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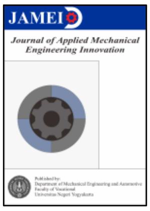

Optimization of The E-Inobus Battery Pack Cooling System Design Using The Computational Fluid Dynamic Method To Overcome Condensation

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ABSTRACT

The use of battery packs as a source of electrical energy on E-Inobus requires a cooling system, the goal is to maintain battery pack performance in optimal conditions. In its application, there are problems due to the use of a cooling system which causes an increase in air humidity inside the battery box resulting in condensation. Therefore, this study aims to obtain a design for optimizing the cooling system battery pack. This study uses the R&D method which refers to the 4D model. The subject of this research is the E-Inobus cooling system battery pack. The object of research is the development of a cooling system battery pack design to prevent condensation. Data collection was carried out to obtain data from testing the cooling system battery pack design using the Computational Fluid Dynamic (CFD) testing method to be used as input parameters in testing the cooling system battery pack optimization design. The results of the battery pack testing and the optimization of the battery pack cooling system design will later be used as control set points in the reconditioned box design. The results of this study are in the form of a reconditioned box design that has a control system. The control system is used to control air velocity and pressure, the purpose of which is to prevent condensation and to maintain fluid temperature and pressure in a balanced condition.

1 Introduction

Transportation modes in Indonesia are slowly experiencing development, one of which is the bus. Buses that initially used fossil fuels as a power source for internal combustion systems are now beginning to develop systems that use electrical energy as the main power supply for the bus's electrical system. The electrical power needed by these bus components is stored in a power storage system called a battery pack

A battery pack is a combination of several battery modules arranged and connected between the positive (+) and negative (-) poles using nickel or copper busbars to become a series circuit that can then be used to store electrical energy on a large scale; the electrical energy stored by this battery pack is what is used as the main power supply on the bus. The batteries used have a long usage cycle, are rechargeable, and have a large power storage

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capacity; however, battery performance and service life are strongly affected by operating temperature [1]. It is recommended to keep the batteries at a temperature of 15°C - 35°C and the temperature difference between battery modules at 5°C to avoid adverse effects [2]. The continuous use of batteries above normal temperatures can reduce battery performance, battery life span, and increase the percentage of battery damage. For this reason, a cooling system such as BTMS (Battery Thermal Management System) or a cooling system is needed to maintain the battery's operating temperature so that it does not exceed the normal operating temperature [3], [4].

PT. INKA (Persero) produces electric buses named E-Inobus based on renewable energy [5]. E-Inobus uses electrical energy from 5 battery packs. The battery packs are equipped with a cooling system that uses cold air from the AC located in the bus cabin; the cold air is distributed to the battery pack through a flexible hose connected to an exhaust fan.

Problems arise when the use of the cooling system sourced from the AC causes an increase in air humidity inside the battery box, leading to condensation. The effect of this condensation can cause a short circuit in the battery pack box. In addition, the operating temperature of the battery module also exceeds the maximum temperature set by the manufacturer, which is ≥40°C [6], [7].

The problems found in the cooling system of the battery pack were raised into a study to create an improvement design with the aim of optimizing the system that has been made. To overcome condensation inside the battery pack box, optimization of the battery pack cooling system is required in terms of both design and the cooling system itself. The optimized design of the battery pack box is designed using Computer Aided Design (CAD) software from Autodesk Inventor Professional 2021. The results of the created design are then tested using Computer Aided Engineering (CAE) software from Ansys Fluent (with Fluent Meshing).

This study focuses on solving the problems that occur in the battery pack cooling system design already used on the E-Inobus, with the hope that this study can provide an optimization design for the battery pack cooling system to overcome the problem of condensation.

2 Method

This study uses a research and development method that refers to the 4-D model. According to Thiagarajan et al. [8], it includes four stages of development, namely: 1) Define, 2) Design, 3) Develop, 4) Disseminate.

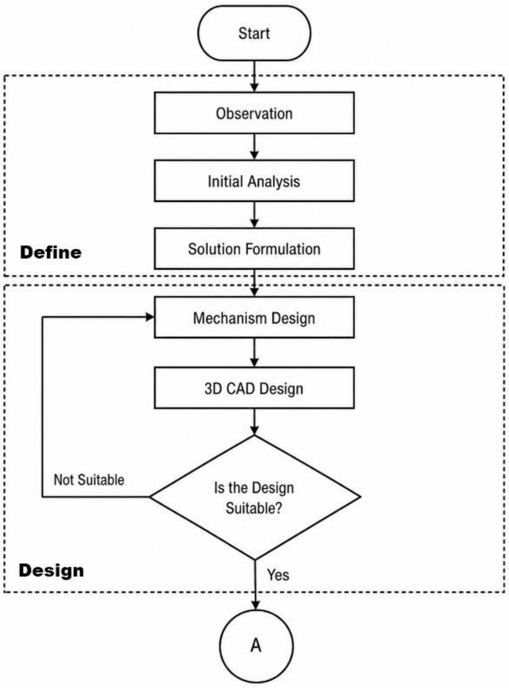

Figure 1. Research Flow Part 1 (Define and Design Stages)

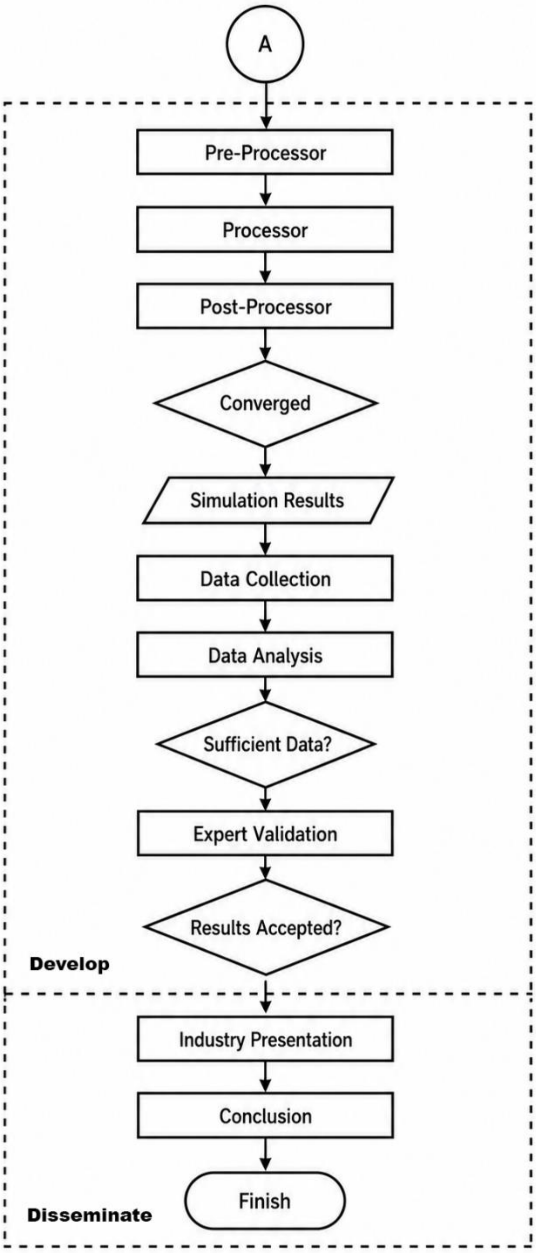

Figure 2. Research Flow Part 2 (Develop and Disseminate Stages)

During the define stage, observations and analyses were conducted to identify a problem that necessitated product development. Observations were conducted on January 18, 2023, and March 2, 2023, at Perum Damri. The results of the observation and analysis activities included: 1) The presence of water in the box battery pack (condensation), 2) The temperature of the battery module exceeded the battery's operational temperature limit (≥ 40˚C), 3) There was a current leak as evidenced by the megger test, 4) During the charging process, the cooling system did not function because the system on the E-Inobus was inactive (off). Next, solutions were formulated based on the problems that had been analyzed. These solutions included: 1) the cooling air needs to be adjusted to the battery's operating temperature so as not to cause condensation, 2) a cooling system needs to be developed to keep the battery's operating temperature below 40˚C, 3) a system needs to be added so that the battery pack cooling system remains on during charging.

The design stage begins with the design of the tool mechanism based on the solution formulated in the define stage. The tool/system design takes the form of a reconditioning box, which will be used to mix air from the outlet of the box battery pack with cooling air sourced from the air conditioner. The purpose of providing a reconditioning box is to prevent forced cooling of the battery by AC air. This reconditioning box is also equipped with an exhaust fan located at the inlet and outlet of the reconditioning box to increase the air flow from the battery pack outlet and to reduce the saturated air pressure inside the battery pack box. Next, a 3D design is created based on the mechanism design that has been made. The software used in the design stage was Autodesk Inventor 2021.

The development stage involved testing the design of the battery pack cooling system optimization using the CFD method, with the design tested using Ansys Fluent software. Based on Figure 1 in the development stage, the testing was divided into three stages: 1) Pre-Processor, 2) Processor, and 3) Post-Processor. The final data from the simulation was then analyzed to find values that met the criteria of the formulated solution.

a. Battery Specifications

The battery used is a cylindrical IFR 26650 3.2V 3600mAh battery with the following specifications:

Density : $2500\,\mathrm{kg}/m^2$
Specific Heat : $1000 J/\mathrm{kgK}$
Source Term : $713{,}239\,\mathrm{W/m^3}$
Thermal Conductivity : $3\,W/\mathrm{mK}$

b. Fluid Specifications

Based on the cooling system that has been implemented in the battery pack system, the type of fluid used is low-temperature air taken from the air conditioner system. The air has the following specifications:

Air Density : $1{,}3\,{}^{kg}/_{m^2}$
Viscosity Coefficient : $0{,}018\,x\,10^{-2}$
Specific Heat of Air : $1005 J/\mathrm{kgK}$
Thermal Conductivity : $0{,}026\,{}^{W}/_{mK}$
Heat Diffusion : $21x10^{-6}\ {}^{m^2}/_{s}$
Source Term : $5.904\ kg/(m^3\ s)$

c. Box Cooling Specifications

Fluid Temperature : $25℃ - 28\ ℃$
Inlet Velocity : $0.019\ m/s$

d. Material Specifications Box

Density : $2700\ kg/m^3$
Heat Capacity : $903\ W/kgK$
Thermal Conductivity : $273\ W/mK$

Table 1. Research Variables

Inlet Temperature (°C)	Inlet Speed (m/s)	Exhaust Fan (Pa)
25-28	2,5	6.613,76
25-28	5,0	26.455,03
25-28	7,5	59.523,81
25-28	10,0	105.820,11
25-28	12,5	165.343,92
25-28	15,0	238.095,24
25-28	17,5	324.074,07
25-28	20,0	423.280,42

3 Result and discussion

3.1 Design Results

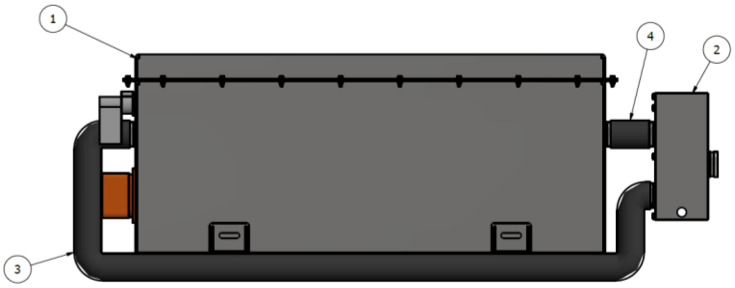

Figure 3. Assembly Optimization of Battery Pack Cooling System Design

Based on the numbering in Figure 3, the following are the names of the parts of the Assembly Optimization of Battery Pack Cooling System Design and their functions:

a. Battery Pack Box

The battery pack box design used is the original design that has been produced and installed on the E-Inobus; the use of this original design aims to minimize model changes due to production cost constraints, and to standardize the optimization model if mass production is desired later.

b. Reconditioned Box

The reconditioned box is an optimization design used to overcome the condensation problem in the battery pack. The working principle of the reconditioned box design is as a battery pack cooling air control medium, aiming to prevent forced cooling so as to minimize the possibility of condensation in the battery pack system. Control is done by adjusting the temperature and velocity of the cooling air before it enters the battery pack box. The air used as battery cooling is a mixture of AC air and internal air from the battery pack box.

c. Flexible Hose Pipe

The flexible hose pipe is the connecting channel between the reconditioned box outlet and the battery pack inlet.

d. Hose Pipe

The hose pipe is the connecting channel between the battery pack box outlet and the reconditioned box inlet.

3.2 Computational Fluid Dynamic Simulation

There are 3 main stages that must be carried out sequentially to obtain CFD simulation data, which include:

a. Pre-Processor

The pre-processor is the process carried out before conducting the simulation; the design that has been exported into STP format is then imported into the design modeler in the ANSYS software. Next, the meshing process or dividing the geometric model into small grids is carried out. The mesh method used is the Finite Volume Method with the following mesh settings [9].

Table 2. Mesh Settings

Parameter	Value
Filler	Poly-hexcore
Sizing Method	Global
Peel Layers	1
Min cell length (m)	0.004
Max cell length (m)	0.016
Parallel meshing	Yes
Polyhedral angle (deg)	30
Check Self Proximity	Yes

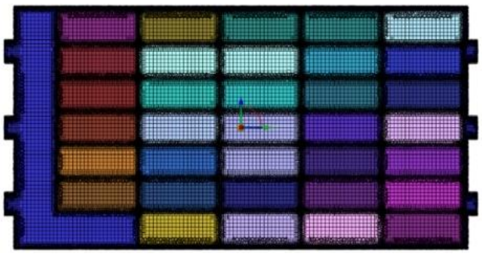

Figure 4. Mesh Assembly Box Battery Pack

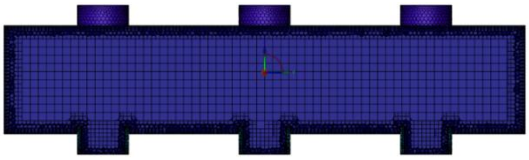

Figure 5. Mesh Assembly Reconditioned Box

b. Processor

The processor is the stage for setting up and inputting CFD simulation parameters in Ansys Fluent. This stage aims to provide settings for the test model for solving CFD problems, as well as entering specification data for fluids and components according to their domains. The settings provided for the test model and the input of domain specification data are shown in Table 3 and Table 4:

Table 3. CFD Testing Model Settings

Parameter	Value
Model	K-epsilon
K-epsilon Model	RNG
Near Wall Treatment	Non-Equlibrium Wall Treatment
Energy	On
Time	Steady
Velocity Vormulation	Absolute

Table 4. CFD Testing Model Settings

Material	Property	Value
Air	Density (kg/m3)	1.3
	CP (J/(kg K))	4128
	Thermal Conductivity (w/(m K))	0.026
	Viscosity (Kg/(m s))	0.00018
Aluminum	Density (kg/m3)	2700
	CP (J/(kg K))	903
	Thermal Conductivity (w/(m K))	237

Material	Property	Value
Battery	Density (kg/m3)	2500
	CP (J/(kg K))	1000
	Thermal Conductivity (w/(m K))	3
	Source Term (W/m3)	713.239

c. Post-Processor

The post-processor stage is the stage for displaying the simulation data that has been carried out in the previous stage. The data displayed is in the form of contours, pathlines, and simulation result values based on predetermined report definitions. The CFD simulation data results are shown in Table 5, the visual contour of the battery module temperature is shown in Figure 6, the visualization of the battery pack box air flow is shown in Figure 7, and the visualization of the reconditioned box air flow is shown in Figure 8:

Table 5. CFD Testing Model Settings

No.	Temperature Inlet (°C)	Air velocity		Battery temperature (°C)		Pressure (Pa)		Temperature Outlet (°C)	Total Heat Transfer (W)
		Inlet (m/s)	Exhaust-Fan (Pa)	Min	Max	Ave	Max		
1	25	2.5	6613.76	26.22	40.39	9.84	24.98	35.84	8.20
2	26			27.21	41.22	9.84	24.98	36.67	9.78
3	27			28.19	42.04	9.84	24.98	37.49	11.37
4	28			29.18	42.87	9.84	24.98	38.32	12.96
5	25	5.0	26455.03	24.76	37.11	23.31	47.24	33.35	4.10
6	26			25.62	37.98	23.31	47.24	34.22	5.77
7	27			26.41	38.86	23.31	47.24	35.08	7.44
8	28			27.25	39.73	23.31	47.24	35.95	9.12
9	25	7.5	59523.81	23.39	35.96	38.81	89.12	32.05	2.41
10	26			24.88	36.83	38.81	89.12	32.94	4.11
11	27			25.58	37.69	38.81	89.12	33.82	5.82
12	28			26.74	38.55	38.81	89.12	34.71	7.53
13	25	10.0	105820.11	23.46	35.64	106232.40	106318.20	31.13	1.44
14	26			24.08	36.51	106232.40	106318.20	32.03	3.19
15	27			24.96	37.38	106232.40	106318.20	32.93	4.90
16	28			26.26	38.26	106232.40	106318.20	33.83	6.64
17	25	12.5	165343.92	22.68	35.32	165951.80	166082.20	30.43	0.81
18	26			23.84	36.12	165951.80	166082.20	31.35	2.56
19	27			24.33	36.99	165951.80	166082.20	32.26	4.29
20	28			25.41	37.86	165951.80	166082.20	33.17	6.07
21	25	15.0	238095.24	22.51	34.94	238934.50	239118.60	29.87	0.36
22	26			23.46	35.76	238934.50	239118.60	30.79	2.12
23	27			23.38	37.04	238934.50	239118.60	31.71	3.86
24	28			25.51	37.89	238934.50	239118.60	32.63	5.64
25	25	17.5	324074.07	23.09	34.89	325178.90	325426.20	29.40	0.06
26	26			23.35	35.47	325178.90	325426.20	30.33	1.80
27	27			24.20	36.99	325178.90	325426.20	31.26	3.56
28	28			25.10	37.69	325178.90	325426.20	32.19	5.31
29	25	20.0	423280.42	22.79	34.42	424685.40	425005.20	29.01	-0.18
30	26			23.17	35.90	424685.40	425005.20	29.94	1.50
31	27			23.59	36.30	424685.40	425005.20	30.88	3.24
32	28			24.71	37.58	424685.40	425005.20	31.81	5.05

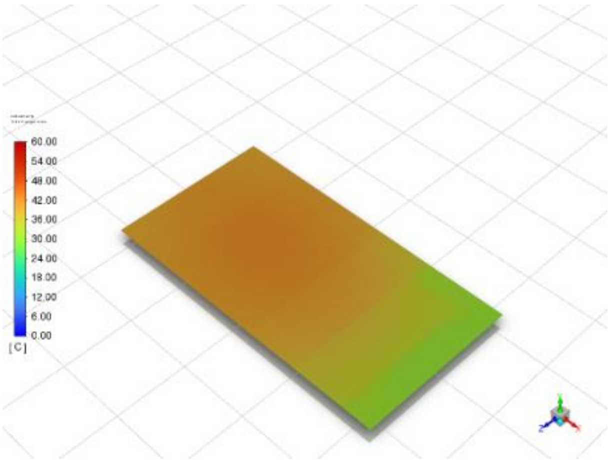

Figure 6. Temperature contour of the battery module

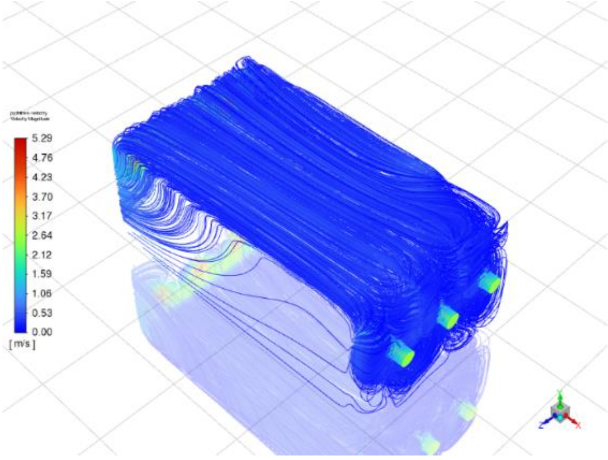

Figure 7. Airflow pathline of the battery pack box

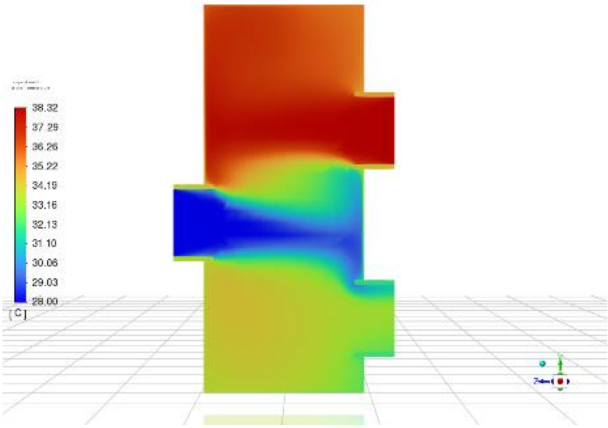

Figure 8. Temperature contour of the reconditioning box

3.3 The Effect of Cooling Temperature Variations

The effect of cooling-air temperature was analyzed to determine the most effective cooling condition. The cooling medium used in the battery pack is air supplied from the cabin air-conditioning system. Therefore, inlet temperature variations of 25°C, 26°C, 27°C, and 28°C were applied at the reconditioning-box inlet. Table 6 summarizes the effect of the cooling temperature variation on battery operating temperature.

Table 6. CFD Testing Model Settings

Temperature inlet (°C)	Velocity (m/s)	Average	Maximum
25	2.5	26.22	40.39
26		27.21	41.22
27		28.19	42.04
28		29.18	42.87

3.4 The Effect of Air Flow Velocity Variation on Pressure

In the overall cooling system design, other factors must be considered such as determining the cooling air flow velocity set point, the air pressure inside the box, and the outlet air flow velocity by the exhaust fan. In determining the velocity set point, a simulation was carried out with variations in cooling air velocity in the inlet domain with values of 2.5 m/s, 5.0 m/s, 7.5 m/s, 10.0 m/s, 12.5 m/s, 15.0 m/s, 17.5 m/s, and 20.0 m/s. The simulation results table with air velocity variations is shown in Table 7:

Table 7. Effect of Air Flow Velocity Variation on Pressure

Velocity (m/s)	Pressure Inlet (Pa)	Box Pressure (Pa)	Pressure Outlet (Pa)
2.5	6250	6274.33	6613.76
5.0	25000	25091.35	26455.03
7.5	56250	56450.4	59523.81
10.0	100000	100338.3	105820.11
12.5	156250	156783.9	165343.92
15.0	225000	225777.6	238095.24
17.5	306250	307318.5	324074.07
20.0	400000	401428.9	423280.42

3.5 The Effect of Air Flow Velocity Variation on Battery Operating Temperature

The battery temperature drop is affected by flow velocity, surface area, and fluid density [3], [4], [9]. This indicates that the relationship between air flow velocity and battery operating temperature is inversely proportional, where the higher the air flow velocity, the lower the battery operating temperature range [4]. In the simulations performed, variations in air flow velocity were given at 2.5 m/s, 5 m/s, 7.5 m/s, 10 m/s, 12.5 m/s, 15 m/s, 17.5 m/s, and 20 m/s.

Table 8. Effect of Airflow Velocity Variation on Battery Operating Temperature

Temperature inlet (°C)	Air Velocity (m/s)	Battery Temperature	
		Ave	Max
2.5	26.22	40.39	2.5
5.0	24.76	37.11	5.0
7.5	23.39	35.96	7.5
10.0	23.46	35.64	10.0
12.5	22.68	35.32	12.5
15.0	22.51	34.94	15.0
17.5	23.09	34.89	17.5
20.0	22.79	34.42	20.0

In the simulation results with air velocity variations, the battery's operational temperature value will be lower if a high cooling air velocity is provided. This is due to a faster heat transfer process so that it is able to lower the battery temperature even with the same cooling temperature value.

At an airflow velocity of 5 m/s, the battery operating temperature range was 24.76°C to 37.11°C. At 10 m/s, the temperature range decreased to approximately 23.46°C to 35.65°C. Compared with the maximum allowable operating temperature, the optimized cooling design can reduce the battery operating temperature by about 5°C. Condensation risk is also affected by saturated air pressure; therefore, airflow distribution was improved by increasing inlet velocity using a fan booster and outlet velocity using an exhaust fan. Figures 9 and 10 compare the airflow pathlines at 2.5 m/s and 20.0 m/s.

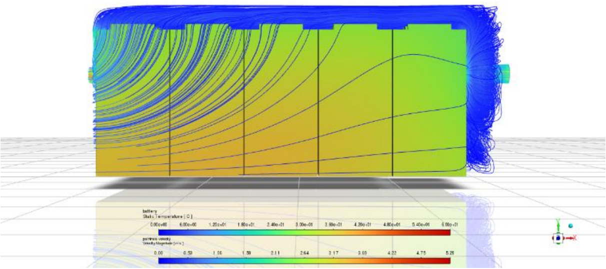

Figure 9. Battery pack pathline at 2.5 m/s

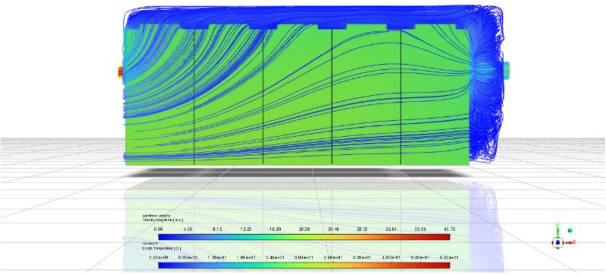

Figure 10. Battery pack pathline at 20.0 m/s

3.6 Analysis of Battery Pack Cooling System Parameter Set Points

Set points are used as input parameters in the reconditioned box design. These set points were obtained after selecting data that has values below the predetermined parameters, the goal being to avoid the possibility of condensation as well as to suppress the battery operating temperature below 40°C. The parameter used in this data selection process is the dew point, with a value of 31.5°C [6], [7]. The dew point value is used as the maximum limit for selecting data taken from the battery pack box outlet.

Table 9. Set-point data

Temperature inlet (°C)	Air Velocity		Battery Temperature	
	Inlet (m/s)	Exhaust Fan (Pa)	Ave	Max
25	10.0	105820.11	23,46	35,64
25	12.5	165343.92	22,68	35,32
26			23,84	36,12
25	15.0	238095.25	22,51	34,94
26			23,46	35,76
25	17.5	324074.07	23,09	34,89
26			23,35	35,47
27			24,20	36,99
28			25,10	37,69
25	20.0	423280.42	22,79	34,42
26			23,17	35,90
27			23,60	36,30
28			24,71	37,58

Based on the calculation results, it was found that with a heat transfer of 0.853 W/(m2 K), an inlet temperature of 26.5°C and an outlet temperature of 30°C were obtained with a total heat transfer value of 0.744 W. By comparing the calculation results and the reconditioned box simulation, the cooling system optimization design will reach ideal conditions at an air flow velocity of 12.5 m/s with an inlet temperature of 25°C. With these values, a battery operational temperature range of 22.68°C - 35.32°C, an outlet temperature of 30.43°C, and a total heat transfer of 0.805 W were obtained. From this comparison, an error value of 1.1% for the inlet temperature and 1.4% for the outlet temperature was obtained.

4 Conclusion

The optimized design of the battery pack cooling system uses a reconditioned box equipped with a control system that can regulate the cooling air flow velocity, as well as the cooling temperature regulated through the reconditioned box. With cooling regulation by the reconditioned box, the battery pack cooling system can prevent the possibility of condensation and achieve ideal cooling conditions based on the set point values obtained through CFD simulations on the optimized battery pack cooling system design.

The 3D model design for optimizing the battery pack cooling system uses a reconditioned box containing 9 fans and 2 solenoid valves. The use of fans in the reconditioned box aims to increase the velocity of the cooling air flow, reducing saturated air pressure in the box so that the cooling fluid does not reach the dew point value.

The results of optimizing the cooling system design using the Computational Fluid Dynamic (CFD) testing method show that increasing the air flow velocity is an effective method to lower the maximum working temperature of the LiFePo4 battery. However, in determining the set point to prevent condensation by considering the dew point value, ideal cooling conditions are obtained at an air flow velocity of 12.5 m/s with an inlet temperature of 25°C. By applying the optimized design of the battery pack cooling system, the working temperature of the module battery can be lowered, resulting in a working temperature range of 22.68°C - 35.32°C, or 5°C below the maximum temperature (40°C).

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Conflicts of Interest

The authors no conflict of interest.

References

[1] D. Linden and T. B. Reddy, *Linden's Handbook of Batteries*, 4th ed. New York: McGraw-Hill, 2011.

[2] A. Pesaran, "Addressing the Impact of Temperature Extremes on Large Format Li-Ion Batteries for Vehicle Applications," *30th International Battery Seminar*, 2013.

[3] L. Merinda, "Analisis Manajemen Termal Pada Sistem Pendingin Sel Baterai Li-Ion Bentuk Prismatik Dengan Variasi Laju Aliran Massa Dan Lebar Channel Menggunakan Metode Computational Fluid Dynamics (CFD)," Surabaya, 2017. [Online]. Available: https://repository.its.ac.id/47164/1/2413100046-Undergraduate_Thesis.pdf

[4] R. Mahamud and C. Park, "Reciprocating air flow for Li-ion battery thermal management to improve temperature uniformity," *J. Power Sources*, vol. 196, no. 13, pp. 5685–5696, Jul. 2011, doi: 10.1016/j.jpowsour.2011.02.076.

[5] PT INKA (Persero), "Berita INKA - Tim Perawatan Bus Listrik E-Inobus Di Balik Suksesnya Transportasi Hijau pada G20." Accessed: Apr. 10, 2023. [Online]. Available: https://www.inka.co.id/berita/903

[6] L. Vyskocil, J. Schmid, and J. Macek, "CFD simulation of air–steam flow with condensation," *Nuclear Engineering and Design*, vol. 279, pp. 147–157, Nov. 2014, doi: 10.1016/j.nucengdes.2014.02.014.

[7] E. N. Slobodina and A. G. Mikhailov, "The Analysis of the Condensation Process Impact on the Vacuum Boiler Operating Efficiency," *Procedia Eng.*, vol. 152, pp. 395–399, 2016, doi: 10.1016/j.proeng.2016.07.720.

[8] Thiagarajan, Semmel, and Semmel, "Thiagarajan, Sivasailam; And Others Instructional Development for Training Teachers of Exceptional Children: A Sourcebook. Indiana Univ., Bloomington. Center for Innovation in," *Research and Development*, no. Mc, 1974.

[9] Y. A. Çengel and J. M. Cimbala, *Fluid Mechanics: Fundamentals and Applications*, 4th ed. New York: McGraw-Hill Education, 2017.