Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi
Terakreditasi "**Peringkat 3**" berdasarkan SK Dirjendiktiristek, Nomor: 225/E/KPT/2022
Volume 6 Nomor 1 Tahun 2024, Januari 2024, Halaman 39-48
Website : http://journal.univpancasila.ac.id/index.php/asiimetrik/

p-ISSN 2655-1861
e-ISSN 2716-2923

Optimization of Heat Transfer Performance Using Response Surface Methodology-Central Composite Design (RSM-CCD) for Nano-Coolant (Al_2O_3+EG/W) in Electric Vehicle Battery

Optimasi Kinerja Perpindahan Panas Menggunakan *Response Surface Methodology-Central Composite Design* (RSM-CCD) untuk *Nano-Coolant* (Al_2O_3+EG/W) pada Baterai Kendaraan Listrik

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Article information:

Received:
22/08/2023
Revised:
07/09/2023
Accepted:
17/09/2023

Abstract

The presence of electric vehicles (EVs) must be supported by batteries that have good-quality energy storage. Battery power is critical to the development of electric cars. Temperature affects battery strength, so operating within the optimum temperature range must be ensured. During the charge and discharge processes, the electrochemical reaction generates hot energy, causing an increase in battery temperature. In this research, the solution to the problem is to make a cooling system with a mini channel cold plate and Al2O3 1%vol+EG/W (50:50) nano coolant. Optimization of heat transfer enhancement using Response Surface Methodology-Central Composite Design (RSM-CCD) and experimental tests with various flow rate variations. The research findings revealed that the RSM-CCD results and the outcomes of studies employing test equipment agreed that the highest cooling fluid flow rate was the most optimal condition, the highest T2 temperature drop of 17.63% occurred at a flow rate of 1.7 LPM, and the lowest T2 temperature was 13.13% at a flow rate of 1 LPM.

Keywords: Al_2O_3 nano fluid, cold plate, electric vehicle battery, RSM-CCD.

***SDGs*:**

7 AFFORDABLE AND CLEAN ENERGY

Abstrak

Kehadiran kendaraan listrik (EV) harus didukung oleh baterai yang memiliki kualitas yang baik sebagai penyimpan energi. Daya baterai sangat penting untuk pengembangan mobil listrik. Suhu mempengaruhi kekuatan baterai, sehingga harus dipastikan beroperasi dalam rentang suhu yang optimal. Temperatur baterai meningkat selama proses pengisian dan pengosongan karena energi panas yang terbentuk selama reaksi elektrokimia. Dalam penelitian ini, solusi untuk masalah tersebut adalah membuat sistem menggunakan pelat pendingin saluran mini dan nano coolant Al_2O_3 1%vol+EG/W (50:50). Optimasi peningkatan perpindahan panas menggunakan *Response Surface Methodology-Central Composite Design* (RSM-CCD) dan uji eksperimental dengan berbagai variasi laju aliran. Dari hasil penelitian didapatkan bahwa hasil RSM-CCD dan hasil eksperimen menggunakan alat uji memiliki kesesuaian, dimana laju alir fluida pendingin tertinggi merupakan kondisi yang paling optimal, penurunan temperatur T2 tertinggi sebesar 17,63% terjadi pada laju alir 1,7 LPM dan temperatur T2 terendah sebesar 13,13% pada laju alir 1 LPM.

Kata Kunci: fluida nano Al_2O_3, pelat dingin, baterai kendaraan listrik, RSM-CCD.

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1. INTRODUCTION

Oil vehicles and exhaust emissions are global issues that are currently being discussed because fossil fuels have a negative influence on the environment. The emergence of electric vehicles (EVs) is very important because they use environmentally friendly energy and have lower noise levels than oil-fueled vehicles (Mahamud and Park, 2011). Long charging time, overheating of batteries, high battery manufacturing costs, safety against heating or short circuits, and limited battery life are the main problems in battery manufacturing. Battery power is critical to the development of electric vehicles, but it is influenced by temperature, so battery operation must be kept below the optimum temperature range of 15ºC to 35ºC (Chen *et al.*, 2016). The temperature of the battery increases during the charging and discharge process due to the hot energy formed during the electrochemical reaction, and this makes it important to have a management system in place to address the battery problems that govern the handling of the problem at hand. Batteries have two types of temperature management systems, internal and external, to reduce the heat generated during electrochemical reactions. Because it is easier to implement, external thermal management systems are becoming more popular. Research on external thermal management systems in battery cooling has been widely conducted, which can be categorized based on methods or techniques such as cooling research using liquid media (Imran, Mahmoud and Jaffal, 2018; Deng *et al.*, 2019; Jiang, Zhao and Rao, 2021; Jaffal *et al.*, 2023), air (Giuliano, Prasad and Advani, 2012), heat pipe (Bernagozzi *et al.*, 2023) and Phase Change Material or PCM (Al-Hallaj and Selman, 2002; Wazeer *et al.*, 2022).

The demand for battery life continues to increase as technology evolves. One way to increase the cooling system's efficiency is to replace the working fluid with a higher thermal conductivity to improve performance (Pastoriza-Gallego *et al.*, 2011; Usri *et al.*, 2015; Chiam *et al.*, 2017). The method to improve heat transfer performance is adding nanoparticles to a base liquid called nanofluid; its function as a coolant is also called nano-coolant. Nanofluid/ nano-coolants have the potential to be widely used in industries such as electronics, transportation, and manufacturing, including the automotive industry (Elias *et al.*, 2014; Subhedar, Ramani and Gupta, 2018). In 1995, the concept of nanofluids was first put forward by Choi (Choi and Eastman, 1995). Which uses water as the base fluid for the nanofluid, then metal particles or metal oxides are added to the base fluid and it is ensured that the nanoparticles are evenly dispersed and stable (Sedeh, Abdollahi and Karimipour, 2019). Previous research using nanofluids as cooling fluids in electric vehicle battery cooling systems have been conducted by Sarchami et al. (Sarchami *et al.*, 2022). Through experimental tests on 18650-type cylindrical lithium batteries, the liquid cooling system designed using ladder channels with alumina nanofluid conditions with a volume fraction of 2%, inflow velocity of 0.4 m/s, can control the peak temperature and temperature difference under the 5C charge/discharge process to stay below 305.13 K, and 2.01 K, respectively. Then Liu et al. in 2018 explore the effect of Al2O3 nanofluids on indirect liquid-based cooling systems for prismatic cell li-ion batteries with a capacity of 35Ah using straight channel cold plates simulated using ANSYS software (Liu, Chika and Zhao, 2018). Variable C-Rate 1C, 2C and 3C and nanofluids with three basic fluids: pure water, Ethylene Glycol (EG) and Engine Oil (EO). After adding Al2O3 nanoparticles, the thermal performance of water, EG and EO base fluids increased at different discharge rates (i.e. 1C, 2C and 3C), although the fluid pressure drops also increased. Adding the volume fraction of the nanoparticles can reduce the temperature rise further and the lower temperature rise inside the cell closer to the aluminium cold plate due to the better cooling effect. Research in terms of cold plate performance in electric vehicle battery cooling systems with liquid media was conducted by Deng et al. (Deng, Zhang and Ran, 2018), by performing CFD simulation comparing widened and elongated channel models on cold plates, The simulation results show that the channel layout with a long flow direction with five channels have the most efficient cooling performance.

Battery heat is a common problem, and liquid-based battery coolers are more popular than others. Water is the traditional coolant liquid, but it has a low boiling point, so ethylene glycol is typically used as a combination, but it also influences the conductivity of the liquid, so it needs to be explored further to improve the performance of the liquid as a coolant (Abdulah, Sukarman and Rajab, 2019). Based on the literature study above, there are several studies using nanofluids as coolants by adding Al2O3 nanoparticles to the base fluid. This study focuses on the optimization of nano-coolant Al2O3+EG / W using RSM-CCD and experimental tests of nanofluids to be used as coolants for electric vehicle batteries.

2. METHODOLOGY

2.1. Cooling Fluid

The fluid used in this study is nanofluid, which is a mixture of basic liquid Ethylene Glycol mixed with Distilled Water, with a ratio of 50:50 (Afrand, Abedini and Teimouri, 2017), After that, Al2O3 nanoparticles with a volume concentration of 1% were inserted. Furthermore, Stabilization/Sedimentation Observation was carried out. Al_2O_3 nanoparticles with a size of 50 nm used are produced by Hebei Suoyi New Material Technology Co. Ltd.

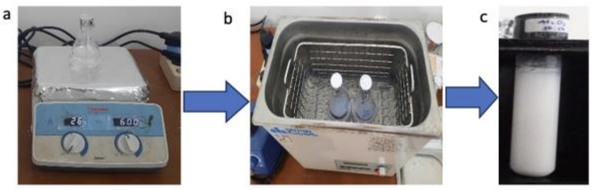

Figure 1. Nanofluid preparation process.

Figure 1 shown the preparation of Al2O3+EG/W nanofluid. The first process is to add Distilled Water (H_2O) and Ethylene Glycol (EG) in a ratio of 50:50 as the base fluid. The mixing process is carried out and stirred on a magnetic stirrer for 1 hour at room temperature with a rotation speed of 600 rpm, as seen in Figure 1a. Then added, Al_2O_3 nanoparticles with a concentration of 1% vol. Ultrasonication is performed by keeping the sample in an ultrasonic bath for one hour. The nanofluid in the tube is maintained in the ultrasonication bath without any other liquid to break the agglomeration, as illustrated in Figure 1b. The results are observed when the nanofluid is fed into the test tube (Figure 1c).

2.2. Cold Plate

The next stage is the design of a mini channel cold plate, which is a means of heat transfer. The cold plate attaches to the battery, and inside the cold plate, there is a mini channel through which nano-coolant passes. The channel is made serpentine to maximize the touch area with a heat source that is from the heat simulator of the electric vehicle battery. The plates are made of 5052 aluminium alloy with chemical elements referring to ASTM-B209, which can be seen in Table 1. The cooling plate made for the study consists of two core parts, namely the body and lid, which are connected using bolts.

Table 1. Chemical composition of aluminium alloy 5052.

Alloy	Mg	Cr	Cu	Fe
5052	2.2- 2.8	0.15- 0.35	0.10	0.40

Mn	Si	Zn	Other elemens	
			each	sum
0.10	0.25	0.10	0.05	0.15

RSM-CCD (Response Surface Methodology-Central Composite Design) analysis is carried out to obtain optimal conditions from various variations affecting nano-coolants before testing experimental test equipment. RSM-CCD analysis in this study used commercial software. Test parameters are adjusted to those in electric vehicle battery cooling systems. This is done to get operating conditions following those in the electric vehicle battery cooling system. The independent variable is the fluid flow rate. The flow rate is determined at 1 to 1.7 LPM, and the intake temperature of the Tin cooling fluid. In contrast, the response variable is the temperature on the surface of the T2 plate with the specified optimization target, namely the minimum result at T2.

Experimental test methods are carried out to obtain actual data from the cooling process on plates for batteries, testing mini channel cold

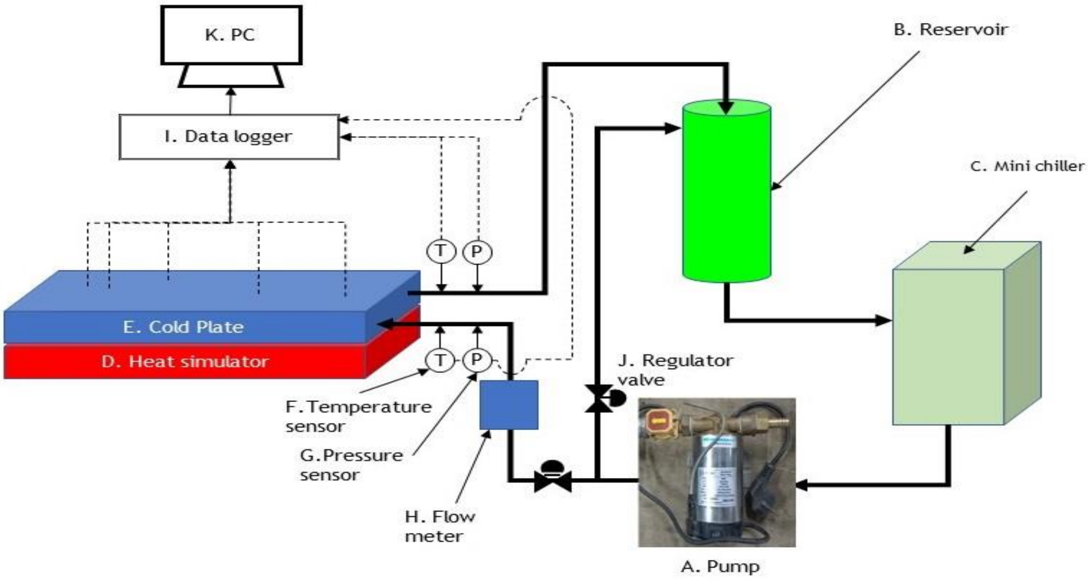

Figure 2. Scheme of experimental test equipment.

plates for forced convection heat transfer using Al_2O_3 + EG / W nano-coolant with a nanoparticle concentration of 1%, fluid flow rate variations between 1 to 1.7 LPM. The schematic of the experimental test equipment can be seen in Figure 2.

The experimental test equipment used in this study consists of several main components, namely:

A. Pump with 220V input power.
B. Reservoir with a capacity of 1.5 litres.
C. Mini Chiller.
D. The heat simulator consists of a 10mm thick aluminium plate. On this heat simulator plate, an electric heater with a power of 450 watts is installed.
E. The cold plate is made of aluminium with a length 200 mm x width 130 mm and an overall thickness of 8 mm; inside the dig-in plate is a serpentine mini channel.
F. Temperature sensor (thermocouple type K).
G. Pressure sensor.
H. Flow rate meter.
I. Data recorder (multi-channel data logger).
J. Regulator Valve.
K. Laptop.

From Figure 3 , the placement of sensor T1 is under the heat simulator plate, where there is a heater as a heat source, and the position of T2 is between the heat simulator and the cooling plate.

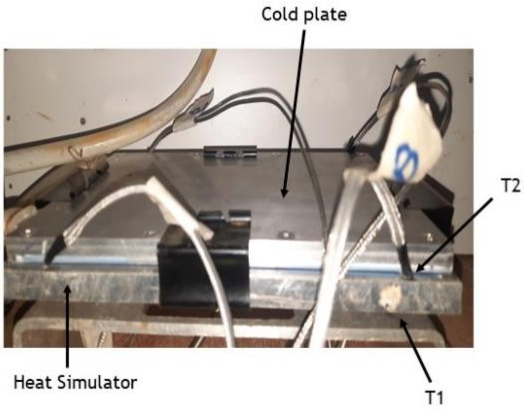

Figure 3. T1 dan T2 position at device.

3. RESULTS AND DISCUSSION

RSM-CCD analysis was carried out with two independent variables, namely flow rate and Tin intake temperature, with a minimum flow rate value of 1 and a maximum of 1.7. The response variable is T2, and the optimization process on T2 is set with a minimum value (goal). The results of the cooling optimization process for electric vehicle battery cold plates can be seen in Figure 4.

Based on Figure 4 shows that T2 decreases with increasing flow rate, it can be seen in the dark blue image that the darker the blue colour, the colder T2, and the darker the green colour, the more T2 heats, the lower the temperature, T2 this is due to the performance of the Al_2O_3 nano

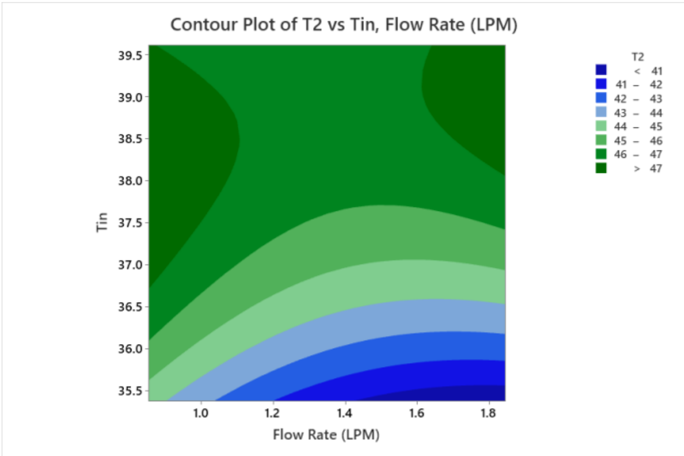

Figure 4. Contour plot.

Table 2. Temperature data of T1 and T2 test results.

Time	No-Coolant		Al_2O_3-1LPM		Al_2O_3-1.4LPM		Al_2O_3-1.7LPM	
	T1	T2	T1	T2	T1	T2	T1	T2
1.00	49.8958	45.9583	53.6042	46.2656	53.5000	46.0313	52.5677	43.0677
2.00	58.2188	51.3490	54.6458	46.5729	54.4010	46.2240	53.7760	43.5885
3.00	59.2760	53.4740	55.4688	47.0208	55.3385	46.6771	54.1198	43.8125
4.00	59.0156	54.3906	55.3906	47.0573	55.6198	46.8490	54.5885	44.2500
5.00	59.3385	55.3646	55.6875	47.2396	55.6927	47.0625	54.7292	44.5208
6.00	59.6042	56.0260	55.6771	47.3750	55.7292	47.0729	54.8854	44.7656
7.00	59.2240	56.4271	55.5625	47.4635	55.8490	47.2500	54.3906	44.8802
8.00	58.9219	56.7917	55.6823	47.5365	55.9063	47.4479	54.7656	45.2500
9.00	59.1823	57.3750	55.8177	47.7708	55.8177	47.6458	54.7188	45.5260
10.00	59.5417	58.0208	55.6875	47.8281	55.0521	47.4271	55.3958	45.9635
11.00	59.5990	58.4792	55.1094	47.7031	55.1771	47.4896	54.9792	46.1146
12.00	59.9688	58.7396	55.0573	47.7813	55.2552	47.6250	54.7865	46.1875
13.00	59.8802	59.1719	55.0781	47.8333	55.3333	47.8125	55.2135	46.5260

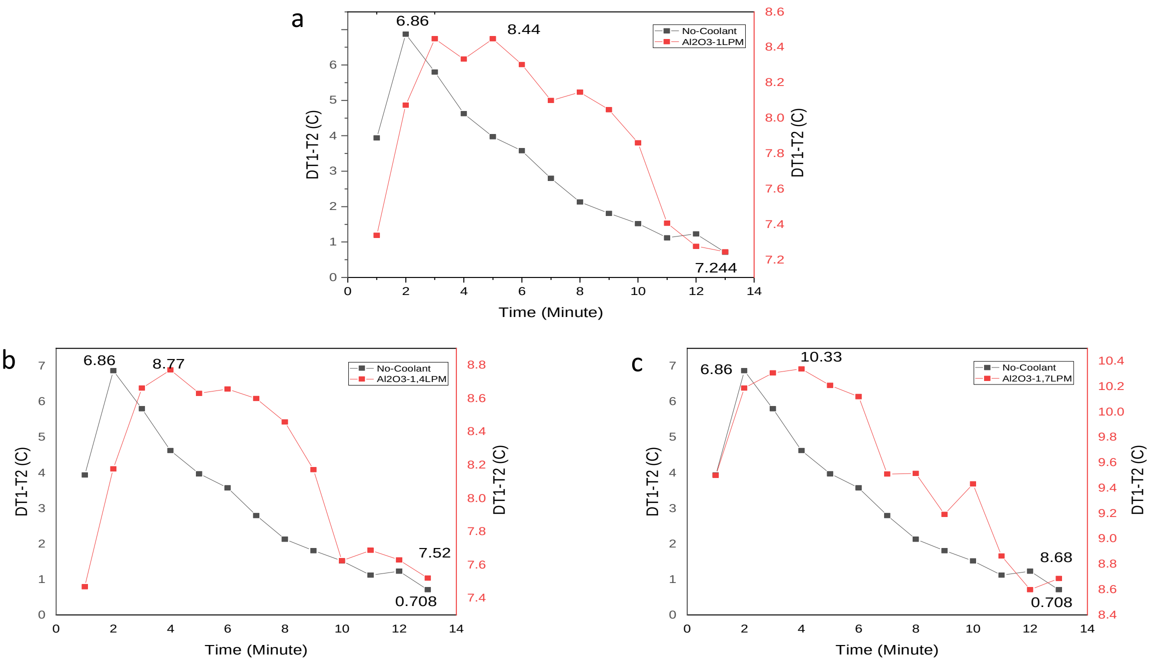

Figure 5. ΔT Graph Without Coolant and by using Al_2O_3 Nano-Coolant

coolant cooling fluid works optimally and with a high flow rate resulting in increased heat transfer because the heat that occurs on the plate is quickly absorbed and transferred quickly at high flow rates.

Electric vehicle battery heat simulator testing was carried out, and the results were observed and analyzed; four temperature sensors (thermocouples) were installed under the hot side aluminium plate, where on this side, there was an electric heater as a heat source set to 60ºC, the position on the hot side was coded T1 and on the side was coded T2.

The data logger records the readings from the sensors fitted to the experimental set-up at time intervals of every 5 seconds, the temperature data is averaged every 1 minute, and the full test results can be seen in Table 2. The results of the experiment can be seen in Figure 5.

From Figure 5, the highest temperature difference occurs when the heating process runs for 4 minutes for the process using Al_2O_3 nano cooling fluid and 2 minutes when not using coolant, then decreases afterwards. This decrease occurs because heating is limited to 60ºC for settings on the controller in the heater. Figure 5a is a graph of ΔT comparison between uncooled and ΔT using Al_2O_3 nano coolant at a flow rate of 1 LPM. Figure 5b shown a comparison graph between ΔT without coolant and ΔT using Al_2O_3 nano coolant at a flow rate of 1.4 LPM, and Figure 5c is a comparison graph between ΔT without coolant and ΔT using Al_2O_3 nano coolant at a flow rate of 1.7 LPM. From the comparison between ΔT without coolant and using coolant from various variations, the highest ΔT occurs at the flow rate using nanofluid at 1.7 LPM, which is 8.68ºC, compared to without coolant, which is 0.708ºC, this happens because the flow rate greatly influences temperature changes; the greater the flow rate, the greater the temperature difference, or the higher the heat transfer performance.

From Table 3, it can be seen that in each cooling process with a flow rate that varies from 1 to 1.7 LPM with the initial temperature, Tin process in data retrieval starts at 37ºC within 13 minutes, from the average temperature comparison between not using a coolant and using coolant in the processing time for 13 minutes, namely, Average Temperature T2 without coolant which is 54.27 ºC, at 1 LPM 47.14ºC, at 1.4 LPM 46.91ºC and the lowest at 1.7 LPM which is 44.70ºC or the highest decrease compared to without coolant which is 9.57ºC equivalent to 17.63%. From the results of a decrease in temperature at T2 in all variations in flow rate, a decrease in pressure in the channel (pressure drop) increases with the increase in flow rate. Compared to the research conducted by Subhedar et al. using Al_2O_3 + EG/W with a base fluid ratio of 50:50 for vehicle radiator coolant (Subhedar, Ramani and Gupta, 2018), these research results are lower, for a volume fraction of 0.2% and a flow rate of 4-9 LPM. The heat transfer performance increases by 30%. This is because there is a difference in the volume fraction of nanoparticles dispersed into the base fluid and a difference in the flow rate used in the research conducted for electric vehicle battery coolants using nanofluids. Likewise, Ali et al., in their research using Al_2O_3 + W nanofluid with variations in nanoparticle concentration of 0.1% to 2% in vehicle radiator applications (Ali, El-Leathy and Al-Sofyany, 2014), from the results obtained that the most optimum nanoparticle concentration is at 1% and there is an increase in heat transfer performance of 14.45 and 13.96% for the air side and nusselt number compared to the base fluid. From these results for the improvement of heat transfer performance is still better in the current study, which is 17, 63%. Where there is a slight difference in research is in the base fluid used, namely between pure water and EG / Water mixture.

Figure 6 shows the difference in T2 temperature values that occur in the process that runs 13 minutes; the lowest T2 temperature occurs during the process using Al_2O_3 coolant at a flow rate of 1.7 LPM, and the highest at a flow rate of 1 LPM where 46.52ºC and 47.833ºC are obtained respectively. The target in this experiment is to reduce the temperature at position T2 to a minimum because position T2 is a description of the heat that will be taken from the electric vehicle battery. The faster the flow rate, the higher the heat transfer from T2 will be absorbed by the fluid flowing in the cold plate.

Table 3. Temperature and pressure using Al2O3 +EG/W nano coolant.

Coolant	Flow Rate (LPM)	T1 avg (°C)	T2 avg (°C)	Pin (bar)	Pout (bar)	ΔP (bar)
No-Coolant	-	56.93	54.27	-	-	-
Al_2O_3+EG/W	1	54.82	47.14	0.37	0.03	0.34
Al_2O_3+EG/W	1.4	54.81	46.91	0.43	0.03	0.39
Al_2O_3+EG/W	1.7	54.11	44.70	0.53	0.04	0.49

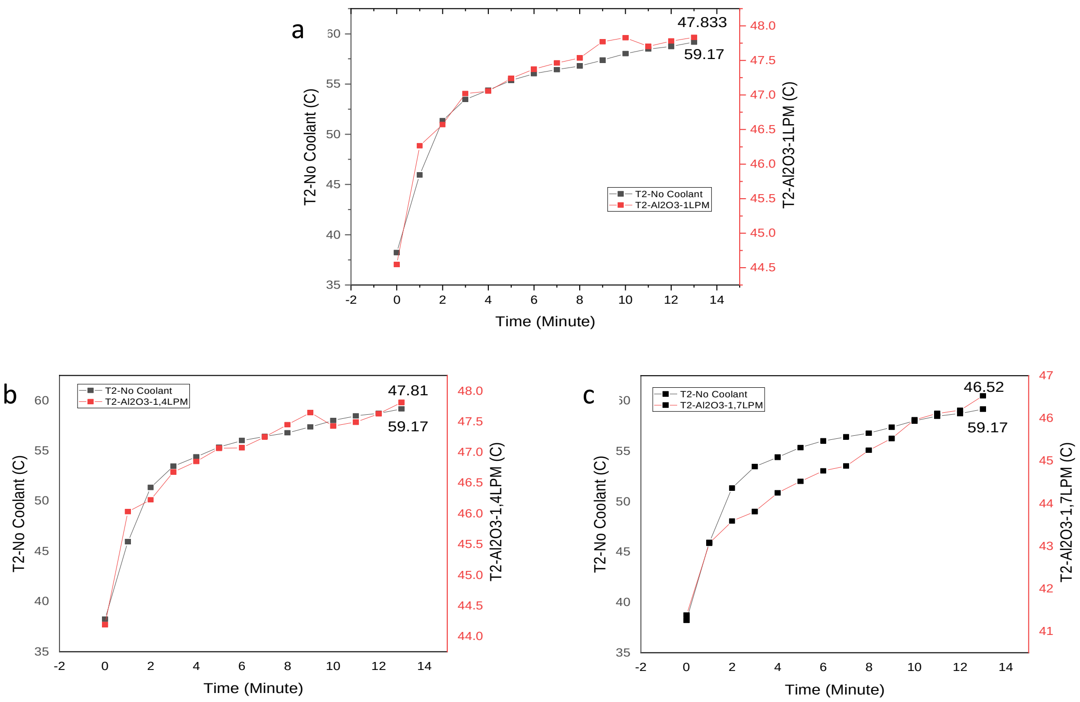

Figure 6. Temperature T2 without and using nano-coolant Al_2O_3

This condition illustrates that cooling using Al_2O_3 nanofluid at the highest flow rate of 1.7 LPM is the best with an increase of 21.37%, This result is close to the results of improving heat transfer performance in research conducted by Ouyang et al. on battery cooling applications using Al2O3 and water nanofluid, where the results of improving heat transfer performance are 23% (Ouyang *et al.*, 2023). From the overall graph, the increase in temperature is directly proportional to the increase in flow rate.

4. CONCLUSION

Research on heat transfer optimization for electriv vehicles battery cooling using nano coolant Al_2O_3 + EG/W was carried out by conducting experimental tests and optimization of RSM-CCD. Based on the test results, it can be concluded that the minimum value of T2 temperature is the desired condition in this study because the T2 temperature sensor is positioned on the desired surface. There is a decrease in temperature in electric vehicle battery applications.

Based on the results of the study, there is a decrease in the lowest T2 temperature of 17.63% occurred at a flow rate of 1 LPM and the highest T2 temperature of 13.13% at a flow rate of 1.7 LPM. The pressure drops increases with the increase in flow rate, namely the lowest ΔP of 0.34 bar and the highest of 0.49 bar.

The optimization using RSM-CCD, a match was obtained between the results of RSM-CCD and the results of experiments using test equipment, where the highest cooling fluid flow rate is the most optimal condition.

From some results in the study, improving heat transfer performance from the fluid side, namely using nano-coolant Al2O3 + EG / W in this study, can improve heat transfer performance, and cold plates for prismatic battery cell cooling can be used and function properly.

ACKNOWLEDGMENTS

Thank you to the Directorate of Research and Community Service, Directorate General of Research and Development of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for funding this research through the Beginner Lecturer Research program for the 2023 implementation year with contract number 778/PP/STT-WKN/PWK/VII/2023.

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