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Performance analysis of a counter-flow indirect evaporative cooling system

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Abstract. A counter-flow regenerative indirect evaporative heat exchanger (RIEHX) was introduced and investigated. This paper aims to conduct an experimental study for the RIEHX to investigate the cooling performance under different operating conditions. The experimental prototype was able to adjust the inlet air flow rate and temperature. The thermal performance of the RIEHX was tested with variable inlet conditions. The experimental results have demonstrated that the supply air can be effectively cooled along the product air flow passages by transferring heat to the wet side of the RIEHX due to water evaporation. Under a constant inlet air velocity, the product air with a higher inlet temperature can obtain a larger temperature reduction. In addition, a lower air flow rate may enhance the cooling effect due to the increased contact duration between the air streams. The proposed system is able to improve the cooling effectiveness of the conventional plate-type indirect evaporative cooler.

1. Introduction

The evaporative cooling technique is an effective and energy saving air-conditioning approach. The air cooling process can be achieved due to the phase change of liquid water to water vapor, which can produce cooled air using much less energy than refrigeration [1]. The evaporative cooling technique are getting more and more attention for air cooling applications [2,3]. The indirect evaporative cooler (IEC) is a key component to provide cooled air by taking advantage of the water evaporation process [4]. The IEC is usually a type of heat and mass exchanger comprising two separated air streams, namely, the product air and the working air [5]. The water is supplied to form the water film on the surface of the channel. The water film directly interacts with the working air. For a conventional IEC, the theoretical achievable lowest temperature is considered as the ambient wet-bulb temperature [6].

Research works have explored possible approaches to adapt the arrangement of the conventional IEC for the purpose of improving the cooling effectiveness [7]. The regenerative indirect evaporative heat exchangers (RIEHX) is capable of achieving a larger temperature reduction for the supply air compared with a conventional IEC [8,9].

The objective of the paper is to introduce a counter-flow RIEHX and study its thermal performance. The flow arrangement of the proposed RIEHX is first describe, followed by the illustration of the experimental setup. The experimental results of the RIEHX is finally presented in terms of the temperature variation.



2. Experimental setup

The one-unit air treatment flow passage of the proposed counter-flow RIEHX is schematically presented in figure 1. The RIEHX consists of alternate working and product channels. The intake air is initially taken into the product channel, while the perforated plate is able to partially branch the pre-treated air flowing into the adjacent working air passages. The diverted air is then contacted with the water film covering the wet channel surface. The schematic of the experiment for the RIEHX is illustrated in figure 2. The measurement was carried out under different conditions. Figure 3 indicates the sensors' location in the counter-flow RIEHX. The measured parameters included the temperature, relative humidity, and velocity at the inlet and outlet in the RIEHX.

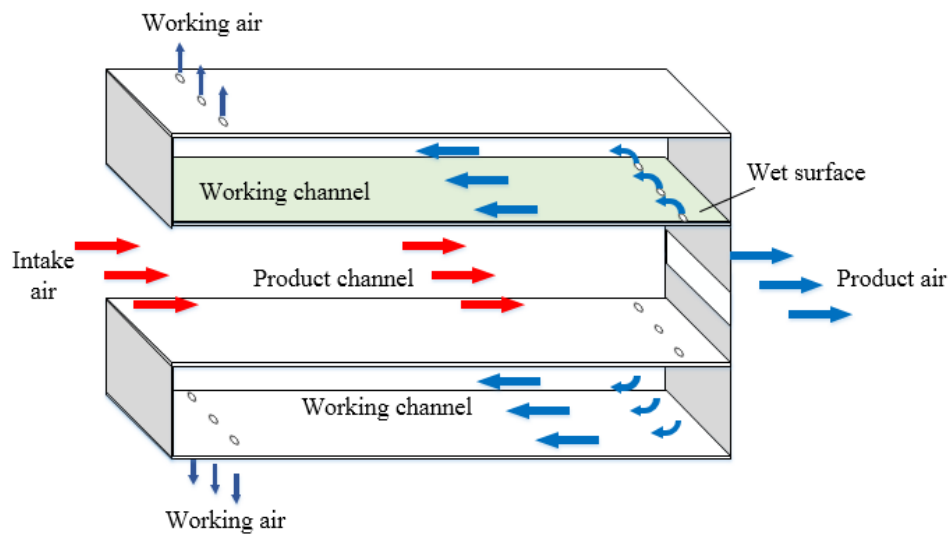


Figure 1. One-unit air treatment flow passage of the RIEHX.

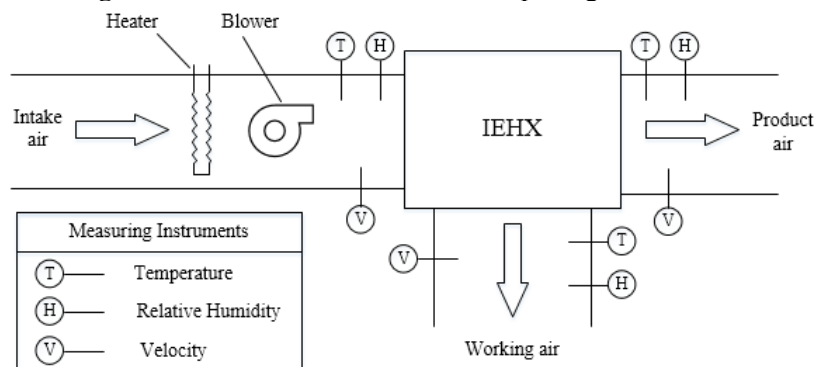


Figure 2. RIEHX experimental setup.

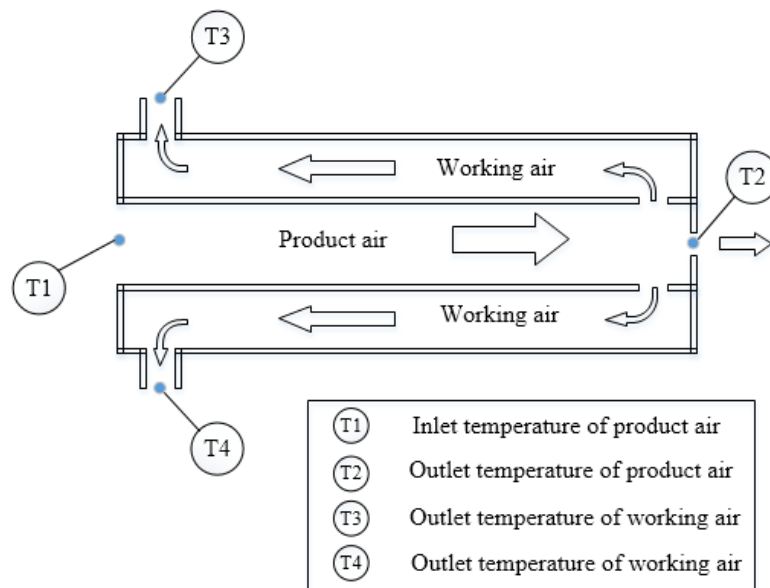


Figure 3. Location of the temperature sensors in the counter-flow IEHX

3. Results and discussion

3.1. Temperature variation

Figure 4 presents the variation of air temperature at four measured locations. The experimental data was collected after the system achieve a steady operating condition. The inlet air velocity was adjusted at 1.5 m/s, while its dry bulb temperature was kept around 28 °C.

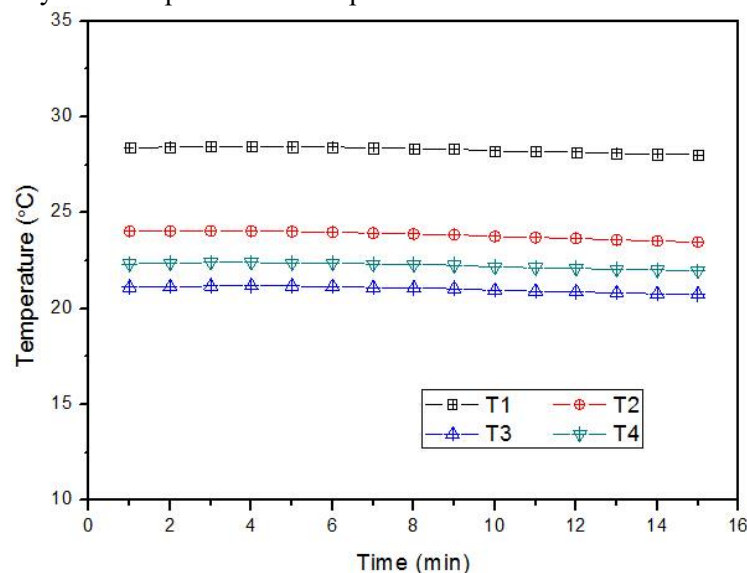


Figure 4. The variation of air temperature at different measured locations.

As shown in figure. 4, the steady-state air temperatures were almost constant. For example, the product air outlet temperature spanned 23.47 °C to 24.05 °C, and its average value was 23.84 °C. The experimental results demonstrated that the product air temperature was effectively reduced by transferring heat to the wet side of the RIEHX. However, in figure 4, it is noted that the working air outlet temperature was slightly lower than the product air outlet temperature. This observation implied

that the RIEHX had not fully utilized the working air's cooling potential. In other words, the RIEHX can be further improved for achieving a higher cooling effectiveness. Another finding in the experiment was that the wicking material in working channel was usually partially wetted. The partial wetting may deteriorate the water vapour mass transfer resulting in a lower cooling efficiency due to the decreased wetting surface area.

3.2. Cooling performance

The performance of the RIEHX was evaluated by investigating the impact of inlet conditions on the change of product air temperature. Figure 5 shows the product air outlet condition of the RIEHX under different operating conditions.

It can be seen from figure. 5 that the product air generally has a higher outlet temperature for increased inlet temperature. In addition, it is observe that the increased inlet product air temperature obtains a larger temperature reduction. For example, the product air outlet temperature ranged from 19.07 °C to 21.67 °C, while the reduction of product temperature increased from 4.80 °C to 6.57 °C. It can be attributed to the reason that the working air has higher potential to vaporise water for increasing the dry bulb temperature. Therefore, the wet working channel is able to absorb more sensible heat and reduce the temperature for the dry side of the RIEHX.

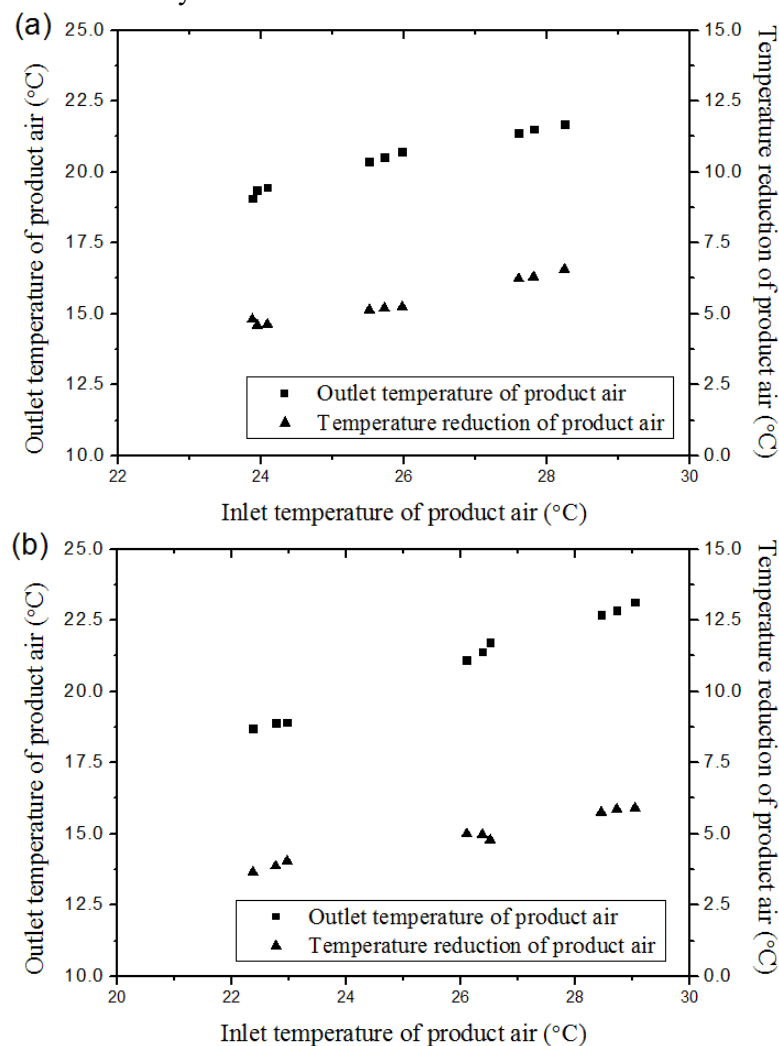


Figure 5. Product air outlet conditions under varying inlet temperatures. (a) for intake air velocity of 1.5 m/s; (b) for intake air velocity of $V=2.0\text{m/s}$.

Another finding was that a higher inlet velocity leads to an increased product air outlet temperature under a constant inlet temperature. It is probably a consequence of the fact that a lower intake air flow rate may enhance the cooling processes due to the increased contact duration for the air streams. For example, the product air outlet temperature spans 21.67°C to 24.05°C for a higher flow rate.

4. Conclusions

An experimental study has been proposed to explore the cooling process of a counter-flow RIEHX. The air flow passages has been designed according to the modification on an M-cycle arrangement. Based on the experimental results, the proposed RIEHX has been demonstrated to have the ability to provide cooled product air with remarkable cooling potential.

Acknowledgements

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