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Research paper

Effect of desorption parameters on performance of solar water-bath solid adsorption ice-making system

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HIGHLIGHTS

- Novel solar water-bath solid adsorption ice-making system.
- Adsorbent bed temperature in water bath was homogeneous.
- Influences of desorption temperature and time on performance were studied.
- Maximum daily ice-making capacity of 7.7 kg was achieved.
- 10 h was the optimal desorption time.

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ABSTRACT

A novel solar water-bath solid adsorption ice-making system with activated carbon-methanol as adsorption working pairs was designed and constructed. The experimental results demonstrated that the desorption temperature and the desorption time had important influences on performance of the ice-making system. The daily ice-making capacity of 5.1 kg and refrigeration cycle coefficient of performance (COP) of 0.0322 could be obtained when the desorption temperature was maintained at 94 °C. However, there were no ice-making phenomenon when the desorption temperature was respectively maintained at 85 °C and 75 °C. With the increasing of desorption time from 7 h to 12 h when the desorption temperature was maintained at 94 °C, the COP of the system dropped gradually from 0.0507 to 0.0370, and the heat utilization efficiency decreased from 0.5969 to 0.4608 due to the gradual increase of energy imported into the system. The daily ice-making capacity increased rapidly from 5.5 kg to 7.6 kg when the desorption time increased from 7 h to 10 h, however, the daily ice-making capacity increased slightly from 7.6 kg to 7.7 kg when the desorption time was increased from 10 h to 12 h. There was an optimal desorption time of 10 h for the system.

1. Introduction

The human society is facing the increasingly serious environmental problems and the energy crisis today, especially the energy consumption for air condition takes more than 15% of the total energy consumption [1]. Solar energy is an environmentally friendly and infinite reserves energy resource, however with disadvantage of low energy density. The adsorption refrigeration technology may utilize low temperature heat sources [2], such as solar energy, to produce cooling, and has potentiality to meet the enormous cooling consumption demand by utilizing green energy.

Many adsorption refrigeration researches focused on the areas of developing novel high efficiency adsorption working pairs [3–6], heat and mass transfer enhancement during adsorption and desorption process [7,8] as well as optimization of the structure [9,10] and refrigeration cycle of adsorption refrigeration system [11–14]. These researches have made some progress. Critoph [15] and Meunier [16] concluded that the activated carbon-methanol (water) pair was superior to the molecular sieve-methanol (water) pair for the low temperature heat source below 150 °C. Amir Sharafian [17] and Ji [18] optimized the heat and mass transfer structures in finned-tube absorbent bed to promote the cooling performance. R.Z. Wang [19] proposed a mass and heat recovery

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cycle. The coefficient of cooling performance (COP) and specific cooling power (SCP) were improved at least by 35% and 25%, respectively. Z.S. Lu [13,20] investigated the combined mass-heat recovery in adsorption refrigerator. The averaged specific cooling power (SCP) of the cycle with and without mass recovery was 502.9 W/kg and 436.7 W/kg respectively. The cycle time was also shorted.

The temperatures in adsorption/desorption cycle, especially the desorption temperature provided by heat source, had a significant impact on the performance of system. In a continuous adsorption refrigeration system powered by parabolic trough solar collector [21], the heat source temperature reached at 120 °C. The increase of the heat source temperature improved markedly the cycle COP, the solar COP and the specific cooling power. However, solar parabolic trough concentrating system was also inevitable to bring the greatly increase of cost. Kubota [22] demonstrated that COP increased slightly with the increasing of hot water temperature in an adsorption chiller. S.W. Hong [23] performed a numerical analysis on the performance of a fin-tube type adsorption chiller associated with heat and mass transfer mechanisms. The temperature of hot water and the fin thickness were the dominant parameters for coefficient of cooling performance (COP) and specific cooling power (SCP). A novel silica gel-water adsorption chiller with two chambers was built [24]. the refrigerating capacity and the coefficient of cooling performance of the chiller are, respectively, 8.69 kW and 0.388 when the heat source temperature and the cooling water temperature are, respectively, at 82.5 °C and 30.4 °C. J. Wang [25] investigates a two-stage adsorption freezing machine powered by the heat source with the temperature below 100 °C. COP and SCP increased with the increasing of heat source temperature.

Traditionally, the cycle period of solar driven adsorption refrigeration is 24 h, that is an adsorption/desorption cycle per day. However, the actual necessary times for adsorption and full desorption are still unrevealed. Saha [26] presented a modelling of an adsorbent bed with annular fins for silica gel-water system, and examined the effects of cycle time, switching time and heating temperature on COP and cooling capacity. In their analysis, higher COP and cooling capacity were obtained when the cycle time was larger and the heating temperature was higher. Khairul Habib [27] found that COP and chiller efficiency increase with longer adsorption/desorption cycle time. However, after a period of time, the increase of COP and chiller efficiency becomes marginal. It could be thought that the refrigerant had been desorbed to the maximum amount, which could be desorbed at the desorption temperature, a longer desorption time could not increase the desorption amount.

In this paper, a novel solar water-bath solid adsorption ice-making system was built. The adsorbent bed was heated in water bath at the desorption stage with the functions of energy storage and stable energy input. The thermal energy of the water bath originated from solar vacuum tube collector, so the heat source temperature ranged from 50 °C to the boiling point of water. The system performances were characterized with change of the desorption temperature and desorption time.

2. Structure and working principle of system

As was shown in Fig. 1, solar water-bath solid adsorption ice-making system was consist of solar collector, thermal insulation water tank, heat storage water tank, adsorption generator (adsorbent bed), condenser, evaporator, vacuum valves and vacuum pressure gauges. The working circulation process of the system contained heating desorption and cooling adsorption, the refrigerant desorption process was conducted during the day, the solar radiation was collected by solar collector to heat the water, and the adsorbent bed was heated by hot water. The energy from solar radiation was received by adsorbent bed to make the inner temperature of adsorbent bed gradually increased. The refrigerant (methanol) would be desorbed from the adsorbent (activated carbon) in the adsorbent bed with the increase of inner temperature of adsorbent bed. The desorbed refrigerant vapour flowed into the condenser to be condensed, and the condensed liquid refrigerant was stored in the evaporator. The adsorption process mainly took place during the night, the solar collector stopped providing energy for adsorbent bed, and the hot water in thermal insulation water tank was transferred into the heat storage water tank to storage, and the cooling water was injected into the thermal insulation water tank to cool the adsorbent bed quickly. The temperature and pressure of adsorbent bed decreased gradually with the injection of cooling water, when the pressure of adsorbent bed decreased to the value which could meet the evaporation requirement of refrigerant, the refrigerant in evaporator would boil and evaporate due to the adsorption effect of adsorbent in adsorbent bed, and the refrigeration effect would be generated, then the adsorption process was completed. This ice-making system had the function of hot water and energy storage, which could avoid the disadvantageous effect of no solar radiation caused by bad weather or night in the desorption process. Therefore, the problem of time restriction existing in the desorption process for solar adsorption ice-making system could be solved. Further study was focused on the optimization of desorption time for refrigeration cycle, which was expected to realize the multiple circulation of the system.

The adsorbent bed was located in the thermal insulation water tank (1520 × 780 × 800 mm), which was made of tin shell and was filled with thermal insulation material in the middle.

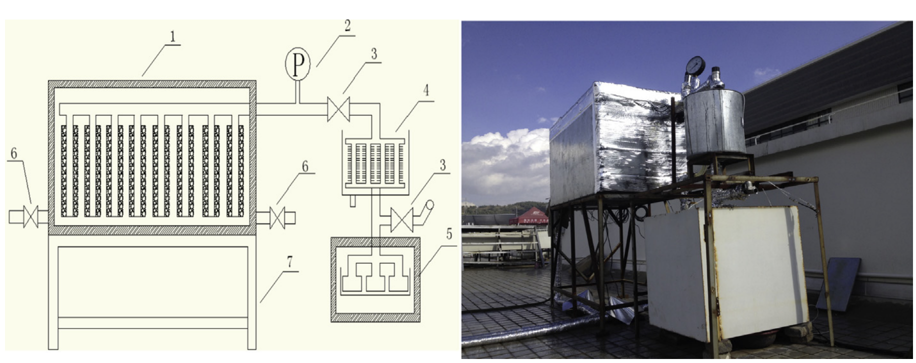

Fig. 1. Configuration and working principle of system. 1. Adsorption generator (adsorbent bed), 2. Vacuum pressure gauge, 3. Vacuum valve, 4. Condenser, 5. Evaporator, 6. Ball valve, 7. Support