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Investigation of solar energy utilization in a novel desiccant based air conditioning system☆

Ertaç Hürdoğan[a,*], Orhan Büyükalaca[a], Tuncay Yılmaz[b], Arif Hepbasli[c,e], İrfan Uçkan[d]

[a] Department of Energy Systems Engineering, Faculty of Engineering, Osmaniye Korkut Ata University, 80000, Osmaniye, Turkey
[b] Department of Mechanical Engineering, Faculty of Engineering, Osmaniye Korkut Ata University, 80000, Osmaniye, Turkey
[c] Department of Mechanical Engineering, College of Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia
[d] Department of Mechanical Engineering, Faculty of Engineering and Architecture, Çukurova University, 01330 Balcalı, Adana, Turkey
[e] Department of Energy Systems Engineering, Faculty of Engineering, Yaşar University, 35100, Izmir, Turkey

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ABSTRACT

In this study, a novel desiccant based air-conditioning system was considered. This system consisted of a desiccant wheel, heat exchangers, fans, evaporative cooler, electric heater unit to simulate solar energy, and refrigeration unit. A model was developed to investigate the utilization of solar energy in the system. In the model, the temperatures obtained from the experiments over the cooling season of 2008 and solar radiation data measured by the State Meteorological Affairs (DMI) between 1986 and 2006 years for Adana were utilized. The increase in the regeneration air temperature due to solar energy assistance for the days, on which the experiments were carried out, was calculated using the model. The results obtained from the model and the experiments were also compared with each other. It may be concluded that utilization of solar energy in the system increases the coefficient of performance (COP) between 50% and 120%.

1. Introduction

Desiccant based air-conditioning systems are a suitable way to improve indoor air quality due to its superior humidity control. These systems are alternatives for air conditioning in health care facilities to reduce the airborne disease transmission [1,2]. In these systems, a desiccant removes moisture from the air, which releases heat and increases the air temperature. A combination of heat exchange with ambient air and evaporative or conventional cooling coils then cools the dry air. Temperature and humidity loads are very effectively and efficiently met by separating them in this way. The desiccant is then dried out (regenerated) to complete the cycle using thermal energy [3].

Desiccant cooling systems are cost effective systems when a cheap heat source, especially solar energy is used to regenerate the desiccant. For this purpose, various studies have been performed both analytically and experimentally. Dai et al. [4] investigated numerically a hybrid solar powered solid adsorption–desiccant cooling system with a 20 m^2 solar collection area for cooling grain. It was indicated that this kind of hybrid solar cooling system used for grain storage is acceptable from both technology and economic operation viewpoints. Kabeel [5] investigated the performance of a solar powered desiccant air conditioning system using a rotary honeycomb wheel, which is utilized for the regeneration and absorption processes, at different conditions of inlet air and radiation intensity. The researcher showed that the system was highly effective in the regeneration process for all flow rates compared with the absorption process. Bourdoukan et al. [6] carried out an experimental study on a desiccant air handling unit powered by vacuum-tube solar collectors. First, the components were studied under various operating conditions. Then overall performance of the installation was evaluated over a day for a moderately humid climate with regeneration solely by solar energy. In these conditions the overall efficiency of the solar installation was 0.55 while the thermodynamic coefficient of performance was 0.45 and the performance indicator based on the electrical consumption was 4.5.

Halliday et al. [7] investigated the potential in the UK for exploiting solar energy to drive desiccant cooling systems. The parametric energy studies were carried out using a solar desiccant computer model developed. They reported that it was feasible to use solar energy to power desiccant cooling systems within the UK. Khalid et al. [8] presented the results of an experimental and simulation study of a solar assisted pre-cooled hybrid desiccant cooling (PHDCS) system for air conditioning applications in Pakistan. They simulated this system using the TRNSYS simulation program. Simulation case studies showed that system could achieve a

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* Corresponding author. Tel.: +90 328 8271000x3552; fax: +90 328 8250097.
E-mail address: ehurdogan@oku.edu.tr (E. Hürdoğan).

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Nomenclature

c_p	specific heat (kJ/kg K)
$\dot{C}$	capacitance rate (kW/K)
COP	coefficient of performance
CR	compensation ratio (%)
$\dot{E}_{tot}$	total energy input rate (kW)
F	collector surface area (m^2)
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{q}$	total solar radiation (W/m^2)
$\dot{Q}$	actual heat transfer rate (kW)
$\dot{Q}_{col}$	the rate of heat transferred from the collectors (kW)
$\dot{Q}_{CC}$	cooling capacity rate (kW)
$\dot{Q}_{max}$	maximum possible heat transfer rate (kW)
$\dot{Q}_{reg}$	energy consumption rate of regeneration heat (kW)
T	temperature (°C)
$\dot{W}$	power consumption rate (kW)

Greek Letter

η_{HE}	heat exchanger effectiveness
η_C	collector efficiency
θ	title angle

Subscripts

1, 2,. . ., 18	states described in Fig. 1
a	ambient
c	cold air
com	compressor
fan	fans
f	fresh air
h	hot air
in	inlet
m	mean
min	minimum
out	outlet
oth	other electrical components
t	inclined surface
w	water

significant energy saving as compared to reheat vapor compression air condition systems. Ge et al. [9] evaluated the performance of a solar driven two-stage rotary desiccant cooling system and a conventional vapor compression system in two cities with different climates: Berlin and Shanghai. The objectives of their study were to compare the thermodynamic and economic performance of the two systems and to obtain useful data for practical applications. Their results showed that the desiccant cooling system was able to meet the cooling demand and provide comfortable supply air in both of cities considered. Li et al. [10] investigated experimentally a solar driven one-rotor two-stage desiccant cooling/heating system. This one-rotor two-stage desiccant cooling/heating system assisted by solar air collectors was installed to produce both cooling during summer and hot air for space heating during winter. Their experimental results indicated that the average thermal COP in cooling cycle was 0.95 in hot and humid climate conditions. The solar COP of system was about 0.45 when thermal efficiency of collector was 50%. This suggested that the system could convert more than 40% of the received solar radiant intensity to cooling power in sunny days.

The literature survey showed that desiccant cooling systems are cost effective systems when a cheap heat source, especially solar energy is used to regenerate the desiccant. In this study, a new desiccant based air-conditioning was considered. The system has a novel design in terms of both air channels and heat exchangers used [11–13]. Regeneration air is taken from outdoor and a rotary regenerative type heat exchanger, which is not common to this type of systems, is used for pre-heating the regeneration air with exhaust air. The main objectives of this contribution are twofold, namely (i) to develop a model for investigating the utilization of solar energy in a novel desiccant based air-conditioning system and (ii) to compare the results obtained from the model and the experiments over the cooling season of 2008 with each other.

2. System description

The system considered in this study was designed, constructed and tested in Cukurova University, Adana, Turkey and has been successfully operated since 2008. The schematic view of a desiccant cooling system studied [11–13] is shown in Fig. 1. The system consists of a desiccant wheel, heat exchangers, fans, evaporative cooler, electric heater unit and refrigeration unit. In the system, three separate air channels are used for fresh, waste and regeneration air streams. Fresh air channel is used to supply fresh air to the air-conditioned room. The waste air sucked from the air-conditioned room is sent to outside via waste air channel. Regeneration air channel is used to remove moisture of desiccant wheel.

Humidity of the fresh outside air (state 1) is absorbed by the desiccant material of the wheel. Sensible cooling of the fresh air is carried out (process 4–5) in a cooling coil, which is fed by chilled water from a refrigeration unit. However, the fresh air is passed through two recuperative type heat exchangers (heat exchanger 1 and 2) before coming to the cooling coil (heat exchanger 3) for cool recovery.

The air sucked from the indoor (state 7) into the waste air duct is evaporatively cooled in an evaporative cooler before entering into heat exchanger 2 in order to increase the cool recovery. In heat exchanger 2, due to the heat transfer from the fresh air to the waste air, temperature of the fresh air decreases and that of the waste air increases (process 9–10). The waste air leaving the heat exchanger is rejected to the outdoors.

The regeneration air first comes to heat exchanger 1 in which heat transfer from the fresh air to the regeneration air takes place. Temperature of the regeneration air at the exit of the desiccant wheel (state 16) is generally higher than that of the regeneration air leaving heat exchanger 1 (state 12). Therefore, a rotary regenerator (heat exchanger 4) is used for heat recovery. The regeneration air leaving the desiccant wheel passes through the heat exchanger 4 (process 16–17), in which heat is transferred from the regeneration air that left the desiccant wheel (state 16) to the regeneration air left heat exchanger 1 (state 12). Although the temperature of the regeneration air is increased in heat exchanger 1 and 4 (process 11–13), it is not high enough for dehumidification of the desiccant wheel. In the experimental set up, the final temperature of the regeneration air is achieved with the help of electric heaters to simulate the cheap heat source (process 14–15). In this study, a model was developed to investigate the utilization of solar energy in the system (process 13–14). The air removes the humidity of the desiccant wheel (process 15–16) and flows through heat exchanger 4 (process 16–17) before discharged to the outdoors. Fig. 2 shows all the processes for the experiment carried out on 02 July 2008, which are typical, on a psychrometric diagram.

Temperature, relative humidity, flow rate, electric current and electrical potential differences were measured with appropriate instruments during the experimental tests. More detailed information of these devices and description of Programmable Logic Controller (PLC) used for the control of the system can be found in the author's previous works [11–13].