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Research Paper

Investigation on air flow patterns of evaporative cooling and dehumidification process for a hybrid refrigeration system

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HIGHLIGHTS

- Air flow patterns for refrigerant subcooling are studied in a hybrid system.
- Close-pattern and open-pattern are achieved based on ambient air ratios R_{amb} (0-1).
- Open-pattern ($R_{amb} = 0.3$) is suggested under typical climate condition.
- Close-pattern ($R_{amb} = 0$) is proposed under extremely humid climate condition.
- Maximum COP_{imp} 12.3% is obtained and optimum working parameters are suggested.

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ABSTRACT

In this paper, two different air flow patterns (close-pattern and open-pattern) are studied to achieve the optimum configurations of a hybrid refrigeration system, in which the refrigerant is subcooled by evaporative cooling of dry air dehumidified by the liquid desiccant. With different ambient air ratios (R_{amb}), full return air ($R_{amb} = 0$) is used in the close-pattern; full ambient air ($R_{amb} = 1$) and mix air ($0 < R_{amb} < 1$) are chosen in the open-pattern respectively. Comparisons of the close-pattern and open-pattern are made under typical climate condition and extremely humid climate condition. Both of the close-pattern and open-pattern ($R_{amb} = 1$) show much higher *COP* than the traditional refrigeration system, with the maximum *COP* improvement 12.3% and 9.8%, respectively. Under typical climate condition, the open-pattern ($R_{amb} = 0.3$) is suggested, the regenerator size has little influence on the system performance and the optimum mass flow ratio of ambient air to solution ($\dot{m}_{amb}/\dot{m}_s$) is between 0.5 and 2 in the regenerator; under extremely humid climate condition, the close-pattern is proposed, the optimum $\dot{m}_{amb}/\dot{m}_s$ is 0.4 and larger regenerator size is suggested. In addition, the latent and sensible heat capacities in the indirect evaporative cooler are illustrated. These findings will be beneficial for the system design and optimization.

1. Introduction

In recent years, liquid desiccant dehumidification method has been widely proposed in the air-conditioning system [1]. The liquid desiccant has the ability to remove moisture from process air, and can recover this ability with lower heat source temperature, which allows the utilization of the low-grade heat source (solar energy or waste heat). What's more, the liquid desiccant has some other advantages such as the capability to remove pollutants and energy storage.

Considerable investigations have been carried out on a variety of hybrid liquid desiccant air conditioning systems. One of the most popular studies is the heat pump driven liquid desiccant air conditioning system [2–4], where the process air is dehumidified by the liquid desiccant and cooled by the evaporator. Some researchers focused on other kinds of hybrid liquid desiccant air conditioning systems [5–9]. Dai et al. [5] established a hybrid system which consisted of desiccant dehumidification, indirect evaporative cooling and vapor compression air conditioning. The dehumidified air was pre-cooled through the indirect evaporative cooling and then further cooled in the evaporator. Tu et al. [6] investigated a novel air-conditioning system, where the air was first dehumidified in the dehumidifier and then sensibly cooled in the indirect and direct evaporative coolers. Zhang et al. [7,8] proposed a hybrid air conditioning system, in which frosting could be retarded by dehumidifying air before entering an outdoor heat exchanger in winter. Yin et al. [9] introduced a liquid desiccant evaporative cooling air conditioning system. In this system, the dry air leaving the dehumidifier went into the evaporative cooler to generate cold water for the cooling need in the room.

Strategies for design and optimization of the hybrid liquid desiccant air conditioning systems have also been studied [10–13]. Ge et al. [10] developed control methods for the supply air

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dehumidification and desiccant solution regeneration processes. Niu et al. [11] studied the effect of fresh air ratios on the liquid desiccant air conditioning system. The maximum power saving ratio was 58.9% when the fresh air ratio was 20%. Li and Yang [12] presented numerical simulation results of an open cycle liquid desiccant dehumidification system, attempting to obtain the best configurations of the solar assisted air-conditioning system.

A novel vapor compression air conditioning system coupled with liquid desiccant dehumidification was proposed in our previous paper [14], where the refrigerant was subcooled by the evaporative cooling of the dehumidified air in the indirect evaporative cooler. In this paper, control strategies of air flow patterns in the dehumidification and evaporative cooling process are studied. Two different air flow patterns (close-pattern and open-pattern) are realized based on different ambient air ratios (R_{amb}). In the close-pattern, full return air ($R_{amb} = 0$) is used. In the open-pattern, the ambient air ratio (R_{amb}) is varying to make use of the full ambient air ($R_{amb} = 1$) and the mixture of the return air and ambient air ($0 < R_{amb} < 1$). Comparisons are made between the close-pattern and open-pattern under the typical climate condition and extremely humid climate condition in Nanjing, China. The optimum working parameters for the open-pattern and close-pattern are also illustrated.

2. System description and air flow patterns

2.1. System description

The hybrid vapor-compression refrigeration system subcooled by liquid desiccant dehumidification and evaporative cooling is composed of a refrigeration cycle, an air cycle and a liquid desiccant cycle, as shown in Fig. 1. The refrigeration cycle includes an evaporator, a compressor, a sensible-heat condenser, a latent-heat condenser, an indirect evaporative cooler and a throttle valve. The air cycle consists of an indirect evaporative cooler, an air-to-air heat exchanger, a dehumidifier and an air cooler, while the liquid desiccant cycle is composed of a dehumidifier, a solution cooler, a solution-to-solution heat exchanger, a regenerator, a sensible-heat condenser and a latent-heat condenser. In the proposed vapor-compression refrigeration system, the liquid refrigerant at the outlet of the

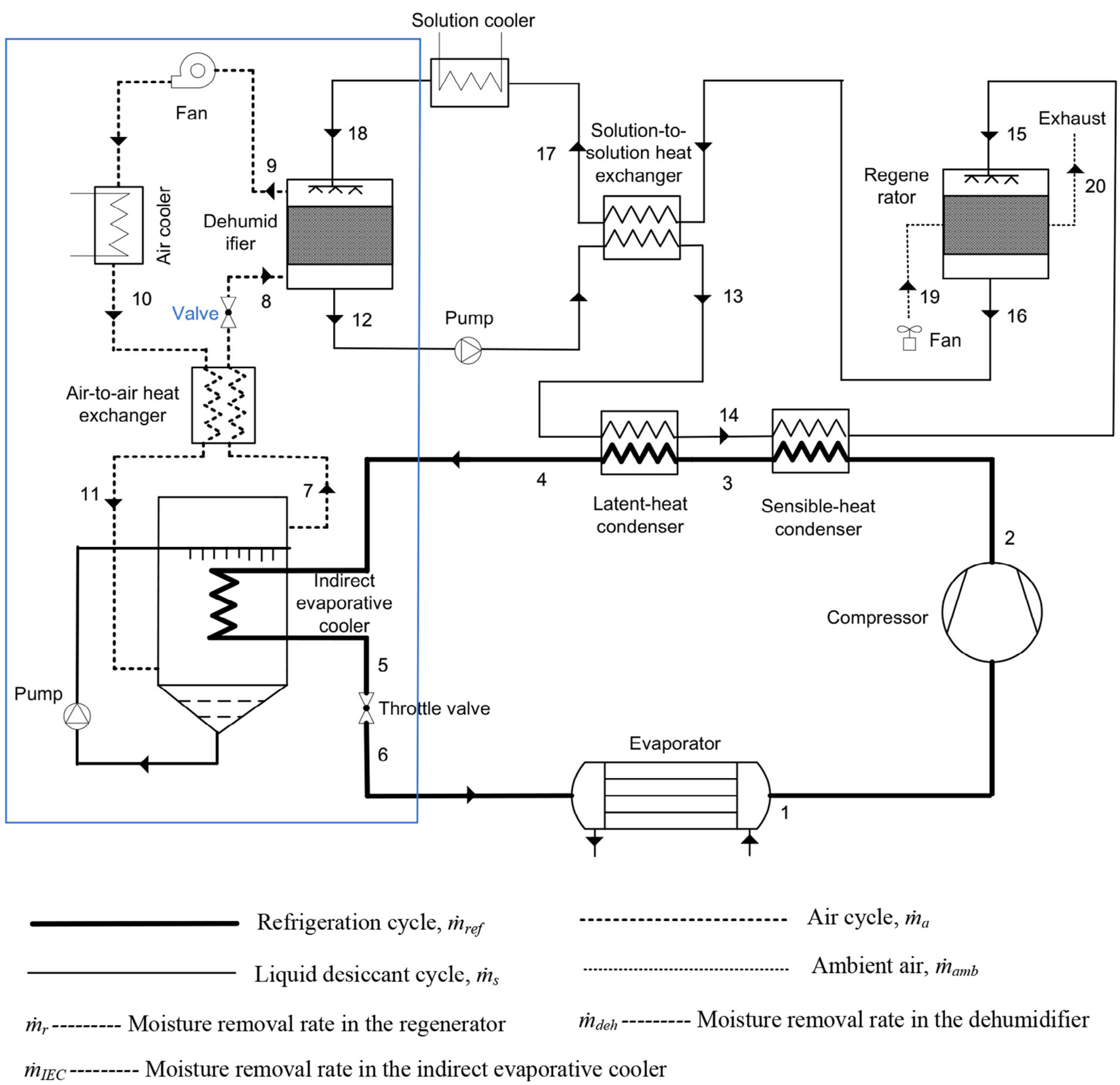

Fig. 1. The hybrid vapor-compression refrigeration system subcooled by liquid desiccant and evaporative cooling.