JIM Vol.6 (1) 2024

Received: 15 01 2024 | Revised: 23 02 2024 | Accepted: 07 04 2024

DOI: 10.15294/jim.v6i1.1907

Page 8 - 18

JIM: Jurnal Inovasi Mesin

# Analysis of Battery Pack Cooling System Design Using Computational Fluid Dynamics Method in Electric Vehicle

Selvia[1*], Rizqi Fitri Naryanto[1], Apip Amrullah[2]

1 Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Semarang, Indonesia

2 Department of Mechanical Engineering, Faculty of Engineering, Universitas Lambung Mangkurat

*selviavan01@students.unnes.ac.id

*Keywords:*
Cooling System
Battery Pack
CFD

*Abstract*

The objective of this research is to address the heat increase in the battery, ensuring it remains below 40°C through a cooling system. Through Computational Fluid Dynamics (CFD) simulations, the impact of using Aluminium 6061, Aluminium Duralumin, and Copper, as well as the effects of cooling fluids H2O and Ethylene Glycol on the battery pack cooling system, are analyzed. Data collection is conducted using Solidworks 2022 with the Flow Simulation feature, followed by a descriptive statistical analysis to identify the optimal cooling system for the battery pack. Simulation results indicate the most optimal performance at an inlet speed of 3 m/s. For H2O, Copper maintains a temperature of 37.14°C, while Aluminium 6061 and Aluminium Duralumin reach temperatures of 37.36°C and 37.34°C, respectively. In the case of Ethylene Glycol at a speed of 3 m/s, Copper records a temperature of 194.75°C, while Aluminium 6061 and Aluminium Duralumin achieve temperatures of 197.94°C and 195.34°C, respectively. Based on this research, Copper and H2O are identified as the best choices.

## 1 Introduction

Batteries have a high energy density and power, lithium-ion batteries (LIB) are the technology of choice for storing electrical energy, both in the consumer electronics sector and the transportation sector [1]. In this study, lithium-ion batteries, especially the LiFePO4 type, have advantages such as resistance to overdischarging, thermodynamic stability, and long cycle life. However, these batteries are prone to low performance at extreme temperatures. The operational temperature range and charging of LiFePO4 batteries also need to be maintained to remain efficient. Research Khalis and Yamin [2] indicates that continuous use of batteries can increase temperature, so an active cooling system with a fan or pump is needed to move the fluid. This increase in temperature can be caused by several factors, including the internal resistance of the battery, energy conversion efficiency, and the operational environment. This is the question, how to transfer heat to the battery to maintain battery temperature to remain in an optimal state. For this reason, the need for an active cooling system designed to cool an electronic component by utilizing a fan or pump to move the fluid. Active cooling systems are characterized by higher performance than passive ones, because passive cooling systems act without external power sources and benefit from natural conditions [3].



ISSN 2746-7694

In fact, experimental analyses show temperature reductions of up to 30°C for active cooling methods against reductions of up to 20°C in the case of passive cooling systems [4]. In the context of an active cooling system, this implies that the heat removed from the equipment or environment by the active cooling system does not actually disappear but is deformed or diverted [5]. Active cooling systems involve the transfer of heat from a cooler area to a hotter one through compressors, compression, and heat dissipation into the outside environment, thus allowing maintenance of lower temperatures inside the cooled chamber or equipment. According to Anugrah et al., [6] explained that heat transfer is the movement of energy from one area to another caused by temperature differences in the area.

Battery thermal system needs to be lowered using cooling system, in battery thermal management there are 2 categories. Internal battery thermal management by managing electrode design to reduce heat production during electrochemical processes, while external battery thermal management by adding other components such as cooling system without changing battery parts [7]. And there are several methods that can be applied in keeping the battery temperature stable. A common method is to transfer heat from a battery cell to a specific medium, one of which uses a cooling plate or other cooling medium as an intermediary for heat transfer. So that the battery lasts a long time and does not break quickly. Fluid and air type cooling systems are used in vehicles with the aim of effectively regulating the temperature in the battery [8]. Battery cooling methods mainly include air cooling, cooling liquid, phase change material cooling [9]. Compared to air, coolant usually has a much higher thermal conductivity. According to X. Xu et al., [10], using Ethylene Glycol and H2O as the cooling system in LiFePO4 batteries is declared effective in cooling. Ethylene Glycol, which is commonly used in refrigeration, has a high boiling point and low freezing point, as well as efficient thermal conductivity. On the other hand, H2O has a low viscosity, allowing good circulation in the cooling system, and high thermal conductivity for heat transfer efficiency. In a battery cooling system, the fluid acts as an intermediary to carry heat from the battery, flowing in pipelines with a certain thermal conductivity. The linkage between materials and cooling systems is important for optimal design and performance. Materials such as Aluminum 6061 and Aluminum Duralumin are often used in refrigeration systems because they are corrosion resistant and lightweight, while Copper has higher thermal conductivity. Therefore, the thermal management technology of vehicle power battery system is one of the key technologies to ensure performance, service life, and safety [11].

The cooling system is designed by taking a reference from the motor coolant. The design of the water jacket or cooling pipe that surrounds the object you want to cool is often used in the manufacture of cooling systems on electric motors. A cooling pipe or water jacket is a pipe made of metal or alloy which, when supplied with water, can provide cooling to objects and can accelerate the heat transfer process relative to its thermal conductivity. Research on water jackets has been conducted by Rehman and Seong [12]. To analyze the performance of the water jacket, a three-dimensional numeric steady state method is used using Computational Fluid Dynamics (CFD) simulation. The results of the study show that the structure of the water jacket has a very significant impact on the maximum temperature area in the motor. An increase in the number of flow paths and an increase in the flow rate of the cooling fluid have an effect on decreasing the maximum temperature of the motor.

The use of liquid cooler as a cooling system in batteries, has been analyzed by Nizam & Putra, [13]. Temperature differences were analyzed in various segments of pack batteries using inlet speeds of 1 m/s, 2 m/s, 3 m/s, and 4 m/s. The results show that the temperature difference obtained is almost similar, the temperature difference on the battery surface is below 0.5°C. The temperature difference is relatively small, causing the distribution of heat generated due to heat absorption on the cooling plate is quite good. This happens because, cooling plates with the same characteristics or geometry have the same ability to absorb heat.

Therefore, research was conducted on the design of cooling systems using 3-dimensional CAD (Computer-Aided Design) software for product design and engineering [14]. The flow in the coolant pipe

Received: 15 01 2024 | Revised: 23 02 2024 | Accepted: 07 04 2024

DOI: 10.15294/jim.v6i1.1907

Page 8 - 18

JIM: Jurnal Inovasi Mesin

is analyzed using the Computational Fluid Dynamics (CFD) method to observe how the fluid moves and the way the fluid interacts with the environment [15]. Determine the most suitable fluid, optimal coolant pipe material, and the right fluid flow velocity, to ensure optimum temperature when the battery is operating. The fluid flow phenoma is observed in the Solidworks 2022 software which utilizes the Flow Simulation feature.

## 2 Research Methods

The research method used is an experimental method with a simulation approach based on Computational Fluid Dynamics (CFD). The CFD simulation process generally consists of three stages: Pre-processing, Processing, and Post-processing (Sukamta et al., 2018). Budiman et al., [16] Previously using a simulation approach by conducting literature review, observation, design, simulation, and analysis of simulation results. In this study, the method was applied to collect information and data about the battery cooling system quantitatively. This research parameter is the object that becomes the center of attention in research to identify research objectives. According to Sugiyono [17], Research variables are all elements in any form that have been determined to be researched with the aim of obtaining data or information on a topic and then formulating conclusions. In this study there are research parameters including, the type of H2O fluid with Ethylene Glycol, Aluminum 6061, Aluminum Duralumin, and Copper materials and the influence on the difference in inlet velocity (1 m / s, 2 m / s, and 3 m / s). Simulation modeling refers to the development and application of computer simulations to analyze heat transfer in electric vehicle battery cooling systems, involving design stages, boundary conditions, parameter inputs, and testing with temperature outputs. These stages can be explained through the flow chart in figure 1.



ISSN 2746-7694

 

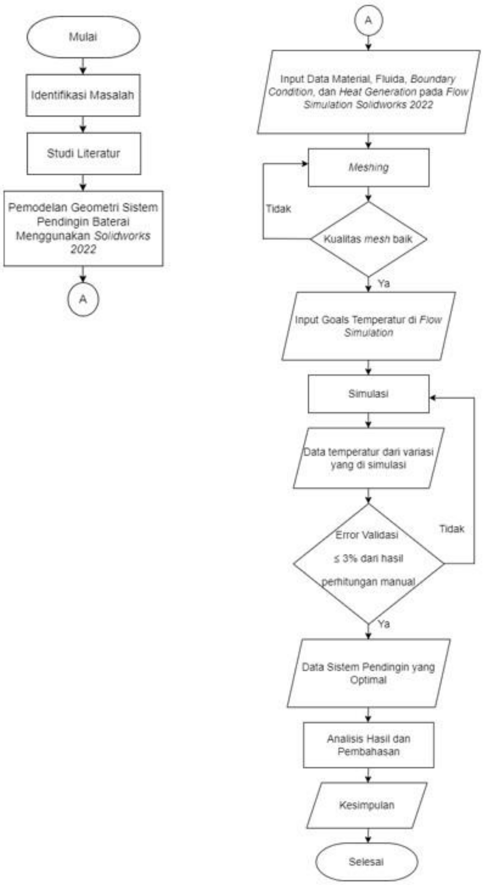


**Figure 1.** Research Flow Chart

1. Pre-Processor

Design of a Cooling System on Electric Vehicle Batteries with LiFePO4 battery specifications that have a nominal battery voltage when operating normally of 3.2 Volt per cell, which is designed using Solidworks 2022 software which will be used to simulate the Flow Simulation feature.

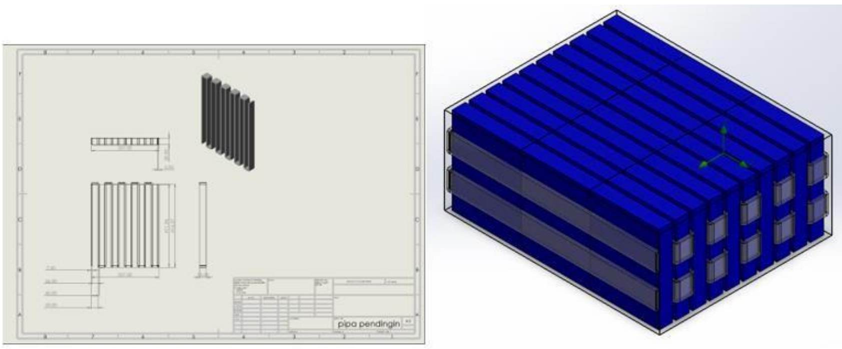


**Figure 2.** Battery Pack Cooling System Design

This design will be used to retrieve simulation data with temperature output or final temperature. In making it, the design of the cooling system was carried out in stages using Solidworks 2022 software. The manufacture of the battery design follows the dimensions of the LiFePO4 battery with a length of 135 mm, a width of 26 mm, and a height of 170 mm. The cooling pipes are installed parallel up and down with inlets and outlets inputted in parallel to prevent heat buildup on one side of the battery. In the cooling pipe has a wall thickness of 2.5 mm. Mesh formation is a step that is applied before starting the simulation process. In this phase, the initial structure is decomposed into small dots. The main purpose of the mesh formation process is to partition the initial geometry into the small elements that make up the structure. The mesh is input at level 5.

2. Solver

This process is a determination of boundary conditions, a numerical process, and will be simulated by providing material variations of Aluminum 6061, Aluminum Duralumin, and Copper. Types of liquid H2O and Ethylene Glycol, as well as variations in inlet velocities of 1 m / s, 2 m / s, and 3 m / s. At this stage also input Heat Generation of 3066,666 watts for 30 pcs of batteries. Heat generation is the process or event that generates or creates heat [18]. The parameters are inputted in the Flow Simulation feature and run; at this time the iteration will continue until the solver finishes. The iteration process in CFD (Computational Fluid Dynamics) simulation refers to the process of repeatability performed by numerical solvers to approximate accurate solutions to complex fluid dynamics equations. The length of the iteration process shows that the calculations are close to true accuracy.

3. Post-Processor

This process has a final temperature plot on the liquid and battery and selected vector and contour direction plots that have color patterns from minimum to maximum points to make it easier to read the simulation results.

## 3 Result and Discussion

The simulation generates the final temperature of the battery and liquid. The results of the final temperature simulation on the H2O liquid type are presented in figures 3, 4, and 5.

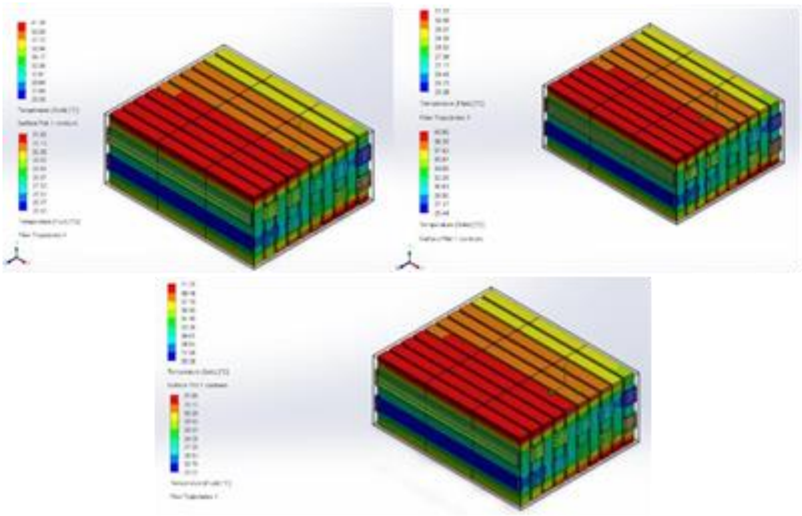

**Figure 3.** Simulation Results of H2O Liquid on Aluminum 6061, Copper, and Aluminum Duralumin Materials at Velocity 1 m/s

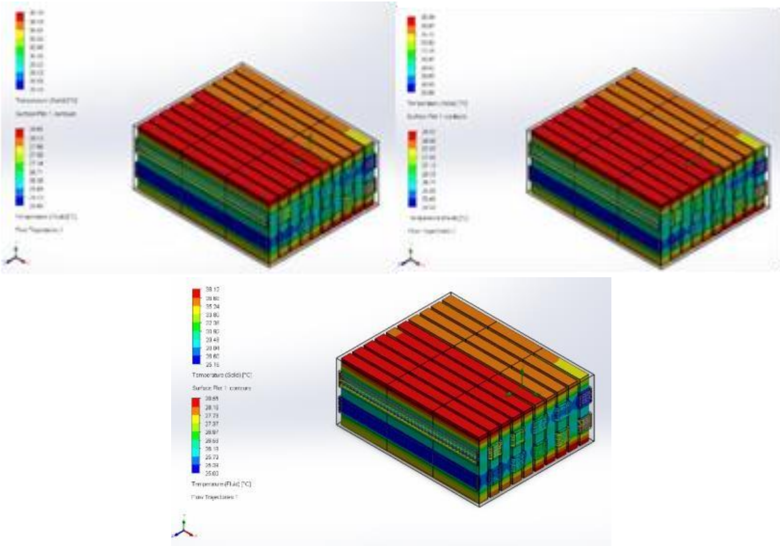

**Figure 4.** Results of H2O Liquid Simulation on Aluminum 6061, Aluminum Duralumin, and Copper Materials at Velocity 2 m/s

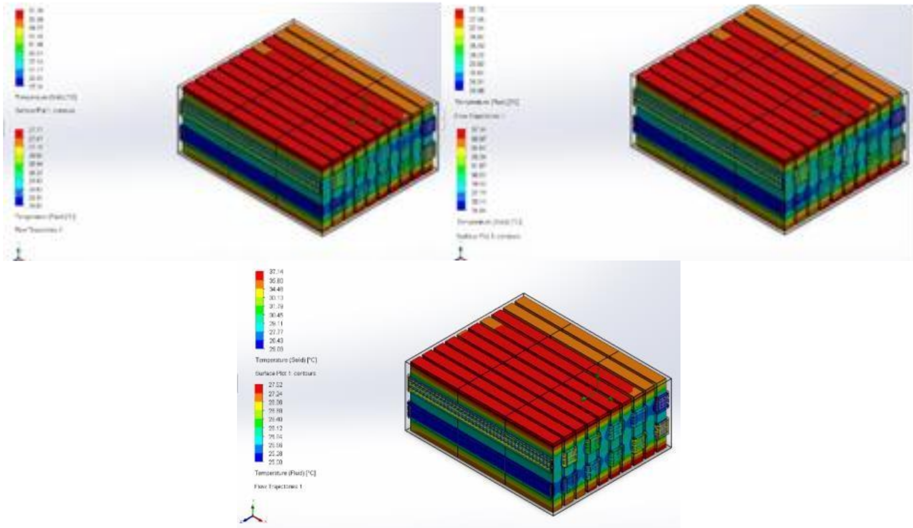

**Figure 5.** Simulation Results of H2O Liquid on Aluminum 6061, Aluminum Duralumin, and Copper at Velocity 3 m/s

The results of the final temperature simulation in batteries and liquids using the type of Ethylene Glycol liquid are presented in figures 6, 7, and 8.

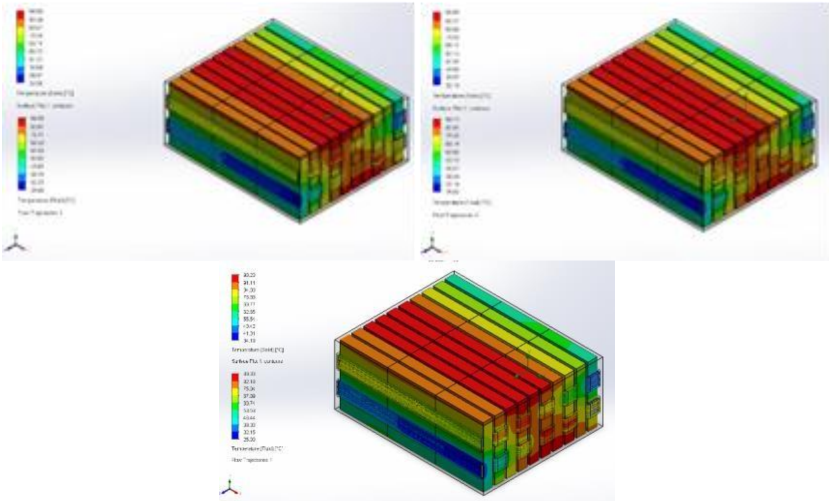

**Figure 6.** Simulation results of *Ethylene Glycol* liquid on Aluminum 6061, Aluminum Duralumin, and Copper at Velocity 1 m/s

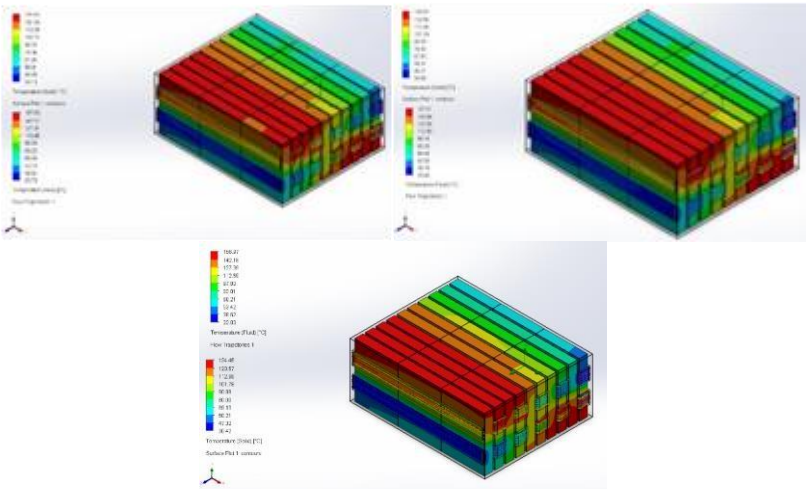

**Figure 7.** Simulation Results of *Ethylene Glycol* Liquid on Aluminum 6061, Aluminum Duralumin, and Copper Materials at Velocity 2 m/s

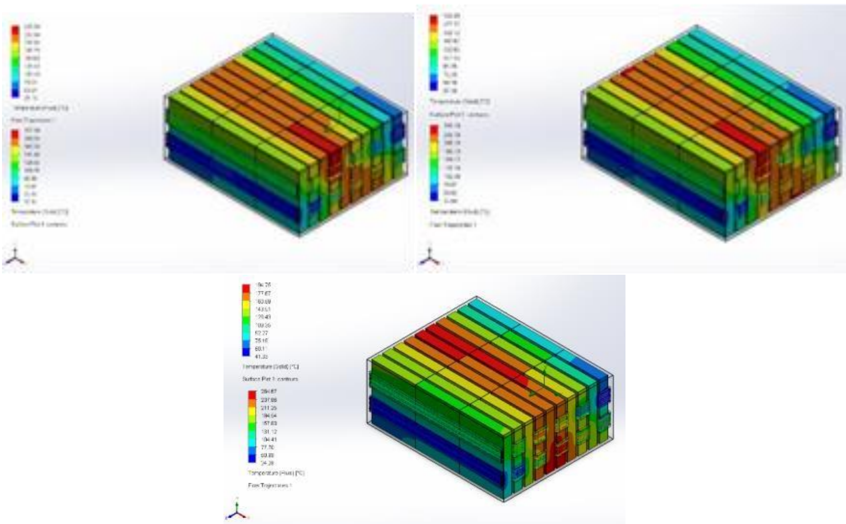

**Figure 8.** Simulation Results of *Ethylene Glycol* Liquid on Aluminum 6061, Aluminum Duralumin, and Copper Materials at Velocity 3 m/s

**Table 1.** Battery Temperature After Simulation with $H_2O$

| Material | Velocity | | |
|---|---|---|---|
| | **1 m/s** | **2 m/s** | **3 m/s** |
| Almunium 6061 | 41,28°C | 38,36°C | 37,36°C |
| Aluminum Duralumin | 41,25°C | 38,34°C | 37,34°C |
| Copper | 40,99°C | 38,12°C | 37,14°C |

**Table 2.** Temperature in Liquid After Simulation with $H_2O$

| Material | Velocity | | |
|---|---|---|---|
| | **1 m/s** | **2 m/s** | **3 m/s** |
| Almunium 6061 | 31,90°C | 28,85°C | 27,77°C |
| Aluminum Duralumin | 31,86°C | 28,82°C | 27,75°C |
| Copper | 31,52°C | 28,55°C | 27,52°C |

**Table 3.** Battery Temperature After Simulation with Ethylene Glycol

| Material | Velocity | | |
|---|---|---|---|
| | **1 m/s** | **2 m/s** | **3 m/s** |
| Almunium 6061 | 98,80°C | 135,46°C | 197,94°C |
| Aluminum Duralumin | 98,66°C | 134,87°C | 195,34°C |
| Copper | 98,23°C | 134,46°C | 194,75°C |

**Table 4.** Temperature in Liquid After Simulation with Ethylene Glycol

| Material | Velocity | | |
|---|---|---|---|
| | **1 m/s** | **2 m/s** | **3 m/s** |
| Almunium 6061 | 89,85°C | 157,53°C | 258,99°C |
| Aluminum Duralumin | 89,70°C | 157,51°C | 258,18°C |
| Copper | 89,33°C | 156,97°C | 264,67°C |

## Temperature Analysis with Flow Speed

Simulating the flow velocity based on data, it was found that the H2O fluid with a flow velocity of 1 m/s caused the temperature in the cooling pipe to increase and the temperature in the battery increased beyond the battery operational temperature of 313 K or 40°C. While at speeds of 2 m/s and 3 m/s produce a lower maximum temperature than the flow speed of 1 m/s. At flow speeds of 2 m/s and 3 m/s have temperatures in the cooling pipes ranging from 300.52K-301.85K or 27.52°C – 28.85°C. In batteries, the temperature is below the operational temperature of the battery, which ranges from 310.14K-311.36K or 37.14°C – 38.36°C. As a heat exchanger where there is no thermal process that can take place by itself, but moves from high temperature to low temperature. In theory, an increase in the velocity of a flow leads to increasded heat transfer by convection (Husen et al., 2020). Based on this, flow speeds of 2 m/s and 3 m/s can be used in cooling systems for batteries

Temperature Analysis with Materials

The simulation that has been carried out provides results on the type of H2O and Ethylene Glycol fluids using the material types of Aluminum 6061, Aluminum Duralumin, and Copper to get similar results. Similar results are that Copper has a lower temperature value compared to Aluminum 6061 and Aluminum Duralumin. This happens because the thermal conductivity possessed by copper is higher than Aluminum 6061 and Aluminum Duralumin, Aluminum 6061 has a thermal conductivity value of 155.5 W/ (m. k) and Duralumin 160 W/ (m. k). Meanwhile, Copper has a thermal conductivity value of 401 W/ (m. k). The thermal conductivity of Aluminum 6061 and Aluminum Duralumin is relatively similar, so both have almost the same ability to transfer heat. In heating or cooling systems, heat transfer efficiency becomes critical. Materials with high thermal conductivity can transfer heat more efficiently, allowing for faster heat transfer between heat sources and coolants.

Temperature Analysis with Liquids

$H_2O$ and Ethylene Glycol fluids are simulated with different velocity variations and material variations. The use of H2O in the cooling system after the simulation obtained good results. At an inlet speed of 1 m/s using Aluminum 6061, Aluminum Duralumin, and Copper materials have a maximum temperature value in > 40°C battery. Meanwhile, at inlet speeds of 2 m/s and 3 m/s, the results are said to be optimal, namely > 37°C and < 40°C. The requirement of an optimal cooling system is 25°C-40°C (Pesaran, 2002). In Ethyelene Glycol after the simulation has poor results, because in the simulation process the flow of Ethylene Glycol fluid does not circulate properly and there is a vortex, which is a vortex in the flow that causes the flow speed to be inconstant and changeable so that it affects the simulation results. The greater the inlet velocity used in the Ethylene Glycol fluid, the higher the temperature. The smaller the inlet speed, the lower the temperature of the battery. The lowest temperature of the Ethylene Glycol fluid using inlet velocity variations and material variations is obtained at an inlet velocity of 1 m/s with copper material, which is 98.23°C. In Aluminum 6061 and Aluminum Duralumin are 98.80°C and 98.66°C. At an inlet speed of 3 m/s the temperature can reach 197.94°C with Aluminum 6061 material. The temperature of the Ethylene Glycol liquid itself is very high and can exceed the temperature in the battery, the highest temperature after the simulation reaches 264.67 ° C using an inlet speed of 3 m/s and Aluminum 6061 material.

Validation

Comparison of manual calculations with simulation calculations is carried out to ensure validation that the research or simulation that has been carried out is accurate. In the process, manual calculations use the heat transfer rate equation to find out the final temperature in the liquid. The final or outlet temperature in the liquid is calculated using the heat transfer formula. Researchers used simulation results from the H2O fluid type as a sample to compare computational calculations with manual calculations. If you use Ethylene Glycol will get a big error result, because in the simulation of the occurrence of *vortex*.  Below is a manual calculation of heat transfer in liquid H2O with several samples

**Table 4.** Percent Error in Liquid After Simulation with $H_2O$

| Material | Velocity | Temperature in Fluid H2O | | Error (%) |
|---|---|---|---|---|
| | | Computing | Manual | |
| Aluminium 6061 | 1 m/s | 31,90 | 31,5963 | 0,95% |
| | 2 m/s | 28,85 | 28,298 | 1,91% |
| | 3 m/s | 27,77 | 27,199 | 2,05% |
| Aluminium | 1 m/s | 31,86 | 31,5963 | 0,83% |

| | | | | |
|---|---|---|---|---|
| Duralumin | 2 m/s | 28,82 | 28,298 | 1,81% |
| | 3 m/s | 27,75 | 27,199 | 1,98% |
| Copper | 1 m/s | 31,52 | 31,5963 | 0,24% |
| | 2 m/s | 28,55 | 28,298 | 0,88% |
| | 3 m/s | 27,52 | 27,199 | 1,16% |

The simulation results with H2O found a percentage difference between computational calculations with manual calculations with a maximum level of 2% and a minimum level of less than 1%. So, the simulation that has been done can be declared valid because the percentage difference is less than 3% (Taufikhairul et all., 2023).

In the calculation, the simulation results with H2O found a percentage difference between computational calculations with manual calculations with a maximum level of 2% and a minimum level of less than 1%. So, the simulation that has been done can be declared valid because the percentage difference is less than.

## 4 Conclusion

$H_2O$ is the best fluid for cooling systems because it has low viscosity and can circulate well. In simulations with inlet speeds of 2 m/s and 3 m/s, H2O in Aluminum 6061, Aluminum Duralumin, and Copper produced battery temperatures in the range of 37.14°C - 38.36°C, which is considered good because it is below 40°C. The influence of the material shows that Copper, when simulated with both types of fluids, gives better results than Aluminum 6061 and Aluminum Duralumin. Similar performance of Aluminium 6061 and Aluminium Duralumin is affected by the thermal conductivity, density, density and geometry of the cooling system. In H2O fluids with a speed of 3 m/s, Copper reaches a battery temperature of 37.14°C, while Aluminum 6061 and Aluminum Duralumin have temperatures of 37.36°C and 37.34°C, respectively. In *Ethylene Glycol*, Copper gives the lowest temperature of 194.75°C, due to its higher thermal conductivity (401 W/ (m. k)) than Aluminum 6061 and Aluminum Duralumin (155.5 W/(m. k) and 160 W/ (m. k)). The simulation results with Copper material and inlet speed of 3 m/s gave the lowest temperature of 37.14°C, more effective than Aluminum 6061 and Aluminum Duralumin. In *Ethylene Glycol*, vortex in the flow causes an unbalanced speed distribution, increasing the temperature in the battery to 98.23°C using Copper. The high velocity of the fluid also increases the rate of heat transfer on the surface of the heat exchanger. In conclusion, the use of H2O with a speed of 3 m/s and Copper material is considered the most effective in reducing battery heat

## 5 Acknowledgement

The author would say thank to Universitas Negeri Semarang and Universitas Lambung Mangkurat for supporting the research.

## References

1. F. J. Günter and N. Wassiliadis, “State of the art of lithium-ion pouch cells in automotive applications: cell teardown and characterization,” *Journal of The Electrochemical Society*, vol. 169, no. 3, p. 30515, 2022.
2. M. Khalis and M. Yamin, “Analisis Suhu Sistem Penggerak Elektrik Pada Prototipe Kendaraan UG-HEV (Hybrid Electric Vehicle),” *AME (Aplikasi Mekanika dan Energi): Jurnal Ilmiah Teknik Mesin*, vol. 7, no. 1, pp. 36–45, 2021.
3. H. G. Teo, P. S. Lee, and M. N. A. Hawlader, “An active cooling system for photovoltaic modules,” *applied energy*, vol. 90, no. 1, pp. 309–315, 2012.
4. M. Hasanuzzaman, A. Malek, M. M. Islam, A. K. Pandey, and N. A. Rahim, “Global advancement of cooling technologies for PV systems: A review,” *Solar Energy*, vol. 137, pp. 25–45, 2016.
5. W. R. Roy, “Thermodynamics of Natural Systems: Gregor M. Anderson, John Wiley \& Sons, 605 Third Avenue, New York, NY 10158. 1996. 382 p. $25.95. ISBN 0-471-10943-6.” Wiley Online Library, 1996.

6. G. P. Anugrah, A. Ismardi, and T. A. Ajiwiguna, “Rancang Bangun Pendingin Untuk Perangkat Elektronik Pada Green House,” *eProceedings of Engineering*, vol. 4, no. 3, 2017.
7. R. Zhao, S. Zhang, J. Liu, and J. Gu, “A review of thermal performance improving methods of lithium ion battery: Electrode modification and thermal management system,” *Journal of Power Sources*, vol. 299, pp. 557–577, 2015.
8. A. K. Thakur, R. Prabakaran, M. R. Elkadeem, S. W. Sharshir, M. Ar\ic\i, C. Wang, W. Zhao, J.-Y. Hwang, and R. Saidur, “A state of art review and future viewpoint on advance cooling techniques for Lithium--ion battery system of electric vehicles,” *Journal of Energy Storage*, vol. 32, p. 101771, 2020.
9. W. Wu, S. Wang, W. Wu, K. Chen, S. Hong, and Y. Lai, “A critical review of battery thermal performance and liquid based battery thermal management,” *Energy conversion and management*, vol. 182, pp. 262–281, 2019.
10. X. Xu, W. Li, B. Xu, and J. Qin, “Numerical study on a water cooling system for prismatic LiFePO4 batteries at abused operating conditions,” *Applied Energy*, vol. 250, pp. 404–412, 2019.
11. W. Zhou, X. Cai, Y. Chen, J. Li, and X. Peng, “Decoding the optimal charge depletion behavior in energy domain for predictive energy management of series plug-in hybrid electric vehicle,” *Applied Energy*, vol. 316, p. 119098, 2022.
12. Z. Rehman and K. Seong, “Three-D numerical thermal analysis of electric motor with cooling jacket,” *Energies*, vol. 11, no. 1, p. 92, 2018.
13. M. Nizam and M. R. A. Putra, “Analysis of lithium-ion indirect liquid cooling battery thermal management system with high discharge rate,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 3, pp. 1414–1420, 2023.
14. S. Tickoo, *SOLIDWORKS 2020 for designers*. Cadcim Technologies, 2020.
15. J. Tu, G. H. Yeoh, C. Liu, and Y. Tao, *Computational fluid dynamics: a practical approach*. Elsevier, 2023.
16. S. Cheng, L. Jiang, Z. Wei, X. Meng, Q. Duan, H. Xiao, J. Sun, and Q. Wang, “Elucidating in-situ heat generation of LiFePO4 semi-solid lithium slurry battery under specific cycling protocols,” *Electrochimica Acta*, vol. 475, p. 143674, 2024.
17. D. Sugiyono, “Metode penelitian pendidikan pendekatan kuantitatif, kualitatif dan R\&D,” 2013.
18. S. Sukamta, T. Thoharudin, and D. M. Nugroho, “Simulasi CFD Aliran Stratified Air-Udara pada Pipa Horisontal,” *Semesta Teknika*, vol. 21, no. 2, pp. 206–215, 2018.