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Experimental study on sorption and heat transfer performance of NaBr-NH_3 for solid sorption heat pipe

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ABSTRACT

NaBr is considered as one of the typical low temperature salts employed for solid sorption refrigeration. The novel concept of solid sorption heat pipe (SSHP) which integrates heat and mass transfer with solid-gas sorption technology is expected to fulfill the continuous heat transfer and alleviate the drawbacks of both conventional heat pipe and thermosyphon. In this paper, an experimental system for both sorption/desorption unit and heat transfer unit is designed and the experiments of non-equilibrium sorption/desorption performances of NaBr-NH_3 and heat transfer performances of SSHP with different molar amounts and inclination angles are carried out, respectively. The test results of sorption/desorption unit demonstrate that the increase of desorption quantity becomes very slow when the heating temperature reaches up to 75 °C and above, and with the increase of condensing pressure, the mass of ammonia desorbed from the ammoniate NaBr becomes less. The investigations of SSHP with 3 mol sorbates show that the heat transfer quantity increases significantly with the heating temperature reaches to 55 °C and above, in which the relatively higher desorption rate can be obtained. The largest value of heat transfer quantity per unit molar ammonia for 3 mol sorbates is close to that of 5 mol under the condition of heating temperature of 90 °C and cooling temperature of 20 °C. When the angle of inclination changes from 90° to 45°, the heat transfer capacity of SSHP declines more significantly compared with that of the angle from 45° to 0°.

1. Introduction

In recent years, more and more attention has been paid to the solid-gas sorption technology owing to the advantage of being absolutely benign for the environment (zero ODP and zero GWP) [1,2] and its high reaction heat and energy density [3,4]. Two main types of solid-gas sorption technologies are adsorption (physical) and chemical reaction, for which sorption happens both on the surface and inside of sorbents, i.e. has both features of absorption and adsorption [2,5]. Generally, a conventional intermittent solid-gas sorption system consists of a sorption bed, an evaporator, and a condenser. In the heating and desorption process, the solid sorbents filled in the sorption bed desorb the sorbates and the desorbed gas condenses in the condenser. While in the cooling and sorption process, the evaporation of the liquid sorbates occurs in the evaporator with the accompany of refrigeration effect [6]. Investigations on the solid sorption technology mainly focus on the sorption materials, working pairs, sorption cycles and performances [7–10]. For example, Thu et al. [9] discussed the analysis of an adsorption (AD) chiller cycle using system entropy generation, which is computed in terms of major dissipative losses in key components such as adsorber, desorber, evaporator and condenser. Kayal et al. [10] reported a detailed characterization and property evaluation of AQSOA zeolites (adsorbent) to form a working pair with water (adsorbate). They found that the water adsorption properties of AQSOA type zeolites are favorable for low temperature heat transmission applications. The metal halide-ammonia working pairs are the common working medium for chemisorption refrigeration and thermal energy storage, and the reaction can be driven easily by a wide temperature range of heat source, especially the low-grade heat source (below 150 °C).

Interesting connections can be evidenced in the literatures between sorption technology and heat pipe (HP), for instance the adsorption refrigeration systems integrated with heat pipes are reasonable for cooling and heating [11,12]. Prof. Wang [11] introduced several novel ideas to use heat pipes in adsorption water chiller or ice maker. A detailed work and experimental results showed that the adsorption refrigerators integrated with heat pipes are very efficient. Dr. Lu et al. [12] investigated the combination of the adsorption refrigeration system with heat pipe technology, in which heat pipe type heating/cooling/heat recovery is

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designed to improve heat transfer performance and adsorption performance.

HP is well known as a reliable and passive heat transfer device in which the capillary forces drive the continuous evaporation/condensation cycle to obtain an extremely high thermal transportation within a small temperature drop [13,14]. The research work in Shanghai Jiao Tong University have proved that HP could be used as heat exchangers for adsorbers, evaporators or condensers in adsorption water chiller, adsorption room air conditioner and adsorption ice maker for fishing boats [15–17]. All the studies above are working on the combination of HP with sorption systems for heat transfer intensification of the system, not for using the sorption technology itself to serve as the HP for heat transfer. Vasiliev et al. earlier proposed sorption HP in the publications [18,19]. They combined the conventional HP with the sorption/desorption phases of solid sorbents in which the conventional HP is used for the desorption and refrigeration processes of sorption system, and the working phases are intermittent for that the desorption and sorption phases need to be switched.

The solid sorption processes are difficult to be used for continuous heat transfer mainly because of the intermittent cooling and heating phases, and most previous studies for HP haven't concentrated on the solid sorption principle for substituting the wick and working fluid in conventional HP. In our previous work, a new concept of solid sorption heat pipe (SSHP) is proposed and its test unit for low-grade heat source is designed and set up [20]. The advantages of SSHP are as follows: (1) It employs the composite solid sorbents with the sorbates as the working pairs to substitute the working fluid in conventional HP. (2) The fundamental driving force of the cycle is the sorption effect, no longer the capillary force in conventional HP. (3) The combination of solid-gas, solid-liquid reaction and condensation process could transfer the thermal energy continuously from sorbent section to condenser section. Based on the preliminary study for verifying the feasibility of SSHP for heat transfer [20], in this paper, non-equilibrium sorption/desorption performances of compact composite sorbents (NaBr with ENG-TSA) are tested and presented firstly. Then the overall heat transfer performances of SSHP with different filling amounts of sorbates and different inclination angles are further investigated under different conditions.

2. Experimental system and testing procedures

Fig. 1 shows the structure of SSHP and the operation modes with different inclinations: (a) 90°, (b) 45° and (c) 0°. The solid sorbents (shadows in the figure) are filled in the sorbent section, and the sorbate is sorbed inside the solid sorbents.

The heat transfer mechanism of SSHP can be illustrated by two working phases:

(1) The heating and desorbing phase. In this phase the sorbent section is heated, and then the sorbate is desorbed and the vapor flows through the vapor channel to the condenser section.
(2) The condensing and liquid reflowing phase. In this phase the vapor at the condenser section is cooled, and then the film condensation starts at the inner walls and the vapor sorbate is condensed into the liquid working fluid with the release of latent heat of condensation.

The desorption performance of solid sorbent influences the performance of SSHP significantly, for which an experimental system which could test both sorption/desorption characteristic and heat transfer performance is designed, as shown in Fig. 2. It mainly consists of condenser/evaporator, sorption bed and one SSHP.

2.1. Non-equilibrium performance test

2.1.1. Test procedures of p-T-x curves

The test procedures are as follows [21]:

(1) First the temperature of condenser is controlled by one cryostat at the condensing temperature. The temperature of sorbent in sorption bed is controlled by one cryostat at the desorption temperature. In this process, open the valves (V3 and V4) between the sorption bed and condenser. The sorbate sorbed by the sorbent in bed desorbs to the condenser and condenses there, and the value of pressure, temperature and differential pressure are collected by the data collector. For a fixed condensing temperature the desorption process of sorbent completes when the level in the vessel reaches a predetermined value.
(2) After the first step the valves are closed. The temperature of the sorption bed is controlled by the cryostat from the highest desorption temperature to the data below environmental temperature, and for each test point the temperature and pressure of the bed are collected when the data do not change.
(3) The above procedures are repeated and the data for different sorption quantities are collected.

2.1.2. Test procedures of isobaric sorption/desorption performance

The test procedures are as follows [21]:

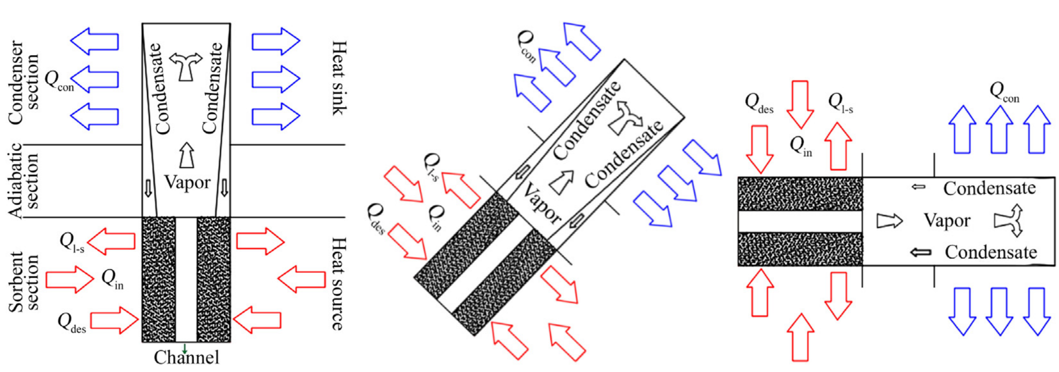

Fig. 1. The structure and operation of SSHP: (a) 90°; (b) 45°; (c) 0°.