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Research Paper

Experimental investigation on performance of lithium-ion battery thermal management system using flat plate loop heat pipe for electric vehicle application ☆

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HIGHLIGHTS

- Flat plate loop heat pipe (FPLHP) is studied in the thermal management system for electric vehicle.
- Distilled water, alcohol, and acetone on thermal performances of FPLHP were tested.
- The FPLHP can start up at fairly low heat load.
- Temperature overshoot phenomena were observed during the start-up period.

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ABSTRACT

The development of electric vehicle batteries has resulted in very high energy density lithium-ion batteries. However, this growth is accompanied by the risk of thermal runaway, which can cause serious accidents. Heat pipes are heat exchangers that are suitable to be applied in electric vehicle battery thermal management for their lightweight and compact size, and they do not require external power supply. This study examined experimentally a flat plate loop heat pipe (FPLHP) performance as a heat exchanger in the thermal management system of the lithium-ion battery for electric vehicle application. The heat generation of the battery was simulated using a cartridge heater. Stainless steel screen mesh was used as the capillary wick. Distilled water, alcohol, and acetone were used as working fluids with a filling ratio of 60%. It was found that acetone gave the best performance that produces a thermal resistance of 0.22 W/°C with 50 °C evaporator temperature at heat flux load of 1.61 W/cm^2.

1. Introduction

The shares of electric vehicles in some European countries are assumed to comprise 53% of the private passenger vehicle fleet in 2030 [1]. One of the important performance parameters of an electric vehicle is the range or cruising capability, which is mainly determined by the performance of the batteries. Batteries with high energy density are needed to deliver high cruising capabilities. Electric vehicles will rely on lithium-ion batteries according to their high energy density, high power density, long service life and environmental friendliness [2]. Advances in battery technology have resulted in very high energy density lithium-ion batteries. However, this progress is also accompanied by the risk of thermal runaway, which can lead to serious accidents, such as that experienced by the Boeing 787 Dreamliner of All Nippon Airways on January 16, 2013, in Japan [3].

Heat generated by a battery, either at the time of charging or discharging, will increase its temperature. The battery performance and lifetime are strongly influenced by their working temperature. In general, the performance of electric vehicles is directly affected by the performance of their batteries [4]. At quite low or high temperatures, the battery performance can be destitute. At very high temperature, lithium-ion batteries can even explode [5]. The desired working temperature range for ordinary lithium-ion batteries is in the range of 25 °C to 50 °C [6]. For the purpose of energy saving and reduction in the cost of electric vehicles, the batteries should be operated in a proper temperature range [7]. Therefore, an efficient thermal management system for the battery packs is essential.

Heat pipes are heat exchangers that are suitable to be applied in thermal management of central processing unit (CPUs) and electric vehicle batteries for their lightweight and compact size, and they do not require external power supply. Studies on heat pipes for electronic cooling have been done by authors and can be found in many

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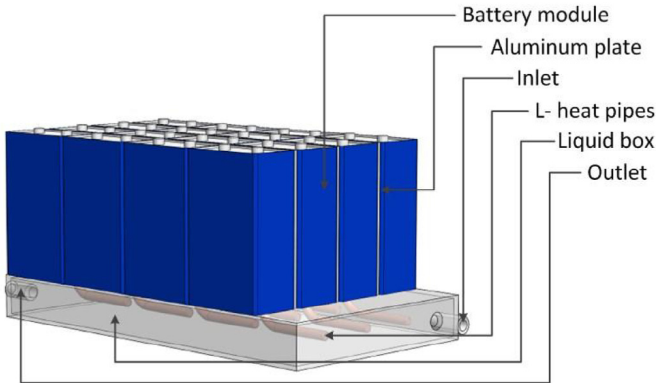

Fig. 1. Thermal management system of electric vehicle battery [15].

references [8,9] and other researchers such as Wang [10] and Weng et al. [11]. Investigations on flat plate heat pipes in electronic cooling have been conducted by Chen et al. [12,13] and Lu and Wei [14]. Rao et al. [7] have examined the use of straight heat pipes on thermal management system of a LiFePo4 battery. Their experimental results showed that the maximum temperature can be kept below 50 °C if the rate of heat generation is below 50 W/cm^2. Wang et al. [15] investigated the application of heat pipe for thermal management system of the electric vehicle battery. In their work, some L-shaped flattened heat pipes were used to transfer heat from the battery to the cooling water as shown in Fig. 1.

Flat plate loop heat pipes have the potential to be applied to the thermal management system of electric vehicle lithium-ion batteries since most of the electric vehicle lithium-ion battery pack has flat surfaces [16]. This paper aims to examine the performance of a flat plate loop heat pipe as a heat exchanger in the thermal management system of lithium-ion batteries for electric vehicle application experimentally.

2. Methodology

Battery simulator was made from aluminum alloy. As a heat source, a cylindrical cartridge heater with a power of 400 W was placed in the battery simulator. A conduction plate made of stainless steel with a size of 105 mm × 40 mm × 15 mm was placed above the battery simulator. Fig. 2 shows the arrangement of the flat loop heat pipe, conduction plate, battery simulator and insulating box used in the experiment in order to minimize heat lost.

The conduction plate was used to determine the conduction heat transfer from the heater to the evaporator by measuring the temperature difference across the plate. Instead of using electric power input, the conduction heat transfer through the conduction plate was used to determine the heat input to the evaporator. The heat input could be determined by the following equation:

$$q = (kA/L)(T_b - T_t) \tag{1}$$

The thermal conductivity of the conduction plate, which was made of stainless steel, was assumed to be 16 W/m K. The battery simulator and the conduction plate were placed inside an insulating box made of polyurethane. On the top surfaces of the conduction plate and the battery simulator, grooves were made for the installation of thermocouples. At the condenser section, an annular heat exchanger was used for heat release to the cooling water. The thermal resistance of the FPLHP was calculated using:

$$R = \frac{(T_e - T_c)}{q} \tag{2}$$

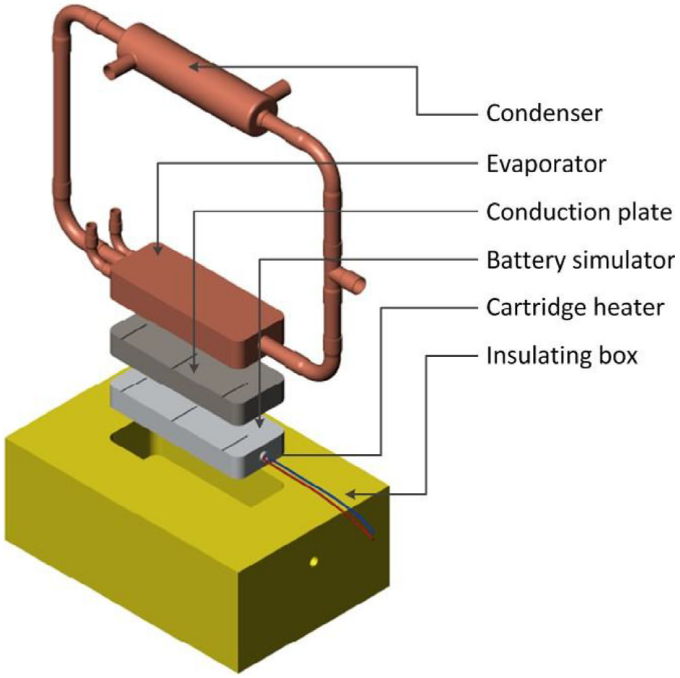

Fig. 2. Flat plate loop heat pipe with battery simulator.

The evaporator was made of copper with a size of 105 mm × 40 m × 15 mm. Each side has 5 mm thickness except for the bottom side which has 3 mm thickness. To assist the evaporation, 1 mm × 1 mm × 60 mm grooves were made on the base surface of the evaporator as shown in Fig. 3.

A stainless steel screen mesh with a size of 300 mesh was placed above the grooves to serve as the capillary wick as shown in Fig. 4. The stainless steel screen meshes capillary wick were also placed on the liquid line to pump back the condensate from the condenser to the evaporator.

The k-type thermocouples with 0.2 mm diameter were used for temperature measurements. Fig. 5 shows the placement of the thermocouples. There were two thermocouples for the evaporator, two thermocouples for vapor line, three thermocouples for the condenser, and two thermocouples for liquid line.

The assembly of the FPLHP was then isolated using glass wool. Ceramic blanket, which has a higher working temperature, was used

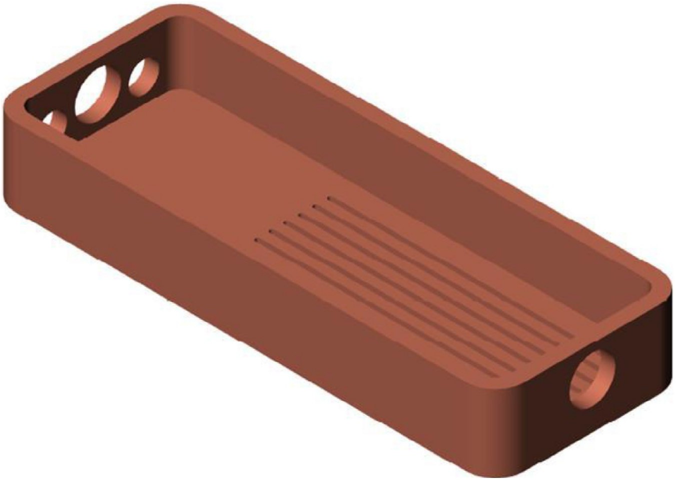

Fig. 3. The evaporator design.