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Experimental investigation on a new method of regenerating dehumidification solution—release solution droplet into vacuum

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HIGHLIGHTS

- Flash evaporation, as a new method to regenerate liquid desiccant, is investigated.
- Characteristic change is analyzed by comparing the values of different conditions.
- Pressure determines the degree of superheat.
- Absorbed heat affects the intensity of the evaporation.
- Radiant heat plays a decisive role in the process of flash evaporation.

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ABSTRACT

Flash evaporation, as a new method to regenerate dehumidification solution, is investigated in this paper. Droplets of lithium chloride and/or calcium chloride solution were suspended on the junction of a thermocouple, whose characteristic change was captured by high-speed camera, infrared camera, and thermocouple, and analyzed by comparing the values of different conditions. The results indicate that the pressure determines the degree of superheat, and the absorbed heat affects the intensity of the evaporation. A stronger surface tension caused by an increase in concentration or in change of solute weakens the intensity of water evaporation; a higher initial droplet temperature improves the evaporation intensity in the beginning stage, having no influence on its final temperature. The smaller the droplet diameter, the lower the minimum temperature is; radiant heat plays a decisive role in the process of flash evaporation, which is almost the only heat source provided to the droplet for evaporation in the stable stage.

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1. Introduction

When a water droplet is evacuated suddenly to an environment with a pressure below its saturation value, a rapid evaporation on the droplet surface occurs, and the sensible heat of the remaining part of the droplet is absorbed in the form of the latent heat of the water evaporated. Thus, the temperature of the droplet drops significantly. When the pressure is close enough to the triple point, fierce evaporation is called “flash evaporation”. Superheating, which can be divided into two situations, is a prerequisite of flash evaporation. One situation is heating the droplet while the heat cannot be transferred to the interior of the droplet quickly; superheating occurs only at the surface of the droplet. The second is suddenly releasing the droplet into a vacuum environment, which causes the entire droplet to reach a superheated state. Thus the flash evaporation happens not only on the surface but also inside the droplet, and consists of two stages—stage of rapid boiling and stage of surface evaporation.

Flash evaporation can be used widely in many fields, such as ice-making, seawater desalination, bio-pharmaceuticals, etc. The objective of this study is to investigate experimentally the flash evaporation preferences of solution droplets released into a vacuum for regeneration. Here the solutions, such as lithium chloride, calcium chloride, etc. are typically used in desiccant air conditioning systems. The idea comes from one of Japan’s patents, in which a novel transport and storage system is designed for the use of the waste cold from the gasification process of LNG [1], as shown in Fig. 1.

The system mainly includes a flash evaporator, a pipeline, and a cold trap. A phase change material (PCM) released to the

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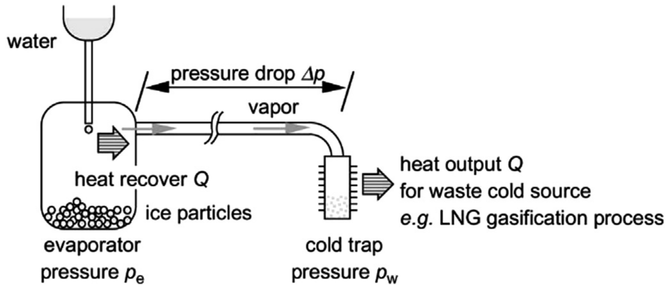

Fig. 1. A novel transport and storage system for waste cold from LNG gasification process [1].

evaporator is cooled by the heat absorption of its evaporation and ultimately freezes. The vapor in the evaporator flows into the cold trap through the pipeline, and is trapped and solidified on a heat transfer surface in the cold trap cooled by the cold from LNG. The driving force of the system is the pressure difference between the evaporator and the cold trap. However, because temperature differences lead to pressure differences, the actual driving force is attributed to temperature differences.

Based on the idea of the above system, if the temperatures of both sides increases simultaneously while maintaining constant low pressure in the evaporator, a similar transport process will still happen. In other words, this process will happen when the dilute solution flowing from the dehumidifier is heated by either waste heat or solar energy to approximately 95 °C, and the cold trap is replaced by a heat exchanger with cooling water at 32 °C flowing inside. The water in the droplets released into the vacuum evaporator will flash evaporate, and then water vapor is driven to the surface of the heat exchanger, finally liquefied into water. The temperature in the remaining part of the droplet drops significantly because the sensible heat of it is absorbed by evaporation. Therefore, the process can not only regenerate the solution, but also reduce its temperature.

To the best of our knowledge, flash evaporation has never been applied in the field of desiccant solution regeneration, but some research findings [2–4], involving droplet flash evaporation in other fields, can be used for the research in this paper. The representatives of the results are as follows.

Shepherd [5] and Avedisian [6] indicated that by suspending a droplet in the immiscible fluid, the image of the internal boiling process could be seen entirely and clearly with a wide range of superheated temperatures. Owen [7] observed the shape changes of droplets hanging in the thermocouple with the absolute pressure of approximately 850 Pa, and presented the basic characteristics in the different phases of the process. Yang and Wong [8] have studied the effects of heat conduction into the droplets through the fiber, and liquid-phase absorption of the radiation from the furnace wall, on the evaporation rate of droplets at micro-gravity conditions. They found that without considering these effects, there is a large discrepancy between their theoretical results and the experimental data of Nomura et al.

At the same time, various theoretical models were proposed to predict the values of evaporation. For example, Shin [9] obtained the characteristics of the change from droplet to ice by using the diffusion-controlled evaporation model, but the heat transfer dominating the evaporation process of the droplets has not sufficiently been expounded upon in this report, since temperature distributions in the droplets were neglected. Isao Satoh [10] developed a theoretical model that can predict the variation in droplet temperature when pressure is suddenly dropped.

In this paper, the detailed temperature transition within the droplet, of both the lithium chloride and calcium chloride solutions, is investigated in the process of flash evaporation. The objectives of this study are: to observe the temperature behavior both in the center and at the surface of a static solution droplet; to discuss how the factors, such as vacuum pressure, initial droplet temperature, and diameter and radiation heat, influence temperature behavior; and to analyze the effect of solution type and concentration on temperature. The experimental results will help in designing liquid desiccant regenerator.

2. Experimental setup

2.1. Test chamber

The schematic of the experimental system in this study is shown in Fig. 2. The test facility consists of a test vessel with two transparent windows on sides, a vacuum pump system, and a data acquisition system. To achieve the surface temperature of the droplets by using an IR themocamera, one of the windows installed on the test vessel was made of CaF_2. The vacuum pump system consists of a vacuum pump and a vacuum chamber. The vacuum chamber is connected to the vacuum pump and test vessel by a vacuum valve, respectively. In order to maintain a stable pressure during an experiment, the volume of the vacuum chamber is about 1000 times bigger than that of the test vessel. The data acquisition system is made up of an IR themocamera, a high-speed zoom camera, a thermocouple, a vacuum gauge, and an Agilent 34970A data collection system. The test vessel's height, length, and width are 100, 100, and 130 mm, respectively. Water of constant temperature was provided to flow through the intermediate interlayer of the test vessel, resulting in a constant indoor temperature. In order to reduce the effects of ambient temperature, insulation materials were used on the outside of the test vessel.

2.2. Measuring instruments

To investigate the flash evaporation performance, parameter values of droplets and working conditions were tested. The values required in the experiment consist of temperature, pressure, droplet diameter, and droplet concentration. An IR themocamera of high-resolution was employed to capture the surface temperatures

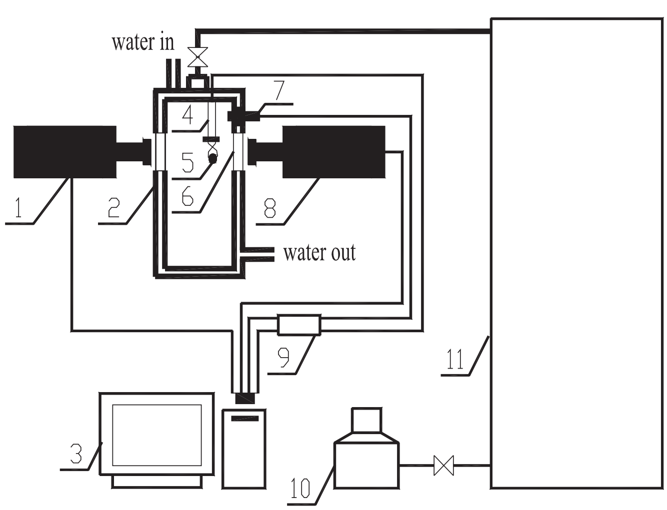

Fig. 2. Experimental apparatus. (1) High-speed zoom camera. (2) Test vessel. (3) Computer. (4) Thermocouple. (5) Solution droplet. (6) CaF_2 window. (7) Vacuum gauge. (8) Thermal infrared imager. (9) Agilent 34970A. (10) Vacuum pump. (11) Chamber.

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