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Performance of desiccant air conditioning system with geothermal energy under different climatic conditions

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ABSTRACT

Energy saving still and continue a major seek in our life, due to the continuous increase in energy consumptions. So, a desiccant air conditioning system with geothermal energy is conducted in the current study. The thermal analysis of air conditioning system with its different components desiccant wheel, solar collector, heat exchanger, ground heat exchanger and water spray evaporative cooler is presented. Three different air conditioning cycles are simulated in the current study for different zones like: hot-dry zone, warm-dry zone, hot-humid zone and the warm-humid zone. The results show that the desiccant air conditioning system successfully provides a better thermal comfort condition in different climates. This hybrid system significantly decreases the supplied air temperature from 12.7 to 21.7 °C at different climate zones. When $\omega_{in,air}$ and T_{Reg} increasing, COP decreases and the ventilation cycle provides the better COP. The highest COP value of the desiccant air conditioning system is about 1.03 while the lowest value is about 0.15. The SHR of makeup cycle is higher than that ventilation cycle at warm and hot-humid zone and vice versa at warm and hot-dry zone. The highest SHR value of the desiccant air conditioning system is about 0.99 while the lowest value is about 0.2. The $T_{sup,air}$, $\omega_{sup,air}$, COP and SHR isolines may easily be used for pre-evaluating of various cooling cycles in different climates. The hybrid system provides a human thermal comfort at different climates.

1. Introduction

The effect of climate conditions on health have been increased attention in recent years. In the past, the air conditioning was restricted to hot climates, but a steep increase in its usage is now seen in moderate and even mild climates due to improved air tightness and better insulation of buildings. Especially in hot-humid areas, air conditioning systems consume a large amount of electrical energy. Desiccant cooling and air dehumidification systems are a good alternative to the traditional air conditioning systems and establish in humid air climate countries. Geothermal Heating and Cooling Systems (GHCS) provide space conditioning cooling and heating capacity.

Ge et al. [1] performed an experimental analysis of a desiccant cooling cycle with two dehumidification stages in a single desiccant wheel. Bourdoukan et al. [2] presented a comparison between ventilation and recirculation operation modes and obtained critical values for cycle component performance characteristics required to produce a given supply air temperature condition. Meckler [3] proposed two-stage solid desiccant air conditioning system integrating with the HVAC system. This kind of two-stage system had also been introduced by Henning [4]. In addition, Mei et al. [5] developed a two-stage desiccant unit for fast-food restaurants. Moreover, Zhang and Niu [6] discussed the use of low regeneration temperature in two-stage desiccant cooling system. Simulation results show that the lower regeneration temperature was required less than for single-stage desiccant cooling system. To date, extensive studies on rotary desiccant air conditioning have been carried out on the basis of mathematical simulation by Nia et al. [7] and Ge et al. [8]. Also, Chung et al. [9] conducted numerical simulation for the desiccant wheel, which was the crucial component of a desiccant cooling system. Ge et al. [10] established a mathematical model for predicting the performance of novel silica gel compound desiccant wheel. Sphaier and Nóbrega [11] presented a simple numerical procedure for designing desiccant cooling systems for analyzing the impact of component characteristics on the overall system performance. The inlet and room conditions, a regeneration temperature, and cycle components' effectiveness values were studied. The results show that a 20–30% decreased in dehumidifier performance can lead to 30–50% reduction in the overall ventilation cycle performance.

La et al. [12] studied an innovative thermally driven air conditioning system. Both dry air and chilled water can be produced

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Nomenclature

A	area, m^2
COP	cooling effectiveness
C_p	specific heat, J/kg K
D_h	hydraulic diameter of the desiccant wheel channels, mm
d_t	thickness of the desiccant, mm
F_R	collector heat-removal factor
G_t	solar radiation, W/m^2
H	Humidex, °C
h_i	enthalpy, J/kg
m	mass flow rate, kg/s
N	wheel speed, RPH
Q_U	useful heat collected, W
SHR	sensible heat ratio
T	temperature, °C
T_1	ambient temperature, °C
U	velocity of air, m/s
U_L	collector heat-loss coefficient, W/m^2 K

Greek Symbols

α	absorptance
η	efficiency
τ	transmittance
ω	humidity ratio

Subscripts

AH	auxiliary air heater
CCU	cooling coil unit
Cool	cooling
db	dry bulb
DW	desiccant wheel
EC	evaporative cooler
HE	heat exchanger
i	points 1, 2, 3, 4, 5, R, 6, 7, 8, 9
In	inlet
R	return air
Reg	regeneration air
Sol	solar air collector
Sup	supplied air
W	water
wb	wet bulb

by combining the technologies of desiccant dehumidification and regenerative evaporative cooling. It was found that the system can achieve a thermal COP higher than 1.0 and an electric COP about 8.0. The temperature of chilled water produced by the system was around 14–20 °C.

La et al. [13] studied the effect of the individual irreversible processes in each component of the thermodynamic performance of open-cycle desiccant cooling cycles. The results indicate that the exergy destruction coefficient of the cycle with moderate performance desiccant wheel is decreased greatly to 3.9%, which is more than 50% lower than that of the cycle with low performance desiccant wheel.

Hürdogana et al. [14] studied a novel desiccant based air-conditioning system. This system consisted of a desiccant wheel, heat exchangers, fans, evaporative cooler, electric heater unit to simulate solar energy, and refrigeration unit. It may be concluded that utilization of solar energy in the system increases the coefficient of performance (COP) between 50% and 120%.

Heidarinejad and Pasdarshahri [15] investigated the effect of some operating conditions such as regeneration temperature and rotational speed on the performance of the desiccant cooling cycle. They have found an optimum value for both regeneration temperature and rotational speed based on the design condition of the cooling cycle.

Panaras et al. [16] studied design parameters on the performance of solid desiccant air-conditioning systems. Specific guidelines for the dimensioning of the systems were proposed, on the basis of an easy to implement the steady state model.

A graphical methodology for the design of desiccant cooling cycles was proposed by Nóbrega and Brum [17]. The results show that the thermal load were not mutually independent on the efficiencies of the supply and exhaust air evaporative coolers.

Evaporative cooling system for a novel configuration of the desiccant air conditioning application was developed and tested Uckan et al. [18]. The energy consumption, coefficient of performance (COP) and cooling capacity of the system were evaluated. The results show that indoor air conditions were in the range of thermal comfort zone defined by ASHRAE and expanded comfort zone for evaporative air conditioning applications.

Ruivo et al. [19] investigated the feasibility of using different interpolation methods to predict the influence of the inlet states of the process and regeneration airflows on the global behavior of a desiccant wheel. The results show that the second approach required fewer reference cases and so was more suitable for the development of a generic, simplified tool that took into account the influence of variable airflow rates and rotation speed on the performance.

Wang et al. [20] studied the economic analysis based on the real-time cooling load profile of geothermal absorption air conditioning system. The study helped engineers appreciate the opportunities and barriers to geothermal applications. Also, Wrobel et al. [21] presented an energy and economic evaluation of solar thermal and geothermal assisted air conditioning system at different geographical locations. Hürdogan et al. [22] conducted a comprehensive exergoeconomic assessment of a desiccant cooling system. The results show that the heater unit was important as its exergy loss rate value was 29.36 times greater than that of the overall system.

Wrobel and Schmitz [23] showed that the decoupling of heat and moisture removal in combination with renewable heat sinks and heat sources can save up to 58% of non-renewable primary energy compared to conventional cooling systems because the over-cooling of the supply air to achieve condensation is omitted.

The feasibility of using a circulating groundwater system to cool down the air conditioners was evaluated by Kuo and Liao [24]. This study confirmed the feasibility of using the groundwater of the Chingmei gravel stratum as a steady and clean cool source for air-conditioners.

Woods and Kozubal [25] presented modeling and experimental results on the liquid desiccant dehumidifier and an indirect evaporative cooler. Several experiments were performed on the prototypes over a range of process and exhaust air flow rates, inlet temperatures and humidities, and desiccant concentrations and flow rates.

This paper presents the performance of the hybrid air conditioning system with three cycles at different climate zones to provide comfort conditions. Three cycles are investigated in this study, namely ventilation, makeup and mix cycles, while different climate