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The evaporation characteristics of liquid nitrogen coolant of HTS maglev in a low-pressure environment

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ABSTRACT

The evacuated tube provides a vacuum condition so that the high temperature superconducting (HTS) Maglev could run at an ultrahigh-speed. While inside the tube, the low-pressure environment could reduce air friction effectively, which is considered to be the main resistance to the Maglev. However, low-pressure would affect the evaporation state of liquid nitrogen (LN2), which is used as the coolant to ensure that the superconductor bulk could reach its superconducting state. This paper studied the evaporation characteristics of LN2 under different pressures, which influence the working time of the HTS Maglev vehicle directly. The results provide an important reference for the evacuated tube HTS Maglev.

1. Introduction

Since H. K. Onnes found superconductivity in 1911, people have been committed to applying it to various application fields [1]. Before the 1980s, the previous superconducting materials with a low critical temperature which need to work at the temperature of liquid helium greatly limit the development of the application. With continuous development of superconducting materials, Bednorz and Müller found the high temperature superconductor in 1986 [2], which soon increases the critical temperature to 90 K for YBaCuO superconductors. And the YBaCuO superconductor has broken through the liquid nitrogen (LN2) temperature barrier (77 K), which results in a rapid development of the superconducting technology. The high temperature superconductor (HTS) has been widely studied in different application fields such as HTS maglev vehicles, superconducting bearings and flywheel energy storage systems. At the end of 2000, the world's first manned HTS maglev testing vehicle was successfully launched in Southwest Jiaotong University, Chengdu, China [3]. No friction between the maglev vehicle and the guideway is a significant advantage of this new transportation tool, which makes the train be able to achieve a high speed. However, when the HTS maglev vehicle reaches a certain speed, air resistance will become a serious factor to limit the speed [4]. For that reason, the research team in Southwest Jiaotong University has further constructed an Evacuated Tube High-Temperature Superconducting Maglev prototype in 2014 [5] to study the running conditions of the maglev vehicle in a low-pressure environment. Due to the decrease of the air resistance, the HTS maglev vehicle can make a higher speed [6–8]. The evacuated tube HTS maglev transportation with advantages of high-speed, energy-saving, environmentally friendly and safety may be a fundamental solution to the traffic problems we are facing today, which will also bring changes to the global economy and social life [9].

With the development of HTS Maglev, the research of evacuated tube is of high-profile, and the pipeline transportation has already been gradually put into implementation [10,11]. Although the low-pressure environment in the evacuated tube helps reduce the air resistance, it brings new problems. One of the important issues is the evaporation state of the LN2. The HTS maglev vehicle cryogenic system consists of Dewars filled with LN2 and installed at the bottom of the vehicle [12]. The LN2 is used as refrigerant to ensure that the superconductor bulk could stay in superconducting state. If the YBaCuO superconductor bulks cannot be kept at a temperature below 90 K, they will lose their superconducting state, and the HTS maglev vehicle will not be suspended [13–16]. While the HTS

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maglev vehicle is running at a high speed, the quench of the superconductors will cause accident of derailment. Note that the low-pressure in the evacuated tube will affect the evaporation state of the LN2. In general, there are some speculations that lacking heat-transfer media in the low-pressure environment will lead to the reduction of the evaporation rate of LN2. Besides, there are many factors which can affect the evaporation state. Predecessors have made some researches [17–19], but they rarely involved vacuum conditions. Meanwhile, the effect of evacuation process on the evaporation state will also affect the working condition of the HTS maglev system. So in this paper, the evaporation state of LN2 under different vacuum degrees was investigated to obtain the comparative results between low-pressure environment and atmospheric pressure environment. Moreover, the experimental results can provide important reference of estimating the safe running time of the HTS maglev vehicle by one full package of LN2, and calculating the frequency of replenishing LN2 roughly in practice.

2. Experiment

2.1. Experimental set-up

The weighing method was used to decide the evaporation amount. Experiments were conducted firstly in a vacuum drying oven by using a precise electronic scale (accuracy of 0.01 g).

The vacuum drying oven was employed to provide the low-pressure condition. As shown in Fig. 1(a), there are one pressure gauge at the top and two valves on the right side, one of which is the outlet which is connected to a vacuum pump and the other is an adjustable air inlet. A foam box presented in Fig. 1(b) was used to play as the Dewar due to its good thermal insulating property. The capacity of LN2 of the box is 1.467 kg. The inner diameter of the box is 136 mm and the inner height is 125 mm. Also, there is a 20 mm hole at the center of the lid acting as the vent hole of the Dewar.

To get more accurate and practical results, the experiments were repeated in the evacuated tube, as shown in Fig. 2. The evacuated tube is connected with a computer-controlled water ring pump and roots pump which can provide a 0.1 atm (10.13 kPa) vacuum environment.

2.2. Measurement process

There are four parts of the research in this paper and the weighing method was used to measure the evaporation rate. The first part is the natural evaporation experiment for a better understanding of the LN2 evaporation. This part was conducted in the vacuum drying oven with the inlet valve opening to shield the effects of airflow above the liquid and also to keep the atmospheric pressure condition. The whole process lasted over 2 h and the data was taken every 30 min. Each group of data was read once a minute in ten minutes.

In the second part, a comparison of LN2 evaporation rate was made among the conditions of 30 kPa, 40 kPa and the atmospheric pressure. By adjusting the outlet and the inlet valves, the pressure in the vacuum drying oven gradually stabilized at the required value. During the evaporation, we adjusted the outlet to equalize the rise of pressure which was caused by evaporation. Then the data of each group was recorded once a minute in twenty minutes. And this experiment was repeated several times for verifying the results.

The third part investigated the effect of evacuation process on the evaporation state. From atmospheric pressure to 50 kPa, the whole process includes four stages shown in Fig. 6 and Table 2. And an evaporation curve under atmospheric pressure was used to compare with it.

In the fourth part, the evaporation experiments were conducted in the evacuated tube, and divided into two stages. The first one is the evacuation process from atmospheric pressure to 40 kPa, and the next one is that the pressure stabilized at 40 kPa. Using the computer-controlled vacuum pump can regulate the pressure in the evacuated tube to meet the experimental requirements. Similarly, a group of evaporation data under atmospheric pressure was used for comparison.

It is worth noting that, before the experiment starts, it is

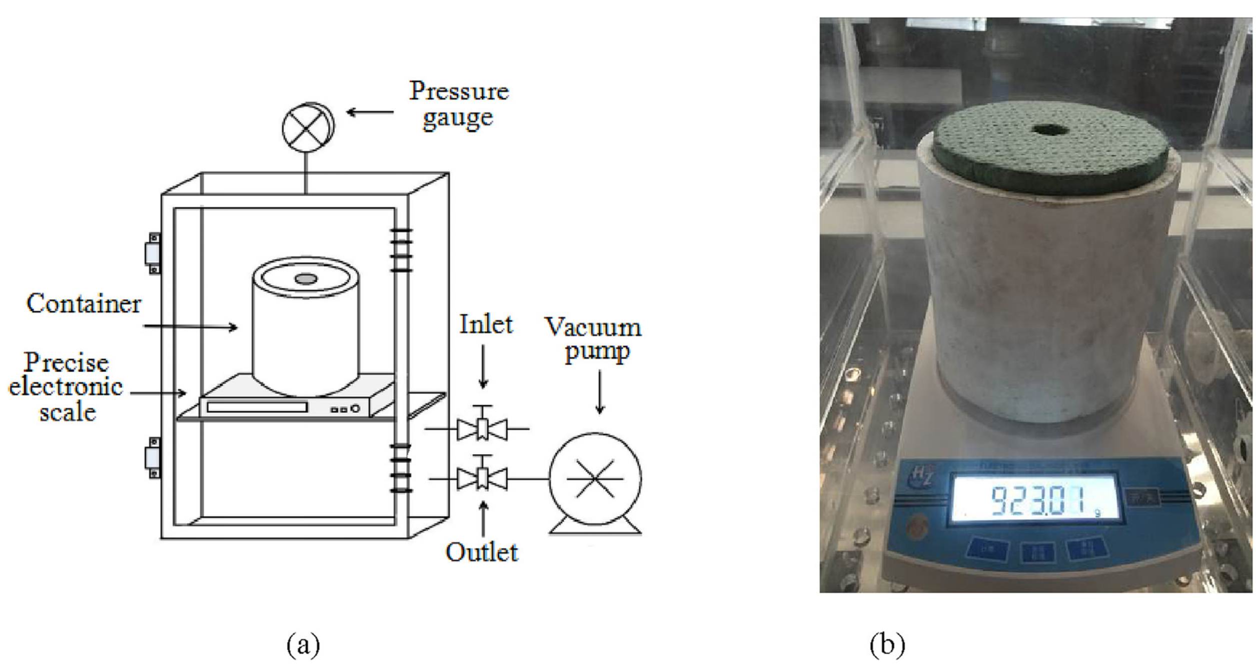

Fig. 1. Experimental set-up, (a) schematic diagram to study the evaporation state of the LN2 in a low-pressure environment by the weighing method in a vacuum drying oven; (b) photo of the precise electronics scale and the LN2 container.