Improving the Performance of Electric Vehicle Battery Cooling Systems with Hybrid Systems

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Abstract. To maintain the ideal battery temperature, the electric car battery cooling system is very important. Battery life will decrease if the battery is often operated at high temperatures. The battery cooling system in electric cars must be made to keep the battery from overheating. Battery performance and life can be improved by keeping it at an ideal temperature, therefore the battery cooling system plays an important role in the continuity and life of electric vehicles. Previous research has attempted to develop an electric vehicle battery cooling system with passive cooling using PCM. The results of using Phase Change Material (PCM) as a cooling medium for electric vehicle batteries can slow down the rate of increase in battery temperature, and with this method, the battery working temperature has not reached below 40°C.In this study, a hybrid cooling system for electric vehicle batteries was developed. The hybrid cooling system in question combines passive cooling in the form of PCM with active cooling in the form of liquid fluid circulation in the PCM. This study was designed using an experimental method, where a battery simulation will be made with a generation temperature reaching 35-65°C. The battery simulation will be covered with a container made of PCM material in the form of paraffin and TiO_2, then liquid fluid will flow inside the PCM to absorb the heat in the PCM due to battery performance. Several PCM concentrations will be tried to obtain an effective PCM composition. The results obtained show that the use of hybrid cooling in electric vehicle batteries has a better battery cooling effect compared to passive cooling and natural cooling and the battery temperature can be maintained below 35°C.

Keywords: Battery Cooling, Hybrid Systems, Performance Enhancements

1 Introduction

With increasing attention to environmental issues, electric vehicles are gradually replacing fossil fuel vehicles due to their renewable energy and cleanliness. Temperature is a key factor that influences the capacity, charging and discharging performance and safety of electric vehicle batteries. The battery cooling system in an

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electric car is very important to maintain the battery's optimal temperature. Batteries that operate at temperatures that are too high or too low can experience degraded performance and shortened lifespan (Feng et al., 2015). Therefore, regulating battery temperature with a cooling system is very crucial.

Electric vehicle battery cooling systems need to be designed to prevent battery temperatures from reaching dangerous levels and reduce the risk of overheating. Well-controlled battery temperature can increase the efficiency of the battery charging and discharging process. By maintaining optimal temperatures, electric cars can achieve better performance and energy efficiency. Batteries that are kept at optimal temperatures will have better performance and longer service life. The battery temperature should be maintained in the range of 15-40 °C to utilize its maximum effectiveness (Jouhara et al., 2019; Pesaran, 2001; Ramadass et al., 2002). The battery cooling system is a key factor in the success and durability of an electric car. A good battery cooling system helps maintain battery temperature stability under various operational conditions, which in turn increases the performance, efficiency and service life of an electric car. Several cooling systems have been tested, such as active cooling, which circulates water from the battery. Passive cooling using phase change materials (PCM) as a coolant has also been developed. Each cooling system has its advantages and disadvantages. Several researchers conducted research on hybrid cooling systems that combine PCM and air circulation (Ling et al., 2015). Experimentally investigated a hybrid battery thermal management system (BTMS) using PCM and forced air during the cyclic discharge process of a lithium-ion battery. With an increase in battery power distribution, namely 1.5°C and 2°C, in the first two cycles BTMS with passive PCM can maintain battery temperature below 45°C. BTMS with a hybrid system can control temperatures below 45°C for the first five cycles. In addition, the airspeed (1, 3, and 5 m/s) was investigated, it was found that the speed of 3 m/s can control the battery temperature within its normal working limit. (Wu et al., 2016) studied PCM-based BTMS with wind speeds of 1–4 m/s, where the result was an increase in temperature from each cycle. (cycle 1: 61.6 C, cycle 2: 78.6°C and cycle 3: 81.9°C). Different things were found with hybrid BTMS where the battery temperature can be maintained 55°C up to three cycles. Numerically investigated air-cooled PCM-based BTMS was numerically investigated by Zhao et al., (2017). Compared to passive PCM-based BTMS, air-cooling-based BTMS can reduce battery temperature by 14.3%. Hybrid BTMS can maintain uniform battery temperature in the range of 5°C (Xie et al., 2017), and developed a battery cooling system using PCM composite combined with air cooling. The results obtained with the PCM composite combined with an airflow rate of 100 m^3/hour can maintain battery temperature in the safe category compared to a cooling system that only relies on air flow rate alone.

To overcome the limitations of active and passive cooling systems, a hybrid cooling system can be developed that takes advantage of the advantages of each passive and active cooler. The electric vehicle battery cooling system is a hybrid system, which combines the PCM cooling system and liquid fluid flowing inside the PCM.

2 Methodology

2.1 Design Experiment

This research was designed using the method *experiment*, where the battery will be simulated with a heater whose temperature is controlled at 35°C-65°C. Before the PCM material is used as a battery cooling material, the PCM candidate in the form of paraffin and TiO_2 will be mixed with several variations of the mixture to get the characteristics of the PCM material which is good for use as a cooling medium. The experimental design of this research is presented in Figure 1.

Figure 1. Design experiment

2.2 Materials

The materials used in this research are PCM materials in the form of paraffin and TiO_2, The paraffin used is paraffin wax, with characterization as in Table 1 and the characteristics of the TiO_2 used are presented in Table 2. Apart from PCM materials, materials for simulating a battery cooling system are needed aluminum plate material as a battery box and copper pipes for liquid fluid circulation in the PCM. For the liquid circulating in the pipe as a PCM cooling medium, raw water is used.

Table 1. Characterization of paraffin wax

Melting temp. (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/mK)	Density (kg/m^3)
64	266	0.339 (solid 45.70 °C)	916 (solid 24 °C)

Source: (Zalba et al., 2003)

Table 2. Characterization of TiO_2

Melting temperature (°C)	Thermal conductivity (W/(m × °K)	Density (kg/m³)	Specific heat capacity [kJ/kg × °K]
1.843	8.9	4250	686.2

2.3 Research Instruments

This research instrument is divided into three, namely instruments for making PCM materials, instruments for testing PCM materials, and instruments for testing the performance of the PCM that is made. To mix PCM materials according to the composition that has been planned use *magnetic stirrer* to get a homogeneous mixture. To test material characteristics, tools in the form of *Fourier Transform Infrared* (FTIR) are used to determine the composition, quality, and homogeneity of the composite material being made. To test PCM performance, the instruments used in this research are a heater to simulate a battery, a thermocouple to measure the temperature that occurs in the battery, a power supply to convert AC to DC, a pump to circulate the coolant, a radiator to cool the fluid.

2.4 Research Procedures

This research will begin with making a test material in the form of a mixture of paraffin and TiO_2 with several mixed compositions. The mixture composition is made with 100% paraffin composition; Paraffin 92% with TiO_2 8%; Paraffin 95% with TiO_2 5%; and Paraffin 98% with TiO_2 2%. This mixture composition is mixed in liquid condition using a magnetic stirrer. The paraffin is stirred first with a magnetic stirrer at a temperature of 80°C with a rotation speed of 80 rpm until the paraffin changes form to liquid, then TiO is slowly $added_2$. After mixing for 2 hours, it was left at room temperature and the material characteristics of each mixture formula were tested. Each mixture formula will also be printed to create a model *casing* electric vehicle battery. The cooling system model will be made in two models, namely using only passive cooling, where the battery is only covered with PCM, and then the battery temperature is observed for 30 minutes. The second cooling system model uses a system *hybrid* by combining passive and active cooling systems. The active cooling system in question means that the battery is cooled with a PCM casing and the PCM casing is cooled with a circulating liquid cooler.

3 Result and Discussion

3.1 Result

From the research data obtained using several cooling methods, it is presented in Figure 2. From Figure 2, it can be seen that the passive cooling system, which only utilizes pure PCM, can maintain the lowest battery temperature, while the hybrid cooling system is a combination of a passive cooling system and is equipped with fluid circulation. The liquid in the PCM shows a higher battery temperature than the passive cooling system, and the temperature difference between the two cooling systems is not significant. For the use of a natural cooling system that only uses a cooling system with free convection, the battery temperature is much greater than the passive and hybrid cooling systems, where the battery temperature reaches 63.85ºC for 2 minutes under natural cooling. For cooling using the passive method, the battery temperature is still below 40ºC. Details are shown in Figure 2.

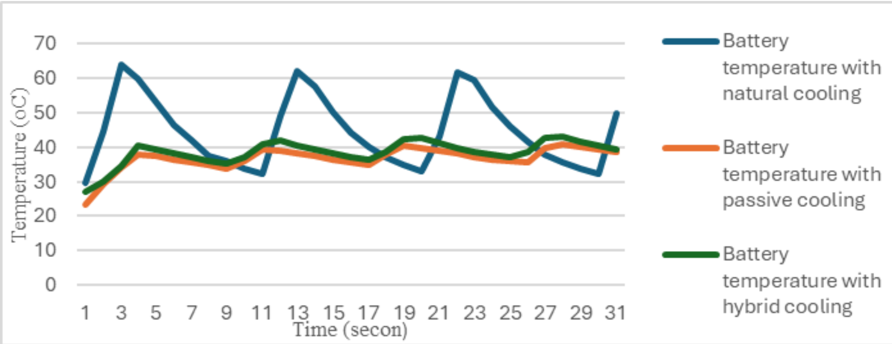

Figure 2. Battery cooling system performance using water circulation in pure PCM, natural cooling, and passive cooling using pure PCM hybrid cooling

Figure 3 shows the research findings related to the addition of 2% TiO_2 to PCM. Although there is no obvious difference between passive and hybrid cooling, Figure 3 illustrates that the battery temperature in the natural cooling system is still higher than in the systems using passive and hybrid cooling. The battery temperature shown by the hybrid cooling system is slightly lower than the battery temperature in the passive cooling system during the first five minutes of operation, and for the subsequent time, it fluctuates between the passive cooling system and the hybrid cooling system.

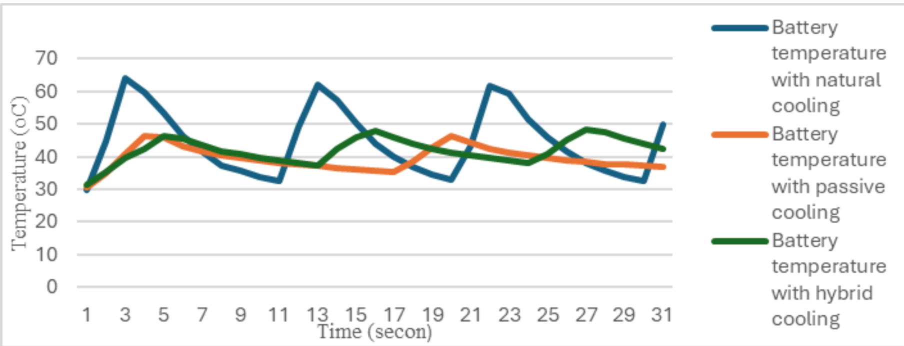

Figure 3. Battery cooling system performance employing 98% paraffin and 2% TiO_2 as PCM in a hybrid, passive, and natural cooling system

By adding 5% TiO_2 to paraffin as PCM, the battery temperature with hybrid cooling showed the lowest temperature, reaching below 35°C, while for passive cooling there are still temperature measurements above 35°C at sometimes. Complete data is presented in Figure 4.

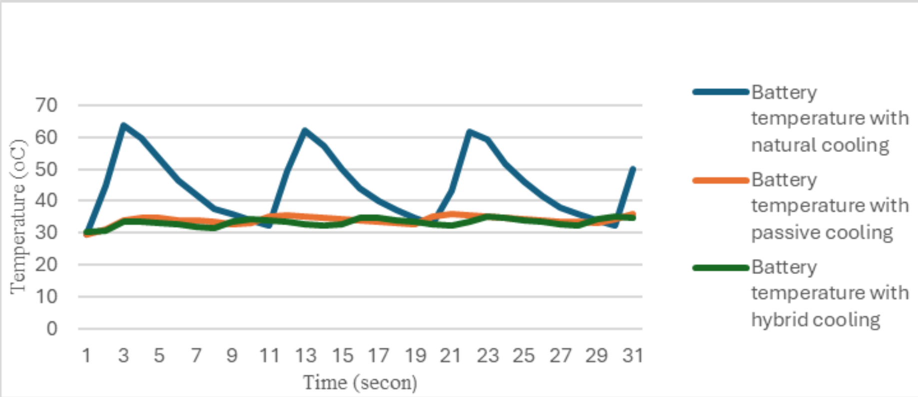

Figure 4. Battery cooling system performance employing 95% paraffin and 5% TiO_2 as PCM in a hybrid, passive, and natural cooling system

Data from observations on the battery cooling system with the addition of 8% TiO_2 shows a greater temperature difference between the hybrid cooling system and the passive cooling system compared to the use of pure PCM, PCM with 2% and 5% TiO_2. Complete data is presented in Figure 5.

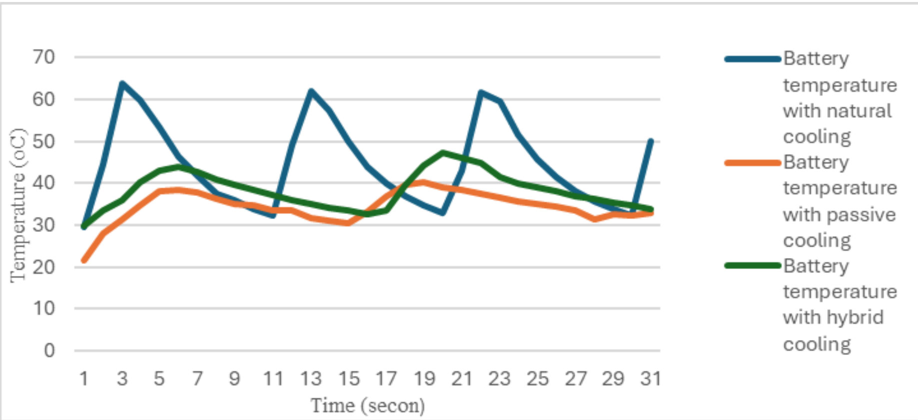

Figure 5. Battery cooling system performance employing 92% paraffin and 8% TiO_2 as PCM in a hybrid, passive, and natural cooling system

3.2 Discussion

From the research data obtained based on the variation of the cooling system studied, it turns out that the use of paraffin as a passive cooling medium has a significant impact on the cooling of electric vehicle batteries compared to natural cooling systems, this is following the research results (Meng & Zhang, 2017; Ho & Gao, 2013; Khan et al., 2016) which state that paraffin has good thermal stability, so it can absorb the heat in the battery. Utilization of Paraffin as PCM for Battery Cooling can maintain the average battery temperature at each measurement and for 30 minutes the battery temperature shows a temperature of 36.71 40°C and this temperature is still within the safe limit for the use of electric vehicle batteries, which is recommended below 40°C. However, in some battery temperature measurement positions some exceed 40.40°C and even reach 45.40°C.

The addition of TiO_2 to paraffin as PCM has a significant impact on lowering battery temperature, where compared to the use of pure PCM which only uses paraffin, heat absorption from the battery can be more effective so that the battery temperature becomes lower. This result is by several related research results showing that the use of TiO_2 as PCM to improve the performance of pure PCM is very effective, this is because the addition of TiO_2 elements to paraffin can improve the weaknesses of paraffin which has low thermal conductivity, so that the addition of TiO_2 causes the conductivity of PCM to be higher and can absorb heat in the battery faster (Li et al., 2016; Mansour et al., 2023; Sami & Etesami, 2017; Ibrahim et al., 2022). From several variations of TiO_2 addition into paraffin, it was found that the addition of 5% TiO_2 showed the most effective cooling system performance, where in passive cooling the average battery temperature up to 30 minutes was 34.06°C and in hybrid cooling the average battery temperature was under 40°C. The addition of 2% TiO_2 showed the average battery temperature within 30 minutes was 41.95°C and the addition of 8% TiO_2 showed the battery temperature was 38.34°C. This phenomenon shows that the more TiO_2 concentration in paraffin causes the thermal conductivity of the PCM to increase, but conductivity that is too high causes a decrease in the latent heat of the PCM so that the performance of the PCM decreases. When compared to the use of several variations of cooling systems applied, the use of hybrid cooling with 95% paraffin PCM and 5% TiO_2 is the most effective, because the absorption of heat from the battery by the PCM is reabsorbed by the fluid flowing in the PCM and cooled using forced convection with a fan to remove heat to the environment.

4 Conclusion

Based on the research results, several conclusions can be drawn. The use of PCM (Phase Change Material) as a cooling medium for electric car batteries demonstrates superior performance compared to natural cooling systems. Among different concentrations of TiO_2 added to paraffin as PCM, the 5% TiO_2 concentration shows the most efficient performance when compared to 2% and 8% concentrations. Additionally, hybrid cooling systems outperform both natural and passive cooling methods, effectively reducing the battery temperature to below 35°C.

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