International Journal of Integrated Science and Technology (IJIST)
Vol. 3, No. 11 November, 2025: 2455-2464

Effect of Battery Cooling System on the Charging Speed of Lithium-Ion Batteries

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ARTICLE INFO
Keywords: Lithium Battery, Cooling System, Fan Cooling, Liquid Cooling, Charging Rate

Received : 20, September
Revised : 25, October
Accepted: 20, November

ABSTRACT
This study aims to investigate the impact of battery cooling systems on the charging speed of lithium-ion batteries. The cooling systems used include a fan and ethylene glycol liquid. The experimental method involved comparing charging times and battery temperatures under three conditions: without cooling, with fan cooling, and with liquid cooling. The results showed that the use of cooling systems accelerated charging time and maintained more stable battery temperatures. Fan cooling provided the fastest charging and more stable temperature compared to no cooling and liquid cooling.

DOI: **https://doi.org/10.59890/ijist.v3i11.203**
https://ntlmultitechpublisher.my.id/index.php/ijist

INTRODUCTION

The global automotive industry is currently undergoing a crucial transition phase from internal combustion engine vehicles to electric vehicles. This transition is driven by the need to reduce air pollution, mostly caused by motor vehicle exhaust emissions. According to report, emissions from the transportation sector significantly contribute to poor air quality in urban areas. Therefore, the development of electric vehicles is a strategic solution in creating an environmentally friendly transportation system.

However, electric vehicles also face several technical challenges, especially in the energy storage system, namely the battery. One main issue is the increase in battery temperature during charging and use. High temperatures can cause performance degradation, cell deterioration, and even dangerous overheating risks. This problem becomes more significant in tropical countries like Indonesia, which has high ambient temperatures, especially in the dry season, accelerating battery temperature rise during vehicle operation.

In previous studies, various approaches have been developed to address battery heat problems, one of which is the use of cooling systems. Baskoro et al. (2021) stated that air-based cooling systems with added fans and coolant can effectively reduce the temperature of electric vehicle batteries. However, in reality, many electric vehicles on the market, especially lithium battery electric motorcycles, are not equipped with adequate battery cooling systems according to manufacturers' technical specifications.

Lithium batteries are widely chosen for their advantages in power density, light weight, and relatively fast charging time. However, there are still few studies specifically investigating the effect of cooling systems on the charging speed of lithium batteries. This creates an important research gap to be addressed. Most previous studies have focused more on temperature management during usage, not during charging, even though this phase is also crucial for battery performance and lifespan.

This study aims to examine the effect of using air- and liquid-based cooling systems on the charging speed of lithium batteries in electric motorcycles. An experimental method with a comparative approach between batteries with and without cooling systems is used. This method is chosen to obtain accurate empirical data on charging performance differences. The results are expected to contribute to developing more efficient battery cooling systems and serve as a reference for the automotive industry in designing optimal battery systems for tropical climates.

LITERATURE REVIEW

The rapid advancement of electronic technology, especially the shift from fuel-powered to electric vehicles, relies heavily on batteries as the main power source. Today, batteries power various modern electronics like electric cars, e-bikes, and other devices. Electric motors offer benefits over traditional vehicles, including lighter weight, lower emissions, and cost savings when batteries are properly charged and discharged. Lithium-ion batteries, widely used, provide high energy, low self-discharge rates, and long lifespans.

However, they function best within a limited temperature range of 20°C to 35°C. Temperatures beyond this range can shorten battery life, reduce capacity, and accelerate aging due to heat generated during charging and discharging chemical reactions. Because of this, maintaining an optimal battery temperature is crucial, often achieved through cooling systems to prevent overheating. A battery consists of one or more electrochemical cells where redox reactions move electrons from the anode (negative electrode) to the cathode (positive electrode), generating electrical energy for external devices, Kurniawan (2020).

In short, managing battery temperature and care is key to ensuring reliable performance, durability, and safety, especially in modern electronics like electric vehicles.

a. Lithium-Ion Battery

A lithium-ion battery is a rechargeable battery with high energy density, long lifespan, and efficient charging. It works by lithium ions moving between the cathode (positive electrode) and anode (negative electrode), enabling efficient charging and discharging. The battery's advantages are fast charging, durability, and stable performance. However, it's sensitive to extreme temperatures and can overcharge without a proper management system.

b. The Impact of Temperature on Battery Performance

High operating temperatures can speed up battery degradation, reduce storage capacity, and lower charging efficiency. Indonesia's tropical climate means higher ambient temperatures, which can worsen the battery's thermal conditions during use and charging. That's why effective temperature management is crucial to maintain battery performance and safety.

c. Heat Transfer

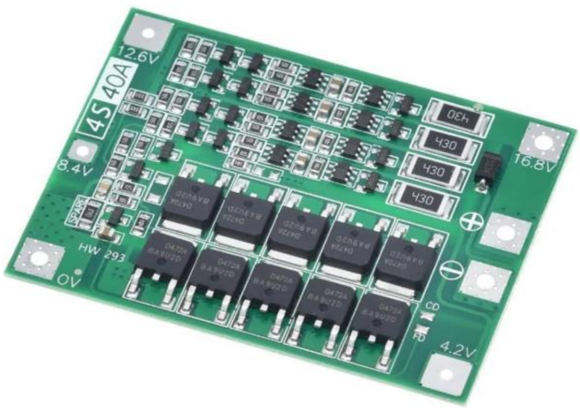
Heat in battery systems moves in three ways: conduction (contact), convection (air or liquid flow), and radiation (energy waves). Cooling can be air or liquid-based. If heat isn't managed well, it builds up and can damage battery parts.

d. Battery cooling systems

Battery cooling systems use air cooling and liquid cooling. The air cooling system uses fans to blow air over the battery surface to remove heat. Its advantages are simple design and low cost, but it's less efficient than liquid cooling, especially in high-temperature environments. C Qalbi, K. Et al. (2023). The liquid cooling system uses a fluid like ethylene glycol that circulates around the battery to absorb heat. A mixture of water and ethylene glycol has proven effective in lowering temperature but requires circulation for maximum efficiency. Without circulation, the liquid can retain excess heat and reduce its effectiveness. A. Sitanggang et al. (2017).

e. Battery Management System (BMS)

Battery cooling systems use air cooling and liquid cooling. Air cooling uses fans to blow air across the battery surface to remove heat. Its advantages are simple design and low cost, but it's less efficient than liquid cooling, especially in high-temperature environments. Lubudi (2020).

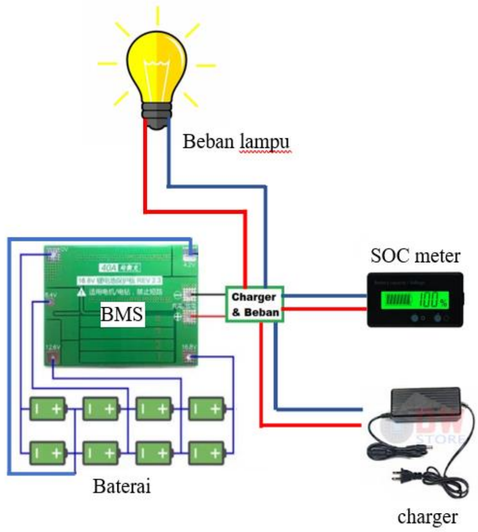


Pic. 1 BMS 4S

METHODOLOGY

This study focuses on lithium-ion batteries used in electric motorcycles, specifically testing their charging performance with and without cooling systems. The research was conducted at Building O, Mechanical Engineering Laboratory, Politeknik Negeri Banjarmasin.

It's an experimental study aimed at exploring the cause-and-effect relationship between the independent variable (battery cooling type) and dependent variables (charging speed and battery temperature). According to Sugiyono, experimental research investigates how a certain treatment affects others in controlled conditions. This approach helps provide a comprehensive picture of how cooling systems influence electric motorcycle battery temperature.

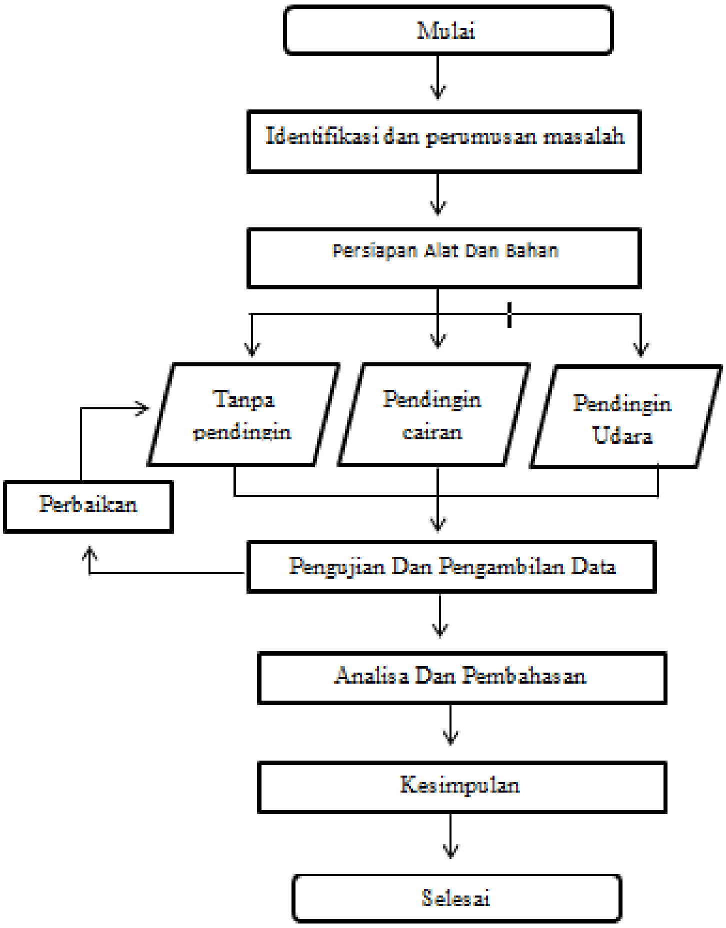


Pic. 2 Battery circuit

The experiment involved three cooling variations: no cooling, fan cooling, and liquid cooling. Tools used included 18650 lithium batteries, digital thermocouples, power meters, and stopwatches.

Data were secondary, consisting of battery temperature and charging speed before and after adding fan and liquid cooling setups. Temperature was measured every 10 minutes via thermometer until average battery heat during the test was established. Collected data included time to charge from 20% to 100%, battery temperature during charging, and charge percentage every 10 minutes. Each test was repeated three times per cooling condition.

Data analysis involved creating comparison graphs of battery temperature and charging speed between systems with and without cooling. Measurements were gathered directly in the lab using temperature sensors, voltmeters, and stopwatches during full charging cycles.



Pic. 3 Conceptual Framework

RESEARCH RESULT

a. Assembly Of The Battery Circuit Without Cooling

The first step was assembling the battery and Battery Management System (BMS) according to the 4S 2P configuration, soldering them together using 0.12 mm thick nickel plates. This 4S 2P lithium battery setup (four cells in series, two in parallel) was chosen to achieve a nominal voltage of 16.8 volts with a capacity of 6000 mAh. The assembly used eight 18650 cells rated at 4.4 volts each.

Initially, the cells were grouped into four parallel pairs, connecting positive to positive and negative to negative terminals with tin-coated nickel plates. Soldering was done carefully using a 60-watt electric soldering iron to ensure strong connections without overheating and damaging the cells. After forming four parallel groups, the next step was connecting them in series by linking the negative terminal of one group to the positive terminal of the next, creating a series circuit. The outermost positive and negative terminals from the first and last groups functioned as the battery pack's main terminals.

Next, a 4S 40A BMS module was installed for safety and system efficiency. The BMS cables were connected as instructed: B- to the negative battery terminal, B+ to the positive terminal, and B1 through B4 to the junctions between the series cells. Careful soldering ensured proper polarity and clean contacts for good conductivity and secure connections.

Finally, all exposed parts were insulated with heat shrink tubing or heat sinks to prevent short circuits. Before use, initial testing with a multimeter confirmed the total voltage ranged between 14.8 and 16.8 volts, depending on cell charge level. Further testing involved powering a DC lamp to verify the BMS properly regulated current flow, protecting the battery from overcharging and over discharging.

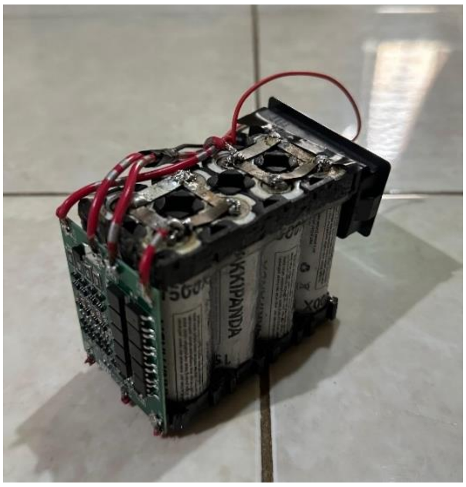
Pic. 4 Battery without cooling

b. Battery Assembly With Fan Cooling

The battery assembly with fan cooling is basically the same as before, but with 12V fans added on both the left and right sides. These fans work by drawing heat away from the battery cells' sides and expelling it from the battery pack. The fans are powered using a 12V DC adapter.

Pic. 5 Battery with fan cooling

The assembly of the battery with liquid cooling is basically the same as before, but with the addition of cooling liquid and resin. The cooling liquid used is ethylene glycol, which wraps around the battery to prevent leaks, sealed by applying resin around it. The resin is a mixture of epoxy and hardener, with a mixing ratio of 2:1—two parts epoxy to one part hardener.

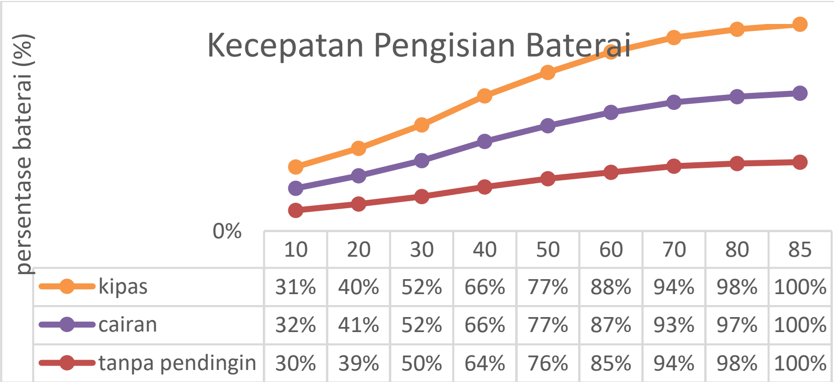


Pic. 6 Battery with liquid cooling

In this study, data on charging speed and battery temperature were collected for batteries without cooling, with fan cooling, and with liquid cooling. Tests were conducted from 20% to 100% charge, repeated three times. The charging data were obtained from the testing time. The test results are shown in the table.

Table. 1 Result Test

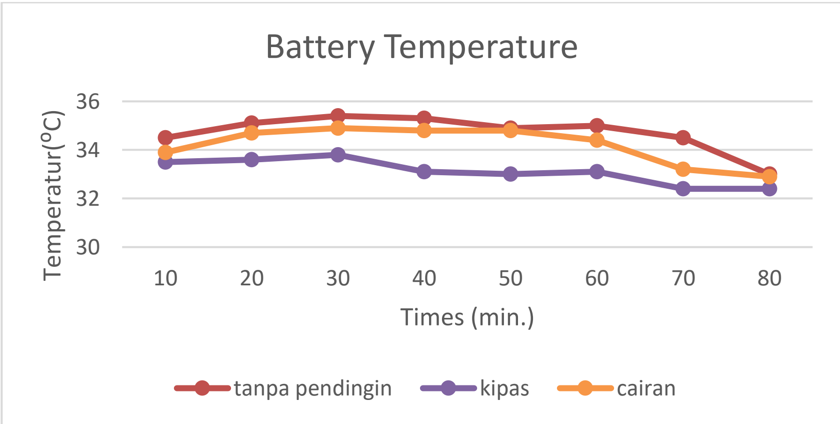
Variation	Testing Stage	Battery capacity	Duration Charging (min.)	Temperature (^OC)		Average Charging (min.)
				Min	Max	
Without cooling	1	20%	85	33,7	35,7	85
	2	20%	86	33,1	36.0	
	3	20%	85	32,3	35,1	
Using Liquid cooling	1	20%	82	33,6	35,3	83
	2	20%	83	32,4	36,2	
	3	20%	83	32,4	34,8	
Using Fan Cooling	1	20%	84	32,7	34,2	84
	2	20%	85	32,3	34,8	
	3	20%	84	31,4	32,8	



Pic. 7 Battery charging speed

From the graph above comparing battery charging speeds without cooling, with a fan, and with liquid cooling, it can be seen that the charging speed without cooling is slower than with cooling.

The charging speed of batteries using a fan is more stable and faster than without cooling because less heat slows down the charging. Meanwhile, batteries with liquid cooling charge very fast at first, beating both fan cooling and no cooling, but then slow down because the heat is stored in the liquid due to lack of circulation to remove it.



Pic. 8 Battery temperature during charging

From the graph above comparing battery temperatures without cooling, with fan cooling, and with liquid cooling, it can be seen that batteries without cooling are hotter than those with cooling. The temperature of batteries using a fan is more stable because the fan sucks in and expels the heat directly, while liquid-cooled batteries do reduce heat but also store it in the liquid due to lack of circulation to remove the heat. This happens due to several factors: 1) High charging current: If the charging current is too high, it can cause a significant temperature increase because the energy entering the battery exceeds its ability to distribute it without generating excessive heat. 2) Chemical process: During discharge, chemical reactions convert electrical energy to chemical energy stored in the battery cells. This process isn't perfectly efficient, so some energy turns into heat. 3) Internal resistance: Every battery has internal resistance, causing some incoming energy to convert into heat due to resistance within the cells.

DISCUSSION

Based on the test results and analysis of the effect of cooling systems on lithium batteries regarding charging speed and temperature stability, it can be concluded that the cooling system plays an important role in improving battery charging efficiency. Batteries without a cooling system showed the slowest charging speed and the highest temperature increase during charging. This is caused by heat accumulation that is not properly managed, causing the charging system to automatically reduce current to prevent thermal risks, which ultimately slows down the charging process.

CONCLUSIONS AND RECOMMENDATIONS

Meanwhile, the fan-based cooling system has proven to be the most effective in maintaining temperature stability and allowing consistent high-current charging. The airflow from the fan continuously removes heat from the battery surface, keeping the temperature within a safe range and optimizing charging performance. On the other hand, the liquid cooling system shows good performance, especially in the initial charging phase, but its effectiveness decreases in the final phase due to lack of liquid circulation, so heat absorbed cannot be expelled effectively.

Therefore, it can be concluded that the use of cooling systems, especially fan-based ones, is highly recommended to maintain the performance and safety of lithium batteries in electric vehicles, especially in high-temperature environments such as tropical regions.

ADVANCED RESEARCH

Based on the test results, further research should focus on developing a liquid cooling system with active circulation to prevent heat buildup during the final charging phase. It's also important to compare how well fan-based, liquid-based, and combined cooling systems perform under different temperature conditions, especially in tropical climates. This research could also explore how varying charging currents affect battery temperature stability and charging speed. Lastly, studying new cooling technologies, like thermoelectric coolers, is needed to improve the performance and safety of lithium batteries in electric vehicles.

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