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A mathematical model for predicting the performance of the solar energy assisted hybrid air conditioning system, with one-rotor six-stage rotary desiccant cooling system

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ABSTRACT

A mathematical model for predicting the performance of solar energy assisted hybrid air conditioning system (SEAHACS) is presented. The honeycombed silica gel desiccant wheel is used in this study. One-rotor six-stage rotary desiccant cooling system, (two-stage dehumidification process, two-stage pre-cooling process and two-stage regeneration process) are realized by only one wheel. Three air streams are involved in the present system. The mathematical model has been validated with the experimental data. The range of regeneration air inlet temperature changed from 65 to 140 °C, area ratio of process air to regeneration air change from 1 to 3.57, regeneration air inlet velocity from 1.5 to 5.5 m/s have been examined for a range of rotation speed from 6 to 20 rev/h. The optimization of these parameters is conducted based on the moisture removal capacity *D*, relative moisture removal capacity, dehumidification coefficient of performance and thermal coefficient of performance. At last, the influences of these main parameters on optimal rotation speed are discussed.

1. Introduction

The traditional resource such as oil and gas cannot meet the rising energy demand. This has led to increasing interest in alternate-energy research such as solar energy, geothermal energy and world is facing a large-scale and potentially devastating global energy crisis. People have already realized wind energy. Besides, increasing occupant comfort demands are leading to growing requirement for air conditioning, whereas deteriorating global energy and environment crisis are starving for energy saving and environmental protection. Thus, how to provide thermal comfort for occupants with low grade thermal energy has attracted more and more attention and extensive types of technologies have been developed [1]. Among these technologies, rotary desiccant cooling, which is advantageous in controlling humidity independently, using low grade thermal energy and being free from CFCs, has been considered as a potential choice. Over a number of years, investigations on rotary desiccant cooling have been widely carried out on the basis of mathematical simulation, thermodynamic analysis, experimental investigation and practical application [2].

Due to the process air is usually heated by released adsorption of heat in dehumidification process and the standalone desiccant system could not handle the air to qualified conditions, auxiliary cooler must be adopted and it is right the main difference between systems.

Various aspects of the desiccant cooling systems have been intensively investigated by many researchers. The desiccant material studies [3–7], rotary desiccant dehumidification and air conditioning processes [8–15], performance modeling of desiccant wheels [16–20]. Ge et al. [12] investigated a one-rotor two-stage rotary desiccant cooling system (OTSDC), in which two-stage dehumidification process is realized by one desiccant wheel. An experimental setup was designed and built to evaluate the system performance under various operation conditions. The effects of different wheel thicknesses at various rotation speeds under Air-conditioning and Refrigeration Institute (ARI) summer and humid conditions were investigated. They are observed that there exits an optimal rotation speed where moisture removal of the system *D* and thermal coefficient of performance COP_{th} are both optimal. Moreover, the unit with wheel thickness of 100 mm performs better for its bigger moisture removal *D* and higher COP_{th}.

From the above literature, there is a lack in using six stage desiccant wheel cooling system. In this study, a solar energy assisted hybrid air conditioning system (SEAHACS) with a one-rotor six-stage rotary desiccant cooling system, in which two-stage dehumidification process, two-stage pre-cooling process and two-stage regeneration process are realized by only one wheel, is proposed and investigated. The need for using six stages may be explained as follows: as the moisture is absorbed from the process air, it is

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Nomenclature

A	channel height (m)
A	cross section area (m^2)
B	channel width (m)
C	layer thickness of desiccant material (m)
C_p	constant pressure specific heat (J/kg K)
COP_{th}	thermal coefficient of performance
D	moisture removal capacity
DCOP	dehumidification coefficient of performance
D_h	hydraulic diameter (m)
f_m	mass friction of desiccant in the wheel
H	convective heat transfer coefficient (W/m^2 K)
H_{sor}	heat of adsorption (J/kg)
K_m	mass transfer coefficient (kg/m^2 s)
L	wheel thickness (m)
N_{uH}	Nusselt number at constant heat flux
N_{uT}	Nusselt number at constant heat temperature
N_u	Nusselt number
$\dot{m}$	mass flow rate (kg/s)
P	perimeter of channel (m)
P_s	the pressure of saturated water vapor (pa)
Q	heat energy (J)
T	temperature (K)
Sh	Sherwood number
U	velocity (m/s)
W	water content of desiccant material (kg/kg)
Y	humidity ratio (kg/kg)
Φ	relative humidity ratio
ε	effectiveness
P	density (kg/m^3)
Z	axial direction
T	time (s)

Subscripts

A	air
In	inlet
L	liquid
out	outlet
P	process
R	regeneration
V	vapor
W	desiccant
c	cooling

heated due to the heat of adsorption released from dehumidification process. Also, due to the regeneration process, the desiccant wheel gets hotter, so the cooling stages in the present study helps to get rid of these bad sources of heat. A numerical model is used to study and discuss the moisture removal capacity and relative moisture removal capacity, dehumidification coefficient of performance, and thermal coefficient of performance considering the operating and design parameters such as area ratio of process air to regeneration air, regeneration air inlet temperature, and inlet velocity of regeneration air.

2. Problem formulation

Fig. 1 illustrates the schematic diagram of the proposed system. The system consists of a desiccant wheel, two cross-flow heat exchangers, two air heaters and three direct evaporative cooler.

2.1. System operation

There exists one process air path (1–2–3–4–5–6), two regeneration air paths (7–8–9–10–11 and 7–8–12–13–14), and two cooling paths (15–16).

The process air cycle is as follows: Process air at state point 1 passes through Section 1 of the desiccant wheel, where its moisture is removed and temperature is increased due to the adsorption heat. Then this hot dry air is sensibly cooled from state points 2–3 in a cross-flow heat exchanger. Afterwards, the process air passes through Section 2 of the desiccant wheel, where its moisture is further removed. And then in another cross-flow heat exchanger, the process air (state 4) is sensibly cooled with a dry air output at state point 5. At state point 5, the process air passes through a direct evaporative cooler; the air stream is humidified and cooled to state point 6.

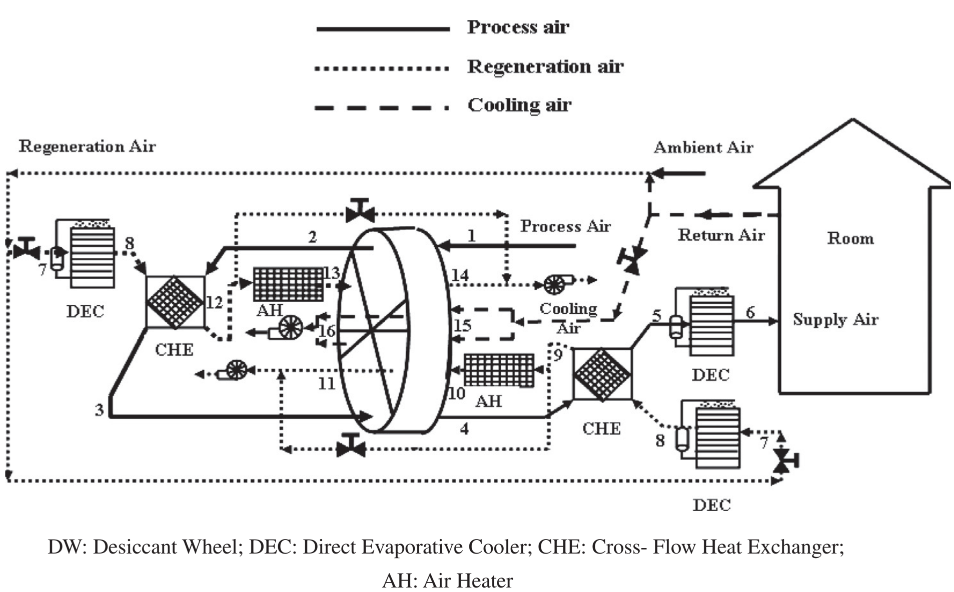

Fig. 1. Schematic diagram of solar energy assisted hybrid air conditioning system.