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EXPERIMENTAL STUDIES ON TWO-PHASE HFE-7000 FOR BATTERY THERMAL MANAGEMENT

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1. ABSTRACT

Immersion heat transfer is a highly effective thermal solution that can be applied without additional equipment, requiring only material adjustments. This study investigates the immersion cooling performance of HEF-7000 dielectric coolant for the thermal management of lithium-ion batteries and compares it with those of natural and forced air convection methods. The results indicated that the immersion method maintains temperature uniformity below 5°C with a maximum temperature of 41°C, indicating superior performance compared to available methods.

2. INTRODUCTION

The rising trend in electric vehicles (EVs) has highlighted significant challenges in enhancing the efficiency of vehicle batteries, especially in high-voltage applications such as pouches, prismatic, and cylindrical designs. With cylindrical batteries prevalent in many car models, our research focuses on optimizing these types to meet the stringent standards of traditional internal combustion engines (ICEs) [1]. Although EVs have high battery costs, they are competitive due to higher energy efficiency, lower maintenance, faster acceleration, and emission-free operation [2]. One critical area is extending battery lifespan and developing effective cooling systems. Initially, air-cooled systems sufficed for early commercial electric cars, but the demand for higher energy capacity has necessitated advanced cooling technologies due to issues like thermal runaway [3]. Liquid immersion cooling, using dielectric fluids like HFE-7000 with suitable boiling points, has emerged as an effective method, providing superior heat transfer compared to traditional air-cooling techniques [4]. Our battery configuration includes a 50.4V charge voltage, 44.4V nominal voltage, 7.14Ah capacity, and 35mOhm internal resistance and utilizes HFE-7000 liquid for optimal operation between 15-35°C [5]. This approach addresses the critical parameters influencing battery thermal management, such as C-rate and flow rate, ensuring efficient and safe battery performance.

3. METHODOLOGY

Fig 1a shows the immersion cooling experimental setup comprising the test section, ITECH Bi-directional DC power supply, condenser, reservoir, pump, and pre-heater. The test section contains a well-sealed chamber, an inlet, an outlet, and a battery pack (Fig 1b). 18650 lithium-ion batteries (LIBs) were used, as they are the most common type in

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EVs. The battery pack has 24 cells configured in a 12S2P layout. Fig 1c illustrates the arrangement of the cells in the battery pack and the locations of the thermocouples. Two thermocouples are installed at the inlet and outlet of the test section, and seven thermocouples are attached to the battery pack to measure the cell temperatures. Three are connected to the top of the pack, three to the bottom, and one to the middle of one of the central cells. Thermal conductive tapes are used to secure them to the battery pack for more accurate temperature measurement. The battery pack can only be charged at 0.25C (1.7 A) and discharged at 1C (6.8 A). Therefore, before the tests, the battery pack is fully charged and left to stand until it reaches the desired initial temperature. A secondary air cooling setup was prepared (Fig 1d). This setup consists of the battery pack with the thermocouples in the same configuration as the immersion method, a fan, an ITECH Bi-directional DC power supply, and a separate DC power supply for the fan. The battery pack temperatures were recorded during discharge at a 1C rate under natural and forced air convection.

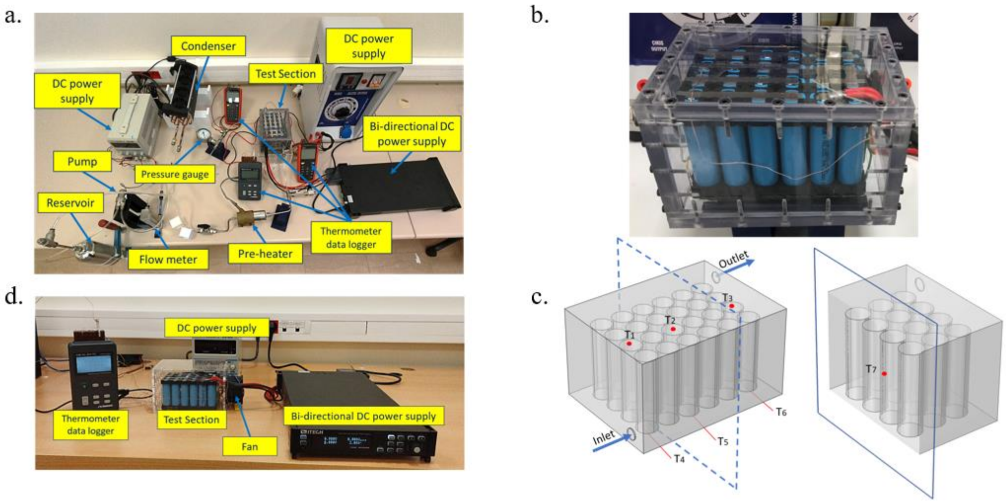

Fig 1. a) The immersion cooling setup, b) The test section, c) Model of the test section and the locations of the thermocouples, d) The setup for natural and forced air convection experiments.

4. RESULTS

Fig 2a presents the temperature variation for 1C rate discharge under natural convection. The temperature exceeded 60°C, which is too high and may damage the batteries. Moreover, the temperatures of the pills were not uniform and ranged from 50°C to 62°C across the battery pack. Fig 2b. shows the effect of forced air convection cooling. This method reduced the maximum temperature to 41°C. However, the battery temperatures were still nonuniform.

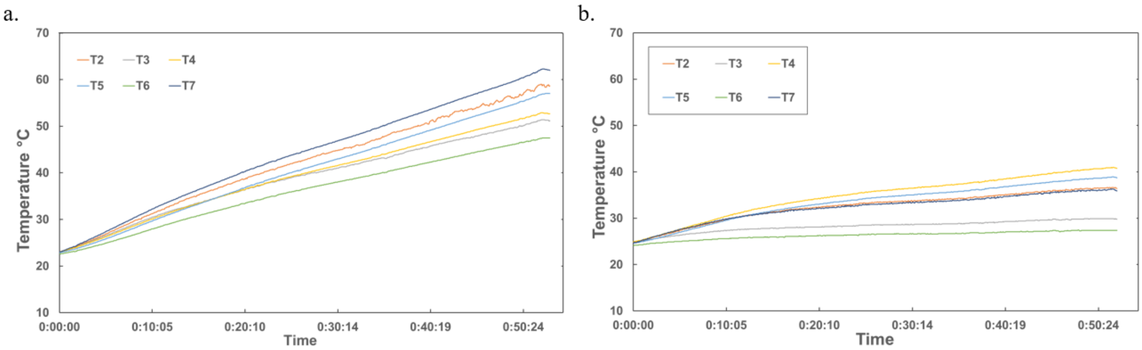

Fig 2. a) Temperature over time for the natural convection experiment, b) Temperature over time for the forced air convection experiment (The locations of the thermocouples are shown in Fig 1c).

Fig 3a. shows the immersion cooling experiment using HFE-7000 with a flow rate of 250mL/min. The cell temperatures are nearly equal in different locations of the battery pack, improving the battery performance. The maximum temperature was 34°C, which is the boiling point of HFE-7000. A phase change occurs at this point, and coolant uses latent heat as the main cooling source. Fig 3b. shows the bubble formation inside the test section at different locations of the battery pack. Overall, the immersion cooling system achieved a lower and more uniform temperature distribution, enhancing battery performance.

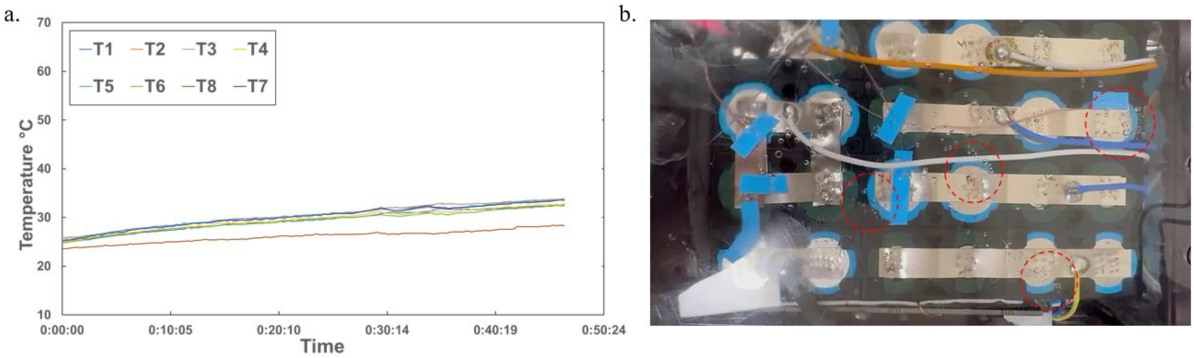

Fig 3. a) Temperature over time for the immersion cooling experiment using HFE-7000 with 15L/hr flow rate. (T8 is the inlet liquid temperature), b) Bubble generation inside the test section.

5. CONCLUSIONS

This study experimentally investigated immersion thermal management for Li-ion batteries. The system performance was characterized and compared with natural and forced air convection methods. The tests were conducted for a discharge rate of 1C, where HFE-7000 was used as the coolant. The results indicated that the maximum temperature in the battery pack reached 62°C under natural convection, which could damage the electrochemical cells. Moreover, the temperature distribution in the battery pack was not uniform. In the forced air convection experiment, the maximum temperature was reduced to 41°C, but the temperature non-uniformity persisted. The immersion cooling system demonstrated a uniform temperature distribution in the battery pack and a maximum temperature of 34°, improving the battery's performance and durability.

ACKNOWLEDGMENT

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