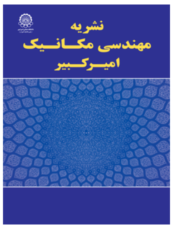


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# Investigation on the effect of addition of nano-titanium oxide particles to phase change material in a hybrid system for battery cooling under constant heat flux

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**ABSTRACT:** Increasing lithium-ion batteries temperature is known as a challenge. In this research, by completing a hybrid heat management system, the effect of adding Nano-titanium oxide particles to paraffin phase change material was investigated on the cooling performance of battery in two constant heat flux, 4.5 and 14 Watts. The hybrid system consists of nano-paraffin and copper metal foam with two working fluids as air and water. For air as working fluid, battery temperature in pure paraffin and nano-paraffins 1, 2, 3 and 4% became 56.2°C, 51.8°C, 50.7°C, 49.3°C and 48°C, respectively. From investigated cases, nano-paraffin 4% had the most decreasing temperature comparing to pure paraffin which was about 17%. Hybrid system with copper foam, nano-paraffin and working fluid as pure water tested in Reynolds numbers 420, 600 and 720. It is shown that the battery temperature reached stable temperatures of 48°C, 46°C and 44°C respectively, which comparing to the pure paraffin case, temperatures reduced by 11%, 12% and 12.5% respectively. Therefore, due to the low thermal conductivity of paraffin, the addition of nanoparticles to phase change materials is beneficial.

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## 1. INTRODUCTION

Lithium-ion batteries are widely used in industry due to their high heat capacity, long life cycle, and low spontaneous discharge rate. But the issue of thermal stability, including challenges such as degradation capacity and even explosion due to overheating and non-uniform heat distribution, has caused many problems in their use. Therefore, using a suitable battery thermal management system that is able to meet the necessary conditions is one of the essential points in designing this type of battery [1]. In order to meet these conditions of thermal management and placing the battery in safe conditions, various strategies such as air cooling, liquid cooling, heat pipe and the use of phase change materials Used. To improve the heat transfer and cooling of lithium-ion batteries in the passive battery system, the use of phase change materials as well as metal foams and their combination has been suggested by some researchers. In an experimental study, Kiani et al. [2] designed a combined thermal management system. The designed system includes the combination of paraffin as the PCM, copper foam as the passive system and the use of alumina nanofluid as the working fluid in the active system part. Their results showed that the use of hybrid system reduced the battery temperature and also delayed the melting time of paraffin. Mashayekhi et al. [3] used nanofluid for the active part of the hybrid system and paraffin and copper foam in the embedded micro channels for the passive part and reported the positive effect of this hybrid system on the thermal management of the battery. One of the negative properties of paraffin is its low thermal conductivity, which has encouraged researchers to use materials with high thermal conductivity such as metal foams and nanoparticles combined with paraffin in order to increase the thermal conductivity of the material [4]. A review of the above shows that the use of hybrid systems can be successful in the thermal management of lithium-ion batteries. However, the addition of nanoparticles to phase change agents and its effect on reducing battery temperature in these hybrid systems has not been investigated. Therefore, in this research, a combined thermal management system including nanoparticles added to paraffin (nano-paraffin) for cooling lithium-ion battery, which has been introduced by references [2-3] has been developed.

## 2. EXPERIMENTAL SETUP

The heat management system with plate heaters is installed inside a box to increase the contact level between the components is shown in Fig. 1. Copper foam with dimensions of 130 × 80 × 32 mm is used and heaters are installed next to them. The heaters are placed next to this copper foam as a battery replacement. The general form of the system is given in [2-3], which will not be retold here.

The nanoparticles distributed in paraffin are titanium oxide ($TiO2$) with an average size of 20 nm. The fabricated nanoparticles were added to the paraffin and the mixture

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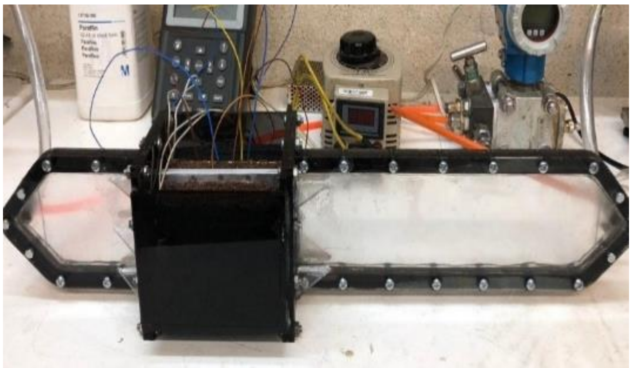


**Fig. 1. Set up of thermal management system with plate heater**

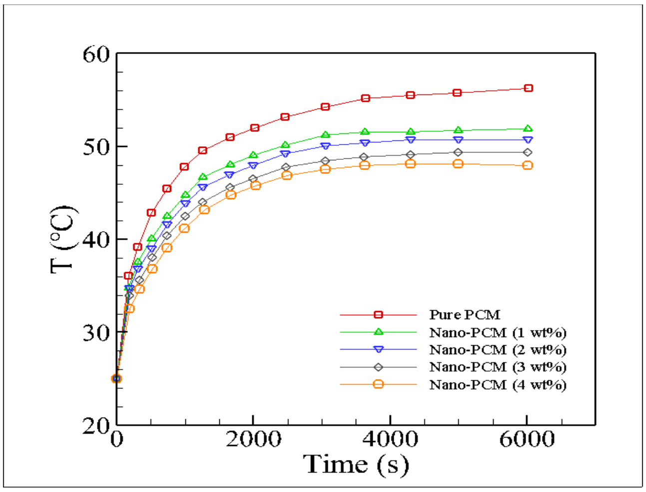
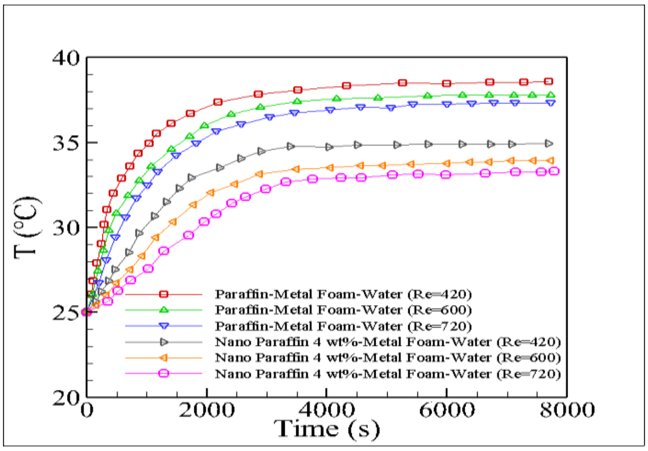
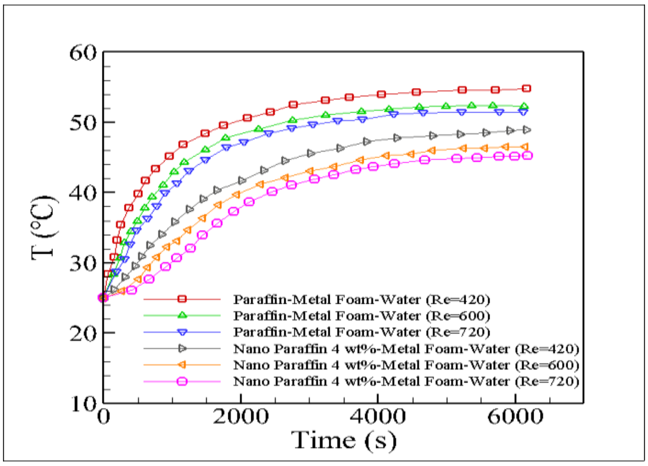



**Fig. 2. Comparison temperature variations of plates batteries between nano-PCM and pure PCM with air as working fluid**




**(a)**




**(b)**

**Fig. 3. The effect of Reynolds number of pure water flow in a combined system the pure water as working fluid and two cases in the passive part, including paraffin-metal foam and 4% nano-paraffin-metal foam in the cooling system at (a) 4.5 Watts and (b) 14 Watts**

was stirred thoroughly for 30 minutes at 65°C and gradually cooled to achieve a uniform distribution of the nanoparticles in the paraffin.

## 3. RESULTS AND DISCUSSION

During the experiments, changes in the temperature of the surface of the battery (heater) have been recorded until the operating conditions are stable or the maximum allowable temperature of 60°C is reached. The results are presented in two sections, including air-cooled cooling system and water-cooled cooling system.

### 3.1. Cooling system with air operating fluid

In order to investigate the effect of adding titanium nanoparticles to the PCM, the results of nanoparaffin prepared in different volume percentages of nanoparticles are compared. In Fig. 2, the experimental results for the maximum temperature changes of the heater over time in five different states of pure paraffin and nanoparaffin in four different volume percentages are given. It can be seen that in all cases of the combined system, pure paraffin and nano-paraffin behave similarly. Also the cooling performance of the system for nanoparaffin has increased significantly compared to pure paraffin. The melting temperature of paraffin is 42 to 44°C. According to these results, the addition of nanoparticles by 4% of volume delayed the melting time of paraffin by 1291 seconds, which increased the cooling performance of the PCM. One hour and 40 minutes after the start of the experiment, battery temperature in pure paraffin, and nanoparaffins with 1, 2, 3 and 4% by volumes is 56.2°C, 51.8, 50.7°C, 49.3°C and 48°C respectively. By comparing the two modes of pure paraffin and nanoparaffin 4% by volume, an approximate amount of 17% reduction in temperature is obtained by adding nanoparticles to paraffin, which indicates the important effect of using nanoparticles in the proposed composite system.

### 3.2. Combined cooling system with pure water operating fluid

For cooling with pure water-working fluid, the inlet flow temperature is assumed to be constant at 24°C. The test was performed at two different thermal powers of 4.5 and 14 Watts and at three Reynolds numbers 420, 600 and 720 to investigate the effect of water cooling on battery temperature control. With increasing Reynolds number, it is observed that the battery temperature changes become closer to each other, which indicates that the effect of increasing Reynolds number at low capacities in decreasing battery temperature has a high limit and more than that, increasing flow rate does not effect. Therefore, at 4.5 Watts of power and despite the copper foam, in no Reynolds number, the battery surface temperature does not reach to a maximum of 60° C, and therefore the water cooling system with paraffin and copper foam can be used well at low thermal capacities and no need for using of nanoparaffin. Compared to cooling the battery with paraffin without copper foam, it is observed that the addition of copper foam has a significant role in controlling the temperature of the battery and not only prevents the paraffin from melting but also keeps the battery temperature stable. According to Fig. 3(a), the addition of nanoparticles to pure paraffin with a combination of copper foam and water flow has significantly reduced the heating temperature. The results show that in the flow of water working fluid with Reynolds number 420, the amount of heating temperature after 2563 seconds has reached a stable temperature of 34°C, which compared to pure paraffin, at the same time about 3°C temperature decreased. Also in Reynolds number equal to 600, the value of heater temperature after 2875 seconds reached a stable temperature of 33°C and in Reynolds number 720, the value of heater temperature after 4244 seconds reached a stable temperature of 32.5°C which comparisons with pure paraffin show 4° C and 4.6° C, respectively.

## 4. CONCLUSION

In this study, the effect of adding nanoparticles to paraffin in a hybrid system has been investigated experimentally. The results in the case of using air-working fluid for the active part of the cooling system showed that firstly, the passive part with paraffin, paraffin-copper foam and nano-paraffin-copper foam to keep the battery temperature in the safe range of 60° C and especially in operating mode with high thermal power (14 Watts in this study) is essential. This showed that if the operating fluid of the air is used in the active part of the system, the passive part of the system must be designed as a combination of nanoparaffin-copper foam so that the battery temperature does not exceed the safe temperature. The results showed that with increasing the volume percentage of titanium oxide nanoparticles to paraffin in the passive part of the hybrid system, the maximum value of the battery temperature has decreased well. The effect of nanoparaffin in the combined system with water-working fluid has also been investigated and the results show the similarity of the general trend of the effect of adding nanoparticles to paraffin in the system with air-flowing fluid. Finally, the present results showed that if the thermal power of the battery is high and the Reynolds number of the working fluid flow is low, the use of nanoparaffin in the hybrid system can easily control the temperature of the battery and keep it within the designed safe range.

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