Optimize Thermal Management And Experiment Of Lifepo4 Battery Pack For Hybrid Electrical Vehicle

Abdul Muchlis[1*], Moh. Yamin[2]

[1,2] Fakultas Teknologi Industri Universitas Gunadarma, Jawa Barat Indonesia
[*]Corresponding author:
Email: muchlis07@staff.gunadarma.ac.id

Abstract.
Hybrid Electric Vehicles (HEV) combines the benefits of gasoline engines and electric motors which can be configured for improving fuel efficiency. Lithium Iron Phosphate (LiFePO4) Phosphate based technology possesses superior thermal and chemical stability which provides better safety characteristics than those of Lithium-ion technology made with other cathode materials. This research conducted by two methods , methods of part 1 is a comparison of the results with the thermal management simulation and experiment, part 2 is a method of optimizing the thermal management for battery pack by using solidwork software. When the fan is on, the forced air flow over the cells removes some of the generated heat. Results of method part 1 is simulation more heat than experiment in the amount of 0.11% – 1.56%. The results of the method part 2 is simulated using the fan 4 fan with a speed of 415 rad/s and battery gap 30mm most efficient compared with 4 fans the other , while the simulation using 6 fan, fan speed 415 rad/s and battery gap 30mm most efficient for all.

Keywords*: Battery, Simulation, Temperature*

I. INTRODUCTION

At industry world incesstanly to do research for energy alternative. In special to motor vehicle that use fossil fuel. It is to produce emission pollution, so that goverment and indutry automobile to cooperate for to obtain solution this problem, exactly to reduce emission pollution. If project to success to appoint to reduce consumtion fossil fuel. Many method for reduce consumtion fossil fuel and alternative power, either one is combination internal combustion engine (ICE) or conventional engine and electrical vehicle.This is to produce power and energy kinetic. The power to continue at wheel. The electrical vehicle have advantage, either one not produce emission air when energy electric to change energy kinetic. Because temperature battery to change high. It is to reduce performa in electrical vehicle. So, it is need management battery for control temperature battery. Battery is cooled by fan, that function is control temperature battery.Problem in the research is management temperature in battery for hybrid electrical vehicle(HEV). This is very important to battery perform. This research use fan, this fan to produce wind force to control battery temperature HEVs. Research Objective is analyze comparison solidwork and experiment and margin error for 1 batttery at charge and discharge situation and effect battery gap, fan velocity and numbers fans with cooling system.

II. METHODS

This research presents thermal management of battery packs in hybrid electric vehicle (HEVs) to maximize pack performance. A battery pack type on this research is LiFePO4 HP-PW-100AH hybrid vehicle system in Toyota Soluna. Configurations system battery is series, capacity battery is 3.65 voltage of single cells. This research was conducted by comparing simulations and experiments on single batteries, not only that this study is also to seek optimization gap, numbers fan and fan speed in the battery pack cooling system with a number of batteries 15 pieces.

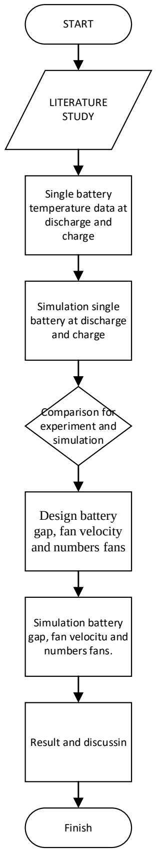


Fig 1. Flowchart

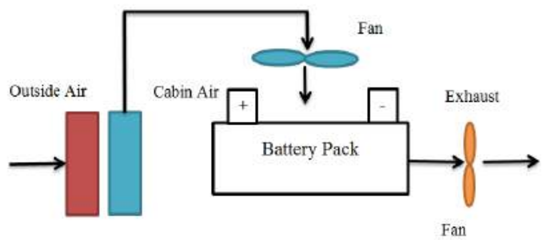


Fig 2. Cooling system thermal management

Experiments conducted on three conditions, namely battery charging 45ºC, 50ºC and 60ºC discharging. The observation point there are 36 points on the surface of the battery, which consists of 6 columns and 6 rows. Just as the figure below:

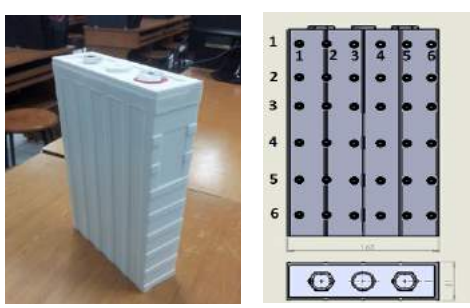


Fig 3. Observation point

Table 1. Battery specifications

Spesifikasi Battery	HP-PW-100AH
Charge Voltage	3.65 V
Discharge Voltage	3.2 V
Nominal Capacity	100 AH
Dimension (L*W*H) (mm)	163 x 51 x 278
Weight	3.4 kg

Temperature Charging	0-45℃
Temperature Discharging	0-60℃

Optimation Battery Gap

To search for the optimization of the battery cooling system, performed with distinction at the gap batteries, that is 10mm, 20mm and 30mm

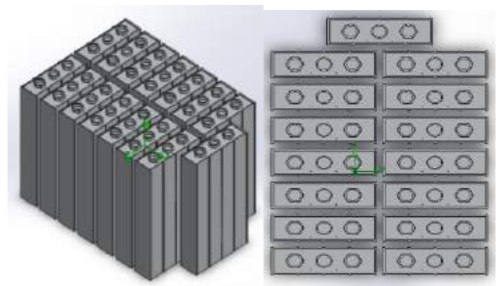


Fig 2. Battery gap 10 mm

Optimize fan arrangement

Cooling by increasing the number of fans to seek optimization of the number of fan with battery gap.

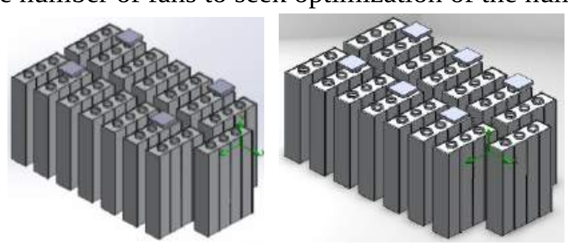


Fig 3. Fan arrangement 4 and 6 pieces

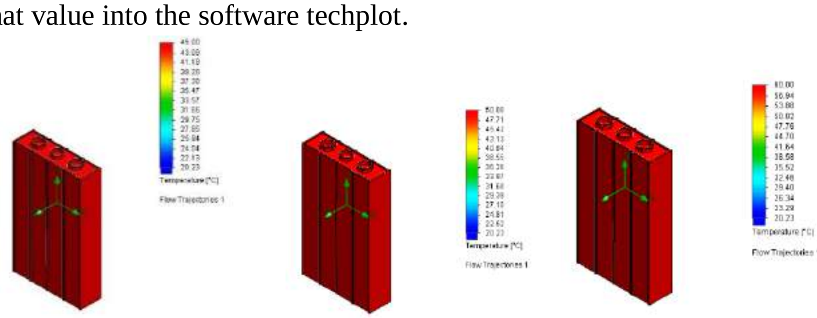
Optimize Fan Speed

Fan speed to seek optimization of cooling the battery gap and the number of fans. The simulation used two types of fans, that is:

1. Axial, comoir Rotron, AC, FA/B-50Hz with Rpm 296.45129 rad/s.
2. Axial, comoir Rotron,DC, FNxxK3 with Rpm 415.21384 rad/s.

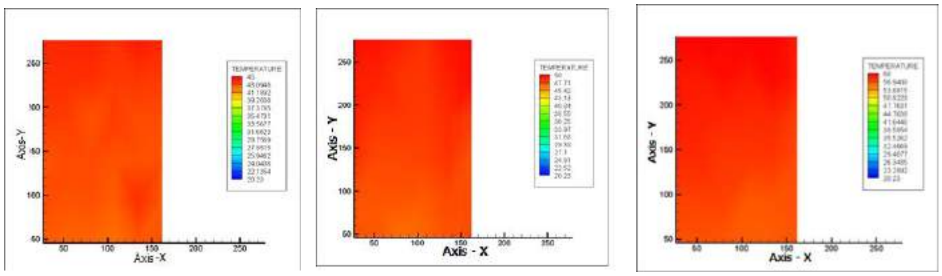
Result And Discussion Experimental And Simulation single battery

Results of the experiment compared with solidwork software, it aims to solidwork effectiveness of the experiment. Experiments performed with a single battery at temperatures of 45ºC battery (charging), 50°C (discharging) and 60°C (discharging). data collection in the experiment takes the temperature at each reservation point and enters that value into the software techplot.



a b c

Fig 4. Simulation of Solidwork software without fan (a) 45^{O}C, (b) 50^{O}C and (c) 60^{O}C.



a b c

Fig 5. Experiment temperature with Techplot 360 without fan (a) 45^{O}C, (b) 50^{O}C and (c) 60^{O}C.

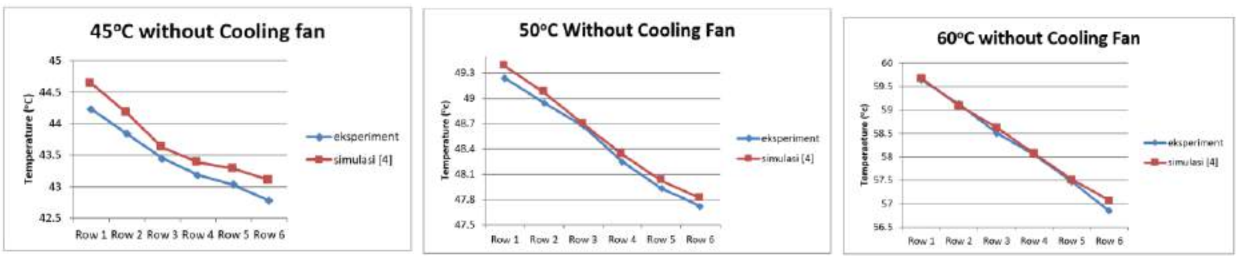


Fig 6. Comparison of experimental method with simulated temperature without cooling fan at 45^{0}C, 50^{0}C, 60^{0}C

Experiments and Simulations of Temperature With Cooling Fan.

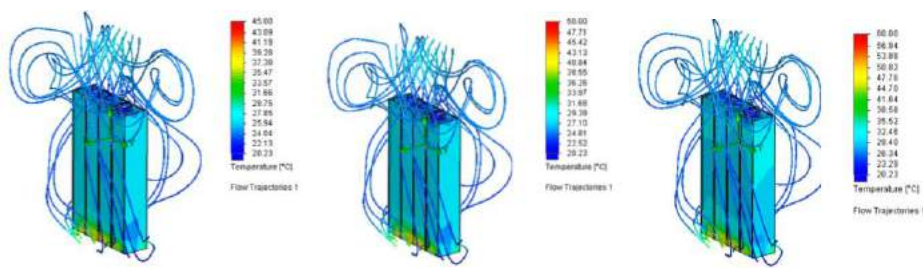


Fig 7. Simulation of Solidwork software with fan (a) 45^{0}C, (b) 50^{0}C, (c) 60^{0}C

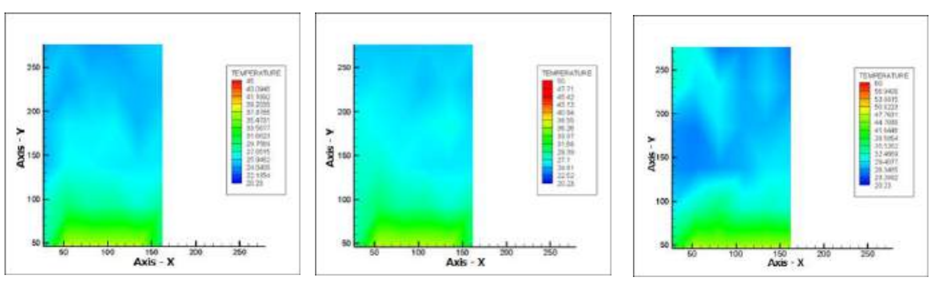


Fig 8. Experiment temperature with Techplot 360 with fan (a) 45^{0}C, (b) 50^{0}C, (c) 60^{0}C

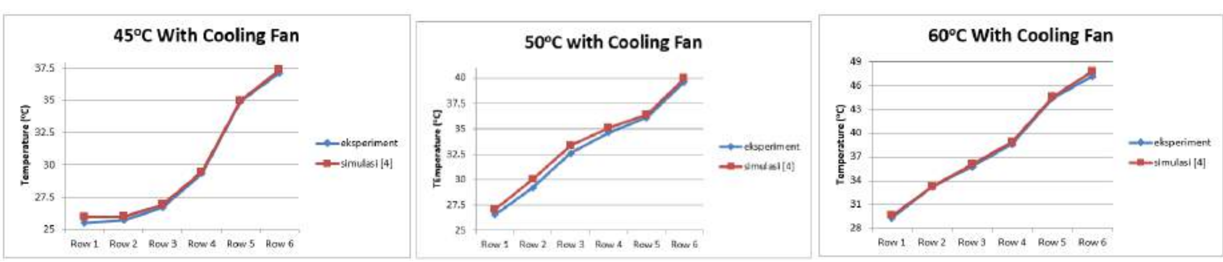


Fig 9. Comparison of experimental method with simulated temperature with cooling fan at (a) 45^{0}C, (b) 50^{0}C, (c) 60^{0}C

Comparison Management Thermal at 45^{o}C (charging), 50^{0}C, 60^{0}C (Discharging)

Table 2. Comparison of temperature 45°C

Method	Thermal Test (ºC)	Fan Status	Temperature (ºC)	Average (ºC)
Experiment	45	off	43.09 - 44.94	43,417
Simulation	45	off	43.10 - 45.00	43,701
Experiment	45	on	25.00 - 37.68	29,884
Simulation	45	on	25.90 - 37.58	30,126

Tabel 3. Comparison of temperature at 50^{o}C (Discharging)

Method	Thermal Test (ºC)	Fan Status	Temperature (ºC)	Average (ºC)
Experiment	50	off	47.00 - 49.90	48,462
Simulation	50	off	47.10 - 50.00	48,555
Experiment	50	on	25.65 - 39.36	33,110
Simulation	50	on	26.05 - 39.78	33,635

Table 4. Comparison of temperature 60°C (Discharging)

Method	Thermal Test (ºC)	Fan Status	Temperature (ºC)	Average (ºC)
Experiment	60	off	56.23- 59.80	58,270896
Simulation	60	off	56.82 - 60.00	58,33875
Experiment	60	on	28.34 - 47.78	38,056042
Simulation	60	on	29.40 - 47.93	38,336667

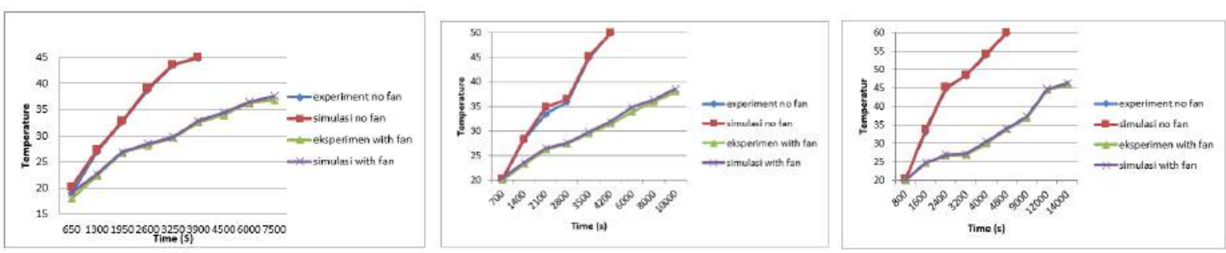


Fig 10. Comparison thermal management (a) 45^{0}C, (b) 50^{0}C, (c) 60^{0}C

Figure 10 show the effectiveness of the cooling system at the time of charging at 45^{0}C. In the experiments without the cooling system, battery temperature at 45^{0}C While using the cooling system, the temperature reached 37.68^{o}C, battery temperature up to 50^{0}C. While using the cooling system, the temperature reached 39.36^{o}C and battery temperature up to 60^{0}C. While using the cooling system, the temperature reached 47.78^{o}C.This research was conducted to look for optimization of thermal management of the battery pack. Research carried out by solidwork software, with the difference in battery gap of 10mm, 20mm and 30mm, the fan speed and the number of fans.

Simulation with fan velocity 415.21384 rad/s and space 30mm

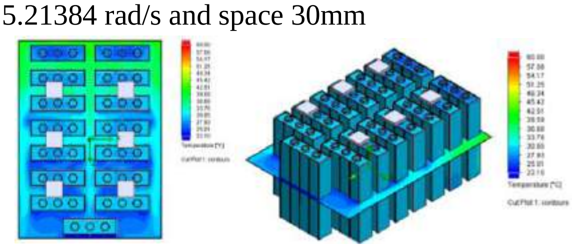


Fig 11. Simulation With 6 Fans, Battery Gap 30mm, Full Speed

In figure 11 shows the fan cools the battery evenly, this is due to the distance 30mm and the fan speed is high rpm. In the figure average temperature of the battery is 25.01 – 39.59ºC

Simulation with 4 cooling fan.

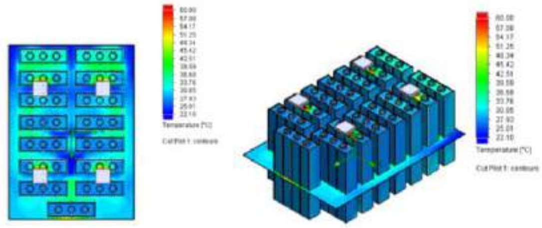


Fig 12. Simulation With 4 Fans, Battery Gap 30mm, Full Speed

In figure 12 shows the fan cools the battery evenly, this is due to the distance 30mm and the fan speed is high enough. Uneven temperature distribution of the fluid so that at the edges of the higher battery temperature. This is due to the amount of fan 4 pieces with a distance of 30mm. In the Figure the average temperature of the battery is 29.54 - 43.38oC.The picture shows the battery temperature is different, but using 6 fan fluid temperature distributions is more evenly distributed compared to 4 fans. The use of more efficient fan 6 for a distance of 30mm with fan speed 415.21384 rad/s with temperature 25.01 – 39.59 oC

Simulation with fan velocity 296.45129 rad/s and space 30mm

Simulation with 6 cooling fan.

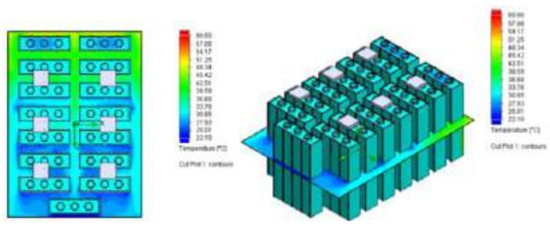


Fig 13. Simulation With 6 Fans, Battery Gap 30mm, Normal Speed

In figure 13 shows the fan cools the battery with a uniform, but the uneven distribution of the fluid temperature is visible on the edge of the battery, this is due to the distance battery 30mm and low fan speed. In the Figure the average temperature of the battery is 25.01 – 42.51ºC

Simulation with 4 cooling fan.

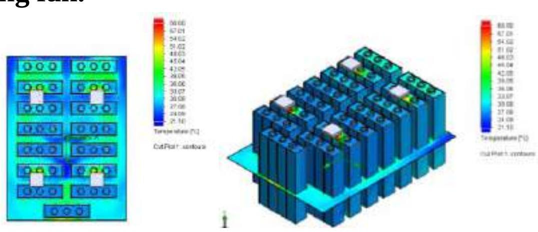


Fig 14. Simulation With 4 Fans, Battery Gap 30mm, Normal Speed

In figure 14 shows the fan cools the battery with a uniform, but the uneven distribution of the fluid temperature is seen in the center of the battery, this is due to the distance to the other battery 1 30mm and low fan speed. In the Figure the average temperature of the battery is 29.54 - 43.38ºC. The picture shows the battery temperature is not much different, but using 6 fan fluid temperature distribution is more evenly distributed compared to 4 fan. The use of more efficient fan 6 for a distance of 30mm with fan speed 296.45129 rad/s with temperature 25.01 – 42.51 oC

Simulation with fan velocity 415.21384 rad/s and space 20mm

Simulation with 6 cooling fan.

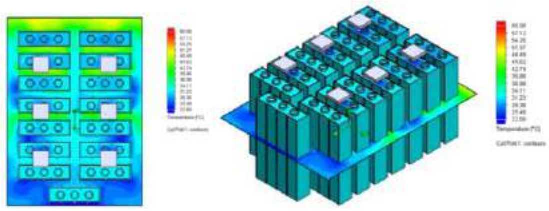


Fig 15. Simulation With 6 Fans, Battery Gap 30mm, Full Speed

In figure 15 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 30mm, while the uneven distribution of the fluid temperature is visible on the edge of the battery. Turbulent fluid flow is experiencing is due within one another battery of 20mm and high fan speeds. In the Figure the average temperature of the battery is 25.48 – 39.59oC

Simulation with 4 cooling fan.

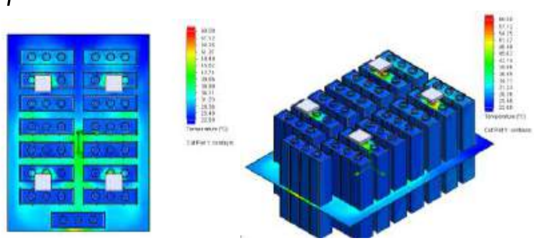


Fig 16. Simulation With 4 Fans, Battery Gap 30mm, Full Speed

In figure 16 shows the fan cools the battery with a uniform and cooler than using a 6 fan while the uneven distribution of the fluid temperature is seen in the middle and edge of the battery. The experience turbulent fluid flow smaller than 6 fan. it is due within one another battery of 20mm and high fan speeds. In the Figure the average temperature of the battery is 28.36 - 42.74°C.

Simulation with fan velocity 296.45129 rad/s and space 20mm

Simulation with 6 cooling fan

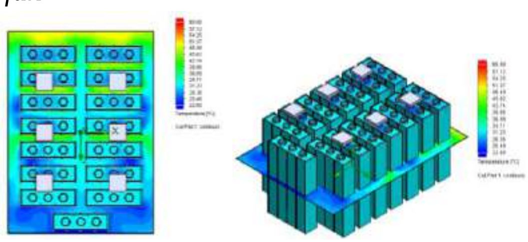


Fig 17. Simulation With 6 Fans, Battery Gap 30mm, Normal Speed

In figure 17 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 30mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the Figure the average temperature of the battery is 25.48 – 42.74 °C.

Simulation with 4 cooling fan

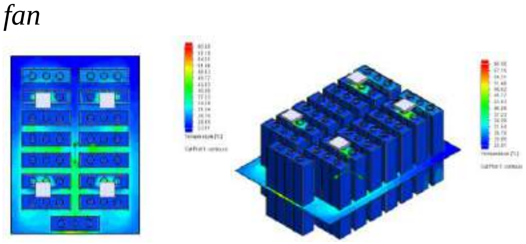


Fig 18. Simulation With 4 Fans, Battery Gap 30mm, Normal Speed

In figure 18 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 30mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the figure the average temperature of the battery is 28.70 - 42.93 ^{o}C.

Simulation with fan velocity 415.21384 rad/s and space 10mm

Simulation with 6 cooling fan

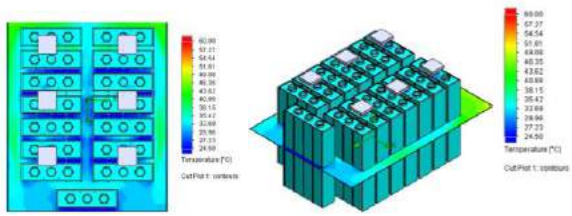


Fig 19. Simulation With 6 Fans, Battery Gap 30mm, Full Speed

In figure 19 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 20mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the figure the average temperature of the battery is 27.23 – 40.88 ^{o}C.

Simulation with 4 cooling fan

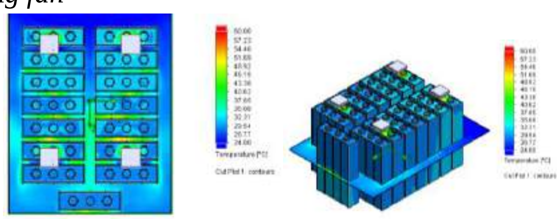


Fig 20. Simulation With 4 Fans, Battery Gap 30mm, Full Speed

In figure 20 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 30mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the Figure the average temperature of the battery is 31.34 - 43.38 ^{o}C. The space simulation with battery 10mm with fan speed 415.21384 rad/s, the use of 4 fan more effective.

Simulation with fan velocity 296.45129 rad/s and space 10mm

Simulation with 6 cooling fan

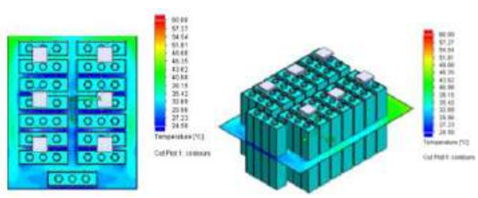


Fig 21. Simulation With 6 Fans, Battery Gap 30mm, Normal Speed

In figure 21 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 20mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the Figure the average temperature of the battery is 27.23 – 43.62 ^{o}C.

Simulation with 4 cooling fan

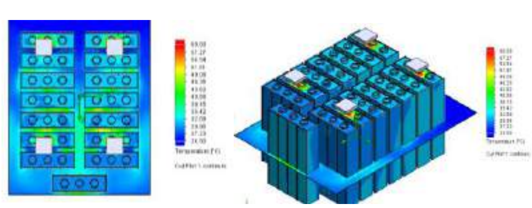


Fig 22. Simulation With 4 Fans, Battery Gap 30mm, Normal Speed

In figure 22 shows the fan cools evenly battery, but the battery temperature higher than the battery space of 20mm, and fan speed and uneven distribution of the fluid temperature is seen in the middle and edge of the battery. In the figure the average temperature of the battery is 29.96 - 43.62oC. In the space simulation with battery 10mm with fan speed 296.45129 rad/s, the use of 4 fan more effective.

Comparison management thermal

Tabel 6. Comparison management thermal with battery gap 30mm

Battery Gap (mm)	Fan	Fan velocity rad/s	Temperature (ºC)	Average (ºC)
30	6	415	25.11-38.79	32.607
30	4	415	27.34 - 39.18	35.309
30	6	296	25.41 - 39.19	33.856
30	4	296	27.93 - 39.59	36.959

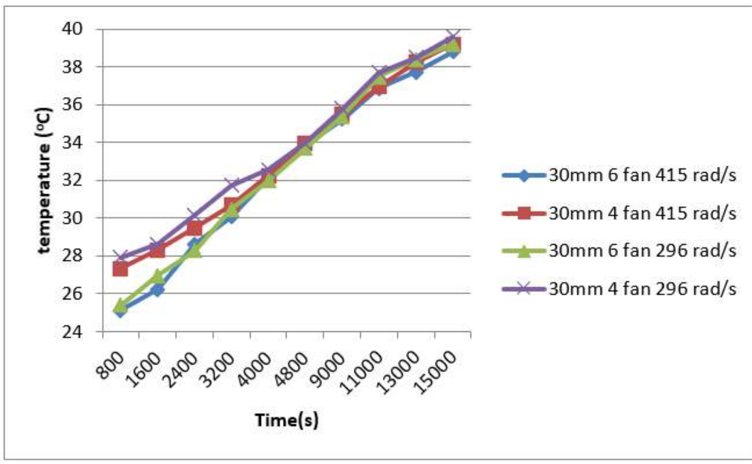


Fig 23. Comparison Management Thermal With Battery Space 30mm

Tabel 7. Comparison management thermal with space battery 20mm

Battery Gap (mm)	Fan	Fan velocity rad/s	Temperature (ºC)	Average (ºC)
20	6	415	25.48 - 39.59	32.524
20	4	415	28.36 - 42.74	35.331
20	6	296	25.88 - 42.74	33.818
20	4	296	28.70 - 42.93	35.359

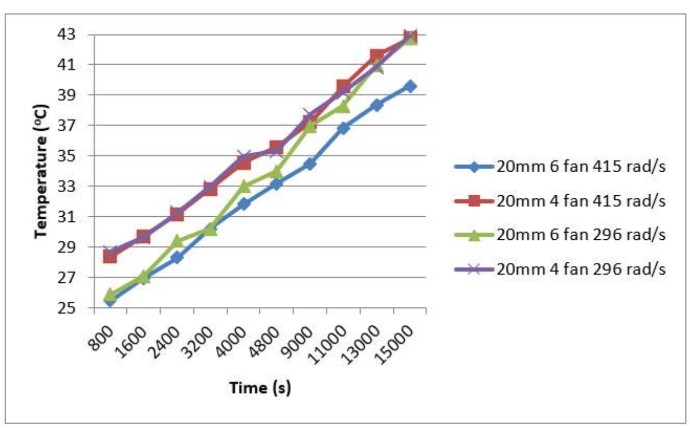


Fig 24. Comparison Management Thermal With Battery Space 20mm

In the figure 24 visible influences the fan speed and the amount of the cooling fan, the greater number of the fan, the more cold and uneven distribution of heat transfer fluid. In the Figure 4 use the maximum speed of the fan and have the highest efficiency.

Tabel 8. Comparison management thermal with space battery 10mm

Battery Gap (mm)	Fan	Fan velocity rad/s	Temperature (ºC)	Average (ºC)
10	6	415	27.23 - 40.88	33.441
10	4	415	29.54 - 43.38	36.224
10	6	296	27.73 - 43.62	35.191
10	4	296	29.96 - 43.62	35.110

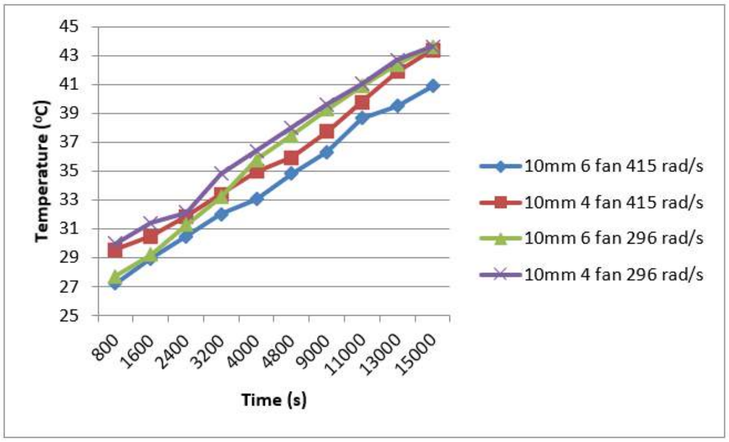


Fig 25. Comparison Management Thermal With Battery Space 10mm

From the figure 24 and 25 seen the influence of the fan speed, battery space and the number of cooling fans. Based on the graph that has obtained the highest level of efficiency is in the battery space and four 20mm cooling fans with fan speed 415.21384 rad/s. whereas the highest efficiency in the heat transfer fluid that is 30mm and 6 cooling fans with fan speed 415.21384 rad/s.

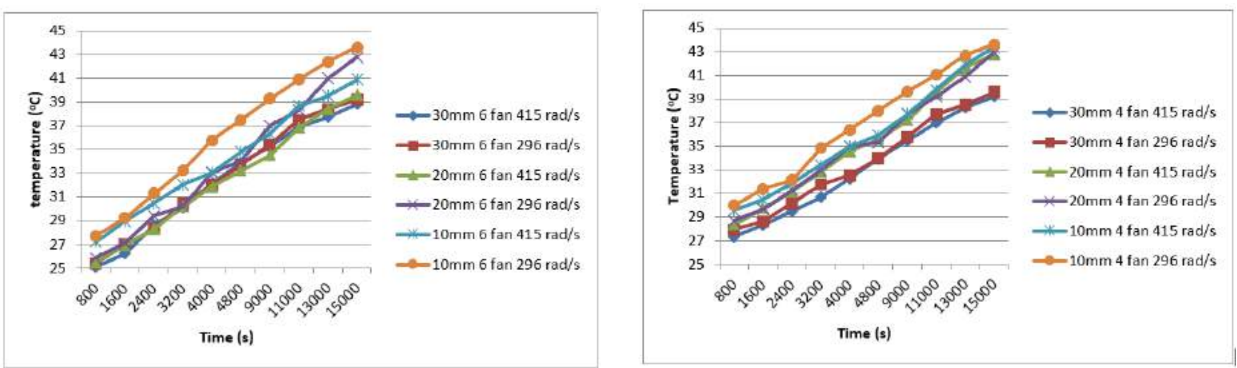


Fig 26. Comparison management thermal with 6 and 4 cooling fan

In the figure 26 show visible influence of the fan speed, battery gap and the number of cooling fans with 6 fan. Highest efficiency is 20mm with 6 fan and use full speed 415.21384 rad/s, whereas the lowest efficiency is 10mm and 6 cooling fans with fan speed 296.45129 rad/s.In the figure 26 show visible influence of the fan speed, battery gap and the number of cooling fans with 4 fan. Highest efficiency is 30mm with 4 fan and use full speed 415.21384 rad/s, but temperature minimum battery is highest for all with 4 cooling fan. Whereas the lowest efficiency is 10mm and 6 cooling fans with fan speed 296.45129 rad/s.To facilitate determining the best thermal management optimization of the ratio seen from the level of the most efficient in the use of 4 and 6 fans.

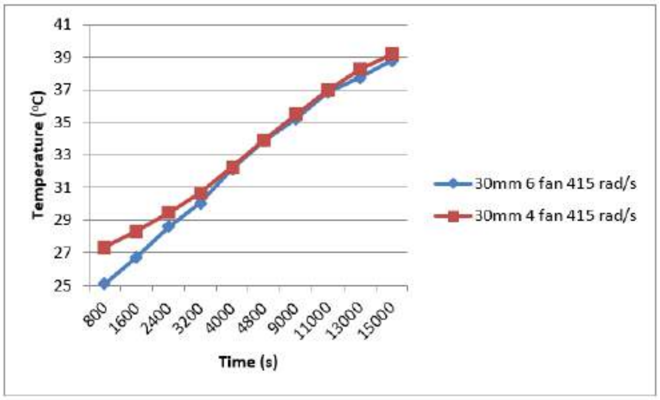


Fig 27. Comparison the most efficient management thermal with 4 and 6 fans.

In the figure 27 show difference in battery temperature . In the cooling system that uses 4 fan with battery gap 30mm, 4 fan, temperature more high than using 6 fan with battery gap 30mm. in the figure 26. show system using 30mm and 6 fan the most efficient for all.

Range Optium of Battery Temperature

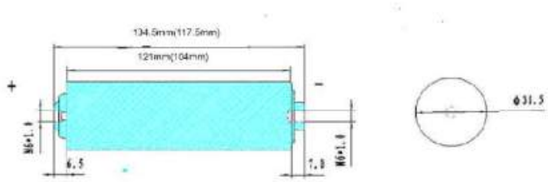
Range optimum of battery temperature is 60 with triple pack, the temperature average is 38.66. Based characteristic of LifeP04 battery, the optimum temperature range beetwen 10°C. – 40°C. The result show that range optimum of battery temperature is 60°C with triple pack model.

The Heat Transfer Coefficient Battery Calculations

Specification Cell Battery

Length Cells : 134.5 mm

Diameter Cells : 33.5 mm = 0.0335 m



The heat transfer coefficient battery 45℃ (Charging)

The heat transfer coefficient battery 45℃ (Charging Position). The forced air flow (Fan) 0.039 m3/s. The value of velocity fan is obtained from database SolidWorks Flow simulation (Papst 4500N).

The ratio of Reynolds number on battery can be calculated by:

$$R_e = \frac{v \times D_h}{\mu}$$

Re is the ratio of Reynolds number, v is the velocity of fan, Dh is the cell diameter, and μ is kinematic viscosity.

$$R_e = \frac{v \times D_h}{\mu} = \frac{0.039\,{m^3}/{s} \times 0.0335\ \text{m}}{17{,}45\ \times 10^{-6}\ {m^2}/{s}} = 74{,}87$$

The result show that the value of Re is 74,87, this value is laminar type of flow. The Nusselt number can be calculated after completed calculations of Reynolds number. Prandtl Numbers be obtained from the table properties of air, Value of Pr 0.7105. The Nusselt number on battery can be calculated by :

$$N_u = 0{,}023 Re^{0.8} Pr^{0.3} = (0.023 \times 74{,}87)^{0.8} \times 0{,}7105^{0.3} = 1{,}394$$

Nu is the Nusselt number, Re is the Reynolds number, and Pr is the Prandtl Numbers.

The result show that the value of Nu is 1,394 with thermal conductivity 0.278 W/ m.°C. The heat transfer coefficient can be calculated by:

$$h = \frac{k}{D} N_u = \frac{0.0278\ ^{W}/_{m.^{\circ}K}}{0.0335\ \text{m}} \times 1{,}394 = 1.157\ ^{\text{W}}/_{\text{m}^2.\text{K}}$$

Where h is heat transfer coefficient, k is thermal conductivity of air, D is the cell diameter, Nu is the Nusselt number. The result show that the value of convection coefficient is 1.157W/m2.K.

Total of convection coefficient on cells in the battery is:

$$1{,}157\ ^{\text{W}}/_{\text{m}^2.\text{K}} \times 8 \text{ cells} = 9.256\ ^{\text{W}}/_{\text{m}^2.\text{K}}$$

Total of convection coefficient on configuration battery pack is :

$$9.256\ ^{\text{W}}/_{\text{m}^2.\text{K}} \times 45 \text{ unit} = 416.52\ ^{\text{W}}/_{\text{m}^2.\text{K}}$$

III. CONCLUSION

Cooling management system of LiFePO4 battery pack for hybrid electrical vehicle application has been done successfully. This is done using battery gap 10mm, 20mm and 30mm, 4 and 6 fans and differences velocity fan.At the comparison experimental and simulation give result, which is cooling system is done by simulation more heat than experiment in the amount of 0.02%.The cooling system in battery pack for 4 fans, battery gap 30mm is the most efficient compared to other 4 fans. While cooling system in the battery pack for 6 fans, battery gap 30mm is the most efficient to all.

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