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ORIGINAL ARTICLE

Performance improvement of a hybrid air conditioning system using the indirect evaporative cooler with internal baffles as a pre-cooling unit

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Desiccant material;
Solar air collector;
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Abstract In the present paper, the effects of the indirect evaporative cooler with internal baffle on the performance of the hybrid air conditioning system are numerically investigated. The hybrid air conditioning system contains two indirect evaporative coolers with internal baffle, one is utilized to pre-cool the air inlet to the desiccant wheel and the other is utilized to pre-cool the supply air inlet to the room. The effects of the inlet conditions of the process and reactivation air and working air ratio on the thermal performance of the hybrid air conditioning system have been analyzed. The results of this study show that in the hybrid air conditioning system for using the indirect evaporative cooler with internal baffle as a pre-cooling unit, the supply air temperature reduced by 21% and the coefficient of performance improved by 71% as compared to previous designs of the hybrid air conditioning system at the same inlet conditions. For increasing process air inlet temperature from 25 °C to 45 °C, supply air temperature increases from 12.7 °C to 14.2 °C, thermal COP increases from 1.87 to 2.84, and supply air relative humidity increases from 76.7% to 77.4%. Also, for increasing the reactivation air inlet temperature from 70 °C to 110 °C, supply air temperature dropped from 15.9 °C to 10.9 °C, supply air relative humidity dropped from 82.7% to 71.8%, and thermal COP dropped from 4.5 to 1.7. The recommended optimal air working ratio in the indirect evaporative cooler with internal baffle should be 0.15.

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Nomenclature

A	area (m^2)
a	slope of saturation line (J/kg K)
C_p	specific heat (J/kg K)
F_R	heat removal factor
F'	collector efficiency factor
G_t	total solar energy (W/m^2)
h	specific enthalpy (J/kg)
k_m	coefficient of mass transfer ($kg/m^2 \cdot s$)
L	wheel thickness (m)
$\dot{m}$	air flow rate (kg/s)
N	wheel rotation speed (rph)
NTU	number of heat transfer units
P_p	channel perimeter (m)
Q_u	useful heat (W)
Q_c	cooling load (W)
Q_r	energy inlet to regeneration air (W)
T_d	desiccant temperature (°C)
U	velocity (m/s)
U_L	heat loss coefficient (W/m^2 °C)
W	ratio of water mass in desiccant wheel (kg_v/kg_w)

Greek symbols

α	absorptance
τ	transmittance
ε	effectiveness
ω	humidity ratio ($kg_w/kg_{dry\ air}$)
δ	sum thickness of water film and wall
β	coefficient of mass transfer ($kg/s/m^2$)
α_d	coefficient of convective heat transfer in dry channel

Subscripts

In	inlet
R	regeneration air
S	supplied air
IEC	indirect evaporative cooler
CPHE	cross flow plate heat exchanger

1. Introduction

The continuous rise in the environmental temperature due to a global warming affects the future air conditioning requirements. The conventional air conditioner consumes the large amount of electrical energy. The desiccant air conditioning system and dehumidification are a good alternative to the conventional air conditioner for protection of environmental and energy saving. The desiccant air conditioning systems use pure water as refrigerant and it can be driven by low-values of thermal energy.

White et al. [1] experimentally studied the performance of solar desiccant cooling system at different design and the operating parameters. Ge et al. [2] experimentally studied the effect of desiccant wheel thickness on the system performance, for using one-rotor two-stage rotary desiccant wheel at various rotation speeds. Ge et al. [3] performed the experimental analysis of the performance characterization of two-stage rotary desiccant system. A mathematical simulation by [4–7] investigated the influence of various parameters on the behavior of the desiccant system. Jae et al. [8] numerically investigated the effect of the wheel rotation speed and the area ratio of reactivation to dehumidification process on the behavior of desiccant wheel. Panaras et al. [9] studied the effect of specific conditions on the performance analysis of a desiccant air conditioner. Elzahzby et al. [10] presented the numerical model to study the effect of inter cooling on the thermal performance of hybrid air conditioner assisted by solar energy at different operating conditions. Elzahzby et al. [11] presented a mathematical model for comparison between the performances of the hybrid air conditioner for using one rotary desiccant system divided into two-stage, four-stage, and six-stage. Also, Elzahzby et al. [12] conducted the mathematical simulation to study the effect of reactivation air inlet condition and area ratio of the dehumidification to reactivation air at different wheel rotation speeds on the performance hybrid air conditioner for using six-stage rotary desiccant wheel.

Kamel [13] investigated the performance analysis of air conditioner for using a hybrid desiccant-vapor compression system. The results show that, for using the hybrid system, at the peak load the size of the vapor compression subsystem in the hybrid air conditioning system is reduced from 23 kW to 15 kW. Ge et al. [14] studied the performance of a solar driven hybrid desiccant-vapor compression system in two cities with different environmental conditions. They found that, the hybrid system has less electrical consumption compared to the conventional vapor compression system.

Jongsoo et al. [15] studied the performance of the hybrid air conditioner for using four-partition rotary desiccant wheel. The influences of various designs and operating parameters on the performance characteristics of hybrid system are investigated. Dong et al. [16] studied the performance of the hybrid air conditioner. The result shows that for the hybrid air conditioner at reactivation temperature of 80 °C, the thermal performance reached to 1.0 and the electric performance reached to 8.0. Ge et al. [17] investigated the performance of desiccant system for using one rotor- single-stage, two-stage rotary desiccant system. The result shows that, at the same reactivation temperature, cooling capacity of two-stage system increases by 40% compared to the cooling capacity of one-stage system.

Kabeel and Mohamed Abdelgaied [18] studied the influence of internal baffles on the behavior of indirect evaporative cooler, and the result showed that, the outlet cooling air temperature decreased by 20.5% and average wet bulb effectiveness increased by 43% for using the internal baffles compared to the case without internal baffles. Kabeel et al. [19] experimentally studied the effect of indirect evaporative cooler with internal baffles as a pre-cooling unit on the performance of evaporative condenser.

This work aims to improve the performance of the hybrid air conditioning system. The effects of the indirect evaporative cooler with internal baffle on the thermal performance of hybrid air conditioner system are numerically investigated. The present hybrid air conditioning system contains two indirect evapora-

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