from the battery to the coolant and then to the air outside because of the temperature differential between the two. It is then employed in conventional passive cooling systems, where it is exhausted via a fan. At the tactical level, cooling systems are classified as either passive or active. For negative battery cooling to work properly and keep the battery pack from overheating or becoming too cold, the ambient air temperature has to be between 10 and 35 degrees Celsius. Active cooling is more difficult and costly to produce than passive cooling. In an active cooling system, a liquid heat exchanger transfers the heat that has been absorbed by the coolant. In certain cases, an electric heater may also be required, in addition to the pump and the heating system.

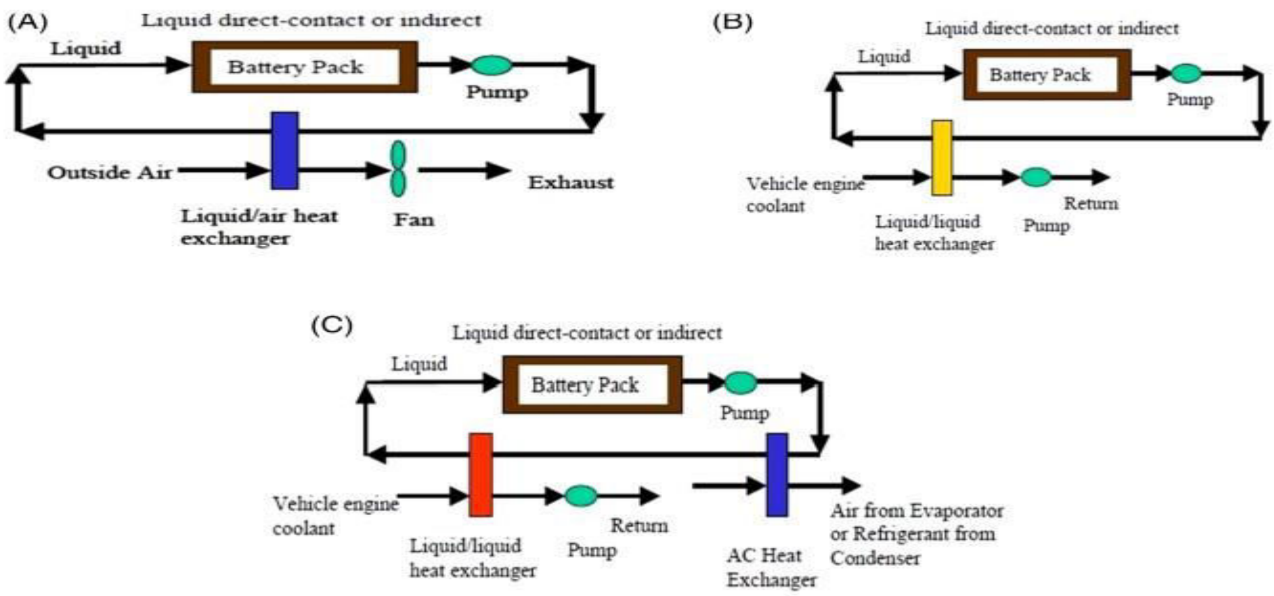
In the early days of EVs and low-energy consumption, batteries used a negative cooling system, which had a number of problems, including limited cooling efficiency and inadequate temperature control. Hydrogels are another kind of passive system. Zhao et al. and Zhang et al. efficiently handled the BTMS-based hydrogel, resulting in excellent performance in both abnormal heat testing and excessive battery discharge. Although hydrogel production is low-cost and straightforward, active cooling has been found to be the norm rather than the exception. Only a few of EV manufacturers, including Tesla Motors and General Motors, use an active cooling system. There are still many open studies on this subject.

Indirect and direct cooling systems

The battery's system is selected according to how liquid it is. Indirect cooling involves a connection between the battery and the cooling medium that does not use liquid. But with direct cooling, the battery is completely immersed in the coolant. Direct cooling necessitates a nonconductive liquid such as hydrofluoroether, mineral oil, deionized water, or silicon oil as opposed to the indirect cooling system's use of water, nanofluid, liquid metal, or a glycol/water combination as coolants. Using silicone oil or mineral oil makes for a more compact design, cheaper manufacturing and maintenance, and simpler overall operation. It takes more effort to chill anything with direct cooling since the liquids used have a greater viscosity.

Indirect cooling makes use of cooling plates to aid in the heat transfer process, however because the heat being transported has a high resistance, the thermal efficiency of the package is reduced. While there are benefits to using direct cooling methods, indirect cooling is safer. Liquids like water and glycol use less power because of their low viscosity and high heat conductivity. Therefore, the efficiency of the heat transfer is enhanced, and increased mass flow rates are less of a challenge to offer. Chen et al. conducted a comparative research of four cooling approaches (fin cooling, indirect and direct liquid cooling, and air cooling) using simulation and statistical analysis to evaluate the direct and indirect cooling efficiency of each .

Fig: A, Passive Cooling—Liquid Circulation; B, Active Moderate Cooling/Heating—Liquid Circulation; C, Active Cooling and Heating—Liquid Circulation



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Analysis and use of various coolants

The thermal conductivity, viscosity, density, and flow velocity of the coolant all play a role in how well heat can be transferred between the coolant and the battery. Water and oil are the two coolants that are most frequently utilised in liquid cooling systems. Nanofluid, liquid metal, and boiling liquid have garnered a lot of interest in recent years for their improved performance in battery pack cooling systems. The thermal physical characteristics of various coolants are listed .

Water/glycol

Indirect cooling makes use of cooling plates to aid in the heat transfer process, however because the heat being transported has a high resistance, the thermal efficiency of the package is reduced. While there are benefits to using direct cooling methods, indirect cooling is safer. Liquids like water and glycol use less power because of their low viscosity and high heat conductivity. Therefore, the efficiency of the heat transfer is enhanced, and increased mass flow rates are less of a challenge to offer. Chen et al. conducted a comparative research of four cooling approaches (fin cooling, indirect and direct liquid cooling, and air cooling) using simulation and statistical analysis to evaluate the direct and indirect cooling efficiency of each. Water can more efficiently convey heat with less pumping effort since it has a larger specific heat capacity, stronger thermal conductivity, and lower viscosity coefficient than air . As a result, water is usually used as the working coolant in liquid cooling systems.

Deng et al. found that on average, a battery generates heat at a rate of 3.75 105 W/m3. Therefore, a maximum temperature of 49.59C and a flow rate of 7.18 103 m/s with a thermal conductivity of 3.75 W/(mK) may be achieved with the use of a single phase pattern to analyse the cooling system during operation.

Panchal et al. showed that using water as a cooling fluid for batteries might lower maximum temperature and ensure temperature uniformity. Through the use of 10 thermocouples, we were able to track the battery's surface temperature while it was subjected to a wide range of conditions.

Malik et al. looked at the efficiency and destruction of energy in the battery pack over a range of temperatures and discharge rates.

The statistics show that the coolant temperature and discharge rate have a major influence on the lithium-ion battery's efficiency and energy destruction. Energy efficiency improves with increasing coolant temperature, reaching a maximum at 40 °C for discharge rates 1 and 2, and a minimum at 30 °C for discharge rates 3 and 4. Similar patterns were seen while energy was being destroyed. It was shown that a maximum exergy destruction of 732.1 J occurs at a 4C discharge rate and a 40 °C coolant temperature. Substantial less energy was lost during cellular metabolism in cells that were exposed to chilling temperatures.

Wang et alexperiment .'s found that raising the water flow rate had the greatest effect on boosting the cooling performance coefficient. It was determined that 4 mL/s was the optimal flow rate. In this way, it is believed that water increases the reliability and effectiveness of air conditioning. The maximum temperature of the battery pack is kept at 48.7 degrees Celsius while the temperature between batteries is kept at 5 degrees Celsius using just 1.37% of the total power under the ideal flow rate indicated before.

Oil

When it comes to cooling, oil has one key distinction from other fluids like water. Oil is not a fire hazard and does not conduct electricity. Battery packs are often submerged in a cooling system designed to transfer heat from the batteries to the oil. High temperatures are limited, and there is little thermal gradient between individual batteries.

Since mineral oil has a greater thermal conductivity and a thinner boundary layer than air, Pesaran noticed that it transfers heat more efficiently at the same flow rate. But since mineral oil has a greater viscosity, oil cooling systems will need more pumping power to maintain the same low rate. Compared to air cooling, mineral oil cooling systems are only 1.5-3 times as efficient at the same pumping power due to the low liquid flow rate that is generally employed.

After comparing many cooling methods, including air cooling, water cooling, and oil cooling, Chen et al. concluded that mineral oil cooling was the most efficient.

Heat transfer efficiency between air and oil was studied by Deng et al., who found that mineral oil had a greater thermal conductivity than air. The research also revealed that oil has a very little thermal layer. Mineral oils have a high viscosity, therefore even if the pumping rate is moderate, the oil cooling system still requires a lot of power. Mineral oil

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has far higher heat transfer efficiency than air does at the same flow rate. Deng et al. conducted a research comparing the cooling efficiency of mineral oil and water casing under identical circumstances (i.e., the same flow rate and channel width). It has been shown that oil reduces pressure at a far faster pace than glycol water does, making oil cooling much more efficient than conventional methods. The main reason for this is because, unlike mineral oil, glycol water can't be placed directly on the battery. The temperature drops rapidly when the mineral oil and battery come into contact with one another. In indirect systems, heat resistance is produced due to the existence of a barrier between the battery and the water. When the channel's diameter is altered, the heat transmission performance remains same. As a consequence, the efficiency with which heat is transferred is reduced. Deng et al. looked into the use of a cooling fluid with the right heat capacity and viscosity to improve the design of the channel structure. He saw that the battery's temperature and power consumption were kept constant by the use of several inputs and a single output.

Submerging the battery pack exposed it to be of far higher quality than the air system. During the design process, it is important to weigh the advantages and disadvantages of various approaches to the problem of leakage, which poses a serious threat to the cooling system. The lower viscosity and increased heat conductivity of water make it an ideal coolant. Both of these coolants play important roles in the industry. However, it grows with oil inversion because the walls of the cooling plates prevent the batteries and water from coming into direct contact. The inlet temperature of the cooling fluid (Tin), the velocity of the outgoing fluid (vout), the incoming velocity (in), the cooling fluid's mass per unit area (mc), the pressure gradient (p), and the channel's inside diameter are all important considerations when building a cooling system.

Karimi investigated several oil and water cooling system flow channel configurations. The battery's temperature and power consumption may be maintained at low levels using his proposed strategies of using a coolant with the appropriate viscosity and heat capacity and optimising the channel architecture with multiple inlets and one outlet.

Nano fluid

When metal particles are added to conventional fluids, the result is nanofluids. When used together, thermal conductivity is significantly improved. Therefore, metals have a much greater thermal conductivity than normal fluids. Metals such as aluminium, copper, nickel, silver, iron, tin, and titanium dioxide (TiO_2), as well as their oxides (Al_2O_3, CuO, Fe_3O_4, and TiO_2), are sometimes dissolved in or added to liquids. There are two criteria that have an immediate effect on the thermal conductivity of nanofluids: the rate of fracture and the concentration of secondary particles.

Deng et al. theoretically analysed the volume percentage of water containing Al_2O_3, TiO_2, and SiO_2 by considering the size of nanoparticles, another critical component influencing the thermal conductivity of nanofluids. This research showed how efficiently nanoparticles may boost the nanofluids' thermal conductivity.

The nanofluid's thermal conductivity is influenced by a wide variety of parameters. Nanoparticle concentration, or the solid volume percentage of a nanofluid, is a key element that may drastically change its thermal conductivity. Liu et al. inserted copper nanoparticles into water. The results show that Cu-water nanofluids have higher thermal conductivity than the original liquid, even at low concentration rates. Adding 0.1 vol% Cu to nanofluids increased their thermal conductivity by 23.8%. Zakaria et al. found that the thermal conductivity of water may be improved by adding Al_2O_3 to a volume percentage of 0.5%, with an increase of more than 0.05 W/(mK).

The size of the nanoparticles is another crucial factor that affects nanofluids' thermal conductivity. The thermal conductivity of nanofluids may allegedly be enhanced by using nanoparticles of a lower size. Liquid layering surrounding nanoparticles and Brownian motion of those particles are two essential methods for enhancing the thermal conductivity of nanofluids. As the size of the nanoparticles is reduced, both processes become very active, and the thermal conductivity increases. To maintain effectiveness, the nanofluid flow rate must be lowered. Huang et al. put a battery inside a slim, cylindrical tank full with NanoAl_2O_3 fluids. The results of the tests indicate a 16-24 degree Celsius reduction in the maximum temperature. This amount of heat was dissipated via air circulation at the tank's outside.

Carbon nanotubes are employed to make nanomaterial that floats on water, as reported by Tran et al. In the presence of $NaC_{12}H_{25}SO_4$, when the nanotube size fraction of 0.05% could be ignored in contrast to the water fraction of 9.36%, the thermal conductivity of the nanofluids was found to be 0.75 W/(m • k). The maximum temperature may be decreased by 6.5% when the frame Boltzmann is used to model the heat transfer between copper and water nanofluids with a Reynolds number of 3 105 and a Cu volume percentage of 6 vol%. In the realm of lithium-ion BTMS, batteries were immersed in a thin, cylindrical tank filled with Al_2O_3-water nanofluids, and heat was dissipated by air blown into the tank's surface. The results of the experiments show a reduction in maximum temperature of the battery of 16-24 °C.

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The results showed that pure water-based nanofluids are superior at limiting the battery pack's maximum temperature and temperature swings. Unlike glycol, pure water has a greater heat conductivity, which is why this works.

Liquid metal

The study of liquid metals began with investigations into mercury. Increased attention has been paid to liquid metal alloys of gallium in recent years. Primary thermal physical parameters of liquid gallium alloy metals are listed below in the table. Because of its low melting point and high boiling point at room temperature, gallium alloy may be used as a liquid for cooling purposes. The high heat conductivity and low viscosity of gallium alloy have also aroused the curiosity of scientists (which is typically several times that of water). In place of the traditional mechanical pumps used in liquid cooling systems, electromagnetic pumps are often employed to push liquid metal. The electromagnetic pump outperforms the mechanical one in both quietness and durability. These personalities help extend the life of the AC and save maintenance costs. The team investigated alternative propulsion mechanisms to electromagnetic force driving.

Li and Liu studied the thermosiphon effect of liquid metals. Liquid metal in the system may be propelled by the buoyancy force caused by the waste heat that must be dissipated.

Zhu et al. put a droplet of liquid metal on top of the hot spot. Droplets of sodium hydroxide (NaOH) solution may be moved through the cooling channel when subjected to a square wave signal with the appropriate amplitude and frequency to create Marangoni flow over the droplet's surface. The high thermal conductivity of the metal droplet allows for efficient heat transmission to the moving liquid.

Hybrid coolants, radiators, and annular channels were all used by Tan et al. for chip thermal control. The liquid cooling system was greatly simplified by the use of a single flow driving technology, the electrically induced actuation action of liquid metal. The cost problem that emerges when using liquid metal as the sole coolant is also addressed by Zhu and Tan's excellent liquid cooling system design, which blends the great thermal conductivity of liquid metal with the high specific heat capacity of water.

Yang et al. were the first to employ liquid metal to cool battery packs. Using numerical modelling and analysis, they compared the liquid metal cooling system to the water cooling system. In the same flow condition, the findings show that the battery temperature, the temperature differential between the batteries, and the power consumption of the pump are all reduced when using a liquid metal cooling system. Liquid metal cooling systems also perform well under difficult conditions, including high power consumption, high ambient temperature, and battery problems.

Boiling liquid

Hydrofluoroether, perfluorocarbons, and chlorofluorocarbons, all of which boil at room temperature, may be used to efficiently cool high-temperature heat sources while preserving a uniform temperature throughout the system. There are obvious benefits to using boiling liquid cooling over traditional cooling methods, which is why it is widely used in the area of cooling electronic devices. But as people became more worried about global warming and the depletion of the ozone layer, hydrofluoroether, a new boiling liquid, began to replace chlorofluorocarbons and perfluorocarbons. Hydrofluoroether is a nonflammable, very resilient liquid that is also harmless for the environment. The American 3 M company developed Novec 7000, the most popular hydrofluoroether used for heat control in lithium batteries. The boiling point of Novec 7000 is 34 degrees Celsius, making it one of the best temperatures for battery operation, and it has a hydrofluoroether concentration of 99.5 percent.

Hirano et al. verified that the use of hydrofluoroether as a direct cooling coolant is possible. The experiment included five charge and discharge cycles at 10C and 20C. Both 80 and 90 degrees Celsius are the absolute maximum temperatures that the battery pack can reach when air circulation is adequate. The Novec 7000-equipped battery packs can keep their internal temperature at or below 35 degrees Celsius after being put through two testing cycles. As an additional measure, the same experiment was performed with Novec 649, which has a boiling point of 49 °C, and it was found that it, too, was able to adjust the temperature of the battery to somewhere about 50 °C. This indicated that controlling the temperature of the battery pack may be achieved by using a coolant with a range of boiling temperatures.

In order to control the cooling performance of the battery, Gils et al. designed a series of tests to examine the effect of the boiling process. The typical boiling curve is seen in Fig. There are several factors that may influence the boiling process, such as the fluid and heater mixture, surface roughness, and system pressure. The results of the experiment showed that the boiling process was affected by the pressure within the boiling chamber. Reducing the pressure within

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the boiling chamber is a quick way to boost the boiling process's efficacy. This means that the battery's cooling capacity may be actively and quickly changed by modifying the pressure in the boiling chamber.

LIQUID-COOLING BTMS TECHNIQUES

We will go through two methods for chilling fins. This method involves transferring heat from the cells to the fins, which is subsequently expelled via a plate. They consist of a group of fins that have been glued together in the space between the battery packs. They help equalise battery temperatures by redistributing the generated heat. How much heat is converted depends on the fin's design. The cooling performance decreases with decreasing temperature differential between the fin and the fluid, which is a downside of utilising cooling on a single plate at the front fins. One such approach is the use of microchannel cold plate technology. The cooling plate is in close contact with the heat generated between the cells. The liquid is pumped into microscopic channels inside the cooling plates to ensure that heat is distributed uniformly across all cells. However, this strategy demands a lot of power because of the lengthy and narrow channel required. A high flow rate of the cooling fluid necessitates the use of an electric pump to keep the pressure constant.

The shape of the channel, the path of the fluid, and the force exerted by the plate under different conditions should all be optimised. The number of linked studies varies when channels are utilised in lieu of fins. In channel geometry, the level of the coolant is lowered once a cooling mechanism for the microchannel plate has been selected. Recent investigations and research initiatives using a liquid cooling system with a cold plate and a single microchannel have provided more support for this idea.

For their research, Garrett and Kim employed a single cooling plate with movable channel location and width to examine how changes to these factors affected average temperature, pressure drop, and temperature uniformity. Results show that the optimised layout effectively reduced pressure loss and maintained a comfortable temperature profile. A narrow inlet serves to facilitate the exit. Their studies are aimed at providing information that may be used to create new and better designs that account for the aforementioned three criteria. Heat production, heat dissipation, and mass flow rate all play a role in the cooling plate's effectiveness. The earlier research is different from this one. The results show that uniform battery temperatures need sharing the heat production.

Huo et al. investigated the effects of overheating on the distribution of a rectangular battery while it was drained at 5 C. Despite altering the number of channels, the external temperature, and the fluid's flow direction, the researchers noticed consistency between the battery and the cooling plate. The results show that the efficiency of battery cooling increases while the efficiency of the system drops below its optimal point as the number of channels and flow rate increase.

Cooling plates optimization

When a different liquid is used, the battery pack takes on a different form. Silicon and mineral oils may be used in a direct cooling system to build the battery pack's framework. The amount of the coolant, the diameter of the inlet and outlet channels, and the distance between the batteries should all be designed around the specifications of the battery pack. When necessary, a supplementary device may be added to enhance coolant flow. Indirect cooling systems need specially designed heat transfer auxiliary devices such cooling plates, jackets, and tubes, in addition to the direct cooling system designs previously described.

Cooling plate efficiency is dependent on a variety of factors, including flow route geometry, channel shape, cooling plate location, channel number, and inlet/outlet channel widths. Optimizing the coolant channel was a priority for Jarrett et al., so they turned to a CFD study to determine the best course of action, factoring in parameters including pressure drop, temperature uniformity, and average temperature. Results showed that pressure loss and average temperature might be reduced by making the serpentine channel wider. For optimal temperature distribution, the channel's cross section should grow gradually along the flow direction. This design ensured uniform heat transmission throughout the whole cooling plate by regulating the coolant flow rate, the heat transfer area, and the temperature differential between the solid and liquid.

Wei et al. studied three types of flows: serpentine flow, serpentine-parallel flow, and the flow without distribution channels. The findings show that the serpentine-parallel layout is preferred because it maintains constant flow rates, pressure drop, and electrolyte temperature.

In the basic layout of the U-turn channel. The construction and operating conditions of the U-turn cooling plate were optimised by Yuan et al. through modelling and experiment. According to the results, the temperature gradient between the batteries was reduced when the U-turn channel's inlet and outflow faced in the same direction. Comparing the U-

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turn channel to the serpentine channel, the similarities are striking. Due to the sinuous flow route and single inlet/outlet configuration, the whole channel is too lengthy and fails to effectively cool the battery located near the outlet. This problem may be alleviated in part by using a cooling plate with many channels.

The increased heat conductivity and smaller grooves on the cooling plate help with this. Most research on the small channels cooling plate has focused on how variables like the number of channels, channel shape, channel width, inflow direction, mass flow rate, and ambient temperature affect the plate's ability to dissipate heat. Because a larger pressure drop and possibility for excessive energy usage by the pump would result from a narrower channel, Xie et al. advise against using a very small diameter. It has been shown that a narrow, deep channel with a thin bottom thickness and a moderately thin channel wall thickness may improve heat transfer performance while still maintaining a pressure drop that is high yet manageable.

Qian's numerical simulation found that the five-channel cooling plate was adequate for keeping the maximum temperature and the temperature variation within an acceptable range. At a specific mass flow rate, the rate of temperature drop levelled out. It would be a waste of pump energy to increase the bulk flow rate if the cooling performance was not greatly improved. It is important to consider energy consumption and cooling efficiency when determining the optimal input flow rate for a specific system. The diameter of the channel is also a critical factor in affecting the efficiency of the cooling. Qian et al., as shown in Table, found that increasing the width of the flow channel from 3 mm to 6 mm resulted in a 55% reduction in the pressure drop, allowing them to use less energy to pump the fluid.

Circular, rectangular, and trapezoidal channels with the same cross-section area were tested and compared for their cooling efficiency by Zhang et al. Three different channel configurations show that the circular channel module has the highest pressure drop for a given flow rate, while the trapezoid channel module provides the optimum cooling performance.

Jin et al. looked into the best way to provide an outlet for the channel. In conventional networks, the majority of nodes simply send data to an endpoint. Maximum temperature increases, and a distinct temperature gradient appears, after the hydrodynamic boundary layer has completely evolved and the straight channel's convective heat transfer coefficient has decreased in the axial direction. In order to force boundary layers to re-initiate, Jin et al. skewed the normally straight fins of a straight channel at an angle, producing a series of oblique fins. we saw a comparison between the growth of the boundary layer in straight channels and angled fin channels. The experimental results show that the heat transfer coefficient in oblique channels is greater than that in straight channels.

Crucial factors include the channel form design, as well as the height and thickness of the cooling plate. By holding the mass flow rate and battery spacing constant, Bai et al. explore a range of cooling plate heights, from 2 cm to 7 cm. He found that the maximum battery temperature and coolant pressure drop may be reduced by increasing the cooling plate's height, but that this trend reverses itself once the plate's height is raised over 5 cm.

Tong et al. modified the thickness of the cooling plate from 0.5 mm to 4 mm. To reduce the temperature gap between the batteries, he found that increasing the thickness of the cooling plate was effective, especially at high discharge rates. When the thickness is greater than 2 mm, however, the typical temperature of the battery is unaffected by the change in thickness. PCM was placed by Bai et al. between the battery and the cooling plate. The effect of increasing the gap between the battery and the melting point of the phase change material on cooling performance is investigated. Results show that using a phase change material in conjunction with cooling plates may dramatically improve temperature uniformity over a space.

future of liquid cooling system

The two most common and affordable coolants are water and oil. They are the most well-liked and potentially useful refrigerant. Multiple analyses have shown that water cooling systems can effectively handle the hottest possible conditions and the widest range of temperatures. Additives may be used to increase a water solution's cooling capability. A modest amount of liquid metal or nanoparticles added to the coolant might increase its thermal conductivity. The system may achieve the same degree of cooling at a lower flow rate because to the enhancement in thermal conductivity, making it especially useful to minimise energy usage. To reduce expenses, additional study of liquid metals and nanofluids is needed. While the oil cooling system's simplified construction is appealing, the energy consumption is considerable due to the oil's high viscosity. Science has not yet investigated oil additives. If additives can be developed to reduce the oil's viscosity coefficient and increase its thermal conductivity, oil cooling will replace all other methods as the most efficient approach to temperature regulation.

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The use of water as a cooling medium has become the norm in recent years. Unfortunately, it's not perfect. When designing a liquid cooling system, it is important to keep in mind the likelihood of liquid leakage. The construction of the liquid cooling system is complex, and the overall pack is too hefty. Mini channel technology allows for a more compact and lightweight cooling plate and jacket. In the future, technological progress will be required to address the issue of increased pressure drop and energy consumption brought on by narrower channels.

II. CONCLUSION

Various liquid cooling system types are compared the performance of various coolants, and examined the pros and cons of various cooling system structures. It also provided an overview of the current state of development of the most recent power lithium-ion battery liquid cooling system. Improve the heat transfer fluid's properties and the liquid channel to increase thermal performance. Water and oil are the most effective coolants for batteries, according to numerous studies, and they can regulate temperature within a desirable range. The structure of the cooling system and preventing liquid leakage remain difficult, and the battery back is overweight. Mini channel cooling plates are compact and light, however the narrow channels cause pressure drops. It will be necessary to create a system that is more effective, uses less energy, and is lighter for future work.

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