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Performance study of solar driven solid desiccant cooling system under Algerian coastal climate

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ABSTRACT

Using solar energy for cooling purposes is an attractive idea with good prospects for conventional air conditioning systems. The replacement of compressor cooling systems by solar driven desiccant cooling systems could make an important contribution to environmental protection. The main argument for the applicability of solar energy is that cooling loads are approximately in phase with solar availability. The "desiccant cooling" technology is innovative in the field of refreshing atmosphere using state changes of water and operating with solar energy. The present work involves the study of an evaporative cooling system by desiccation coupled with a solar installation, reducing thereby energy consumption and using clean and free energy. The results show that the system can control moisture and therefore provide acceptable comfort conditions, confirming that it is suitable for wet areas such as coastal cities of our country.

Introduction

In order to limit the energy demand for air conditioning applications, it is necessary to develop alternative techniques to current refrigeration. The use of the heat generated by the solar collectors is an attractive option for the cooling process operating by heat [1,2]. Solar cooling technologies currently available for commercial applications (absorption, adsorption, and desiccant cooling) are characterized by a thermal coefficient of performance fairly low (between 0.5 and 0.7) compared to the compression process [3]. That is why it is necessary to optimize the system to improve its average intrinsic performance and to maximize the contribution of the solar heat supply. This optimization will achieve larger primary energy savings and thus make these solutions more competitive. Desiccant dehumidification cooling technology is a viable alternative which has a successful track record over more than 60 years for industrial applications such as product drying and corrosion prevention, clean rooms, hospitals, museums, and other special cases requiring highly controlled humidity levels. A desiccant cooling system is a technology that can help to avoid the previous shortcomings of conventional vapor compression technology. It is based on coupling active desiccant dehumidification with direct evaporative cooling. In this case, there is no need for a compressor; the

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Nomenclature

C_{pf}	Specific heat of thermal fluid, kJ/kg K
C_{pv}	Specific heat of water vapor, kJ/kg K
F_RU_g	Overall global heat loss, W/m^2 K
$F_R(\tau\alpha)$	Optical efficiency of the collector, /
G	Solar radiation, W/m^2
H	Enthalpy of desiccant, kJ/kg
M_d	Mass of adsorbent, kg
P_{vent}	Fan power, W
Q_u	Useful energy, W
S	Wheel surface, m^2
S_c	Solar collector surface, m^2
T_a	Air temperature, °C
T_{eq}	Desiccant equilibrium temperature, °C
Tf_e, Tf_s	Inlet, outlet fluid temperature of the solar collector, °C
T_{hi}	Temperature at the inlet of humidifier, °C
T_{ho}	Temperature at the outlet of humidifier, °C
T_{hum}	Humidifier temperature, °C
T_m	Desiccant temperature, °C
V	Wheel volume, m^3
W	Water vapor in the desiccant, kg/kg ad
h_a	Enthalpy of air, kJ/kg
h_c	Convective heat-transfer coefficient, W/K m^2
h_{fg}	Specific enthalpy, kJ/kg
h_m	Convective mass-transfer coefficient, kg/m^2 s
m_f	Mass of thermal fluid, kJ
q_v	Flow rate, m^3/s
t	Time, s
u	Air speed, m/s
v_a	Specific air volume, m^3
w_a	Specific air humidity, kg/kg as
w_{eq}	Specific air humidity at equilibrium, kg/kg as
ΔP	Pressure drop, Pa
ε	Vacuum fraction, /
ε_{hum}	Humidifier efficiency, /
ε_{tot}	Total fans efficiency, /
η	Efficiency of solar collector, /

energy used is for pumping water through the evaporative cooler, for pushing the air around the system, and to regenerate the desiccant wheel.

The origin of the desiccant dehumidification cooling technology is the open system for air conditioning first described by Carl Munters (1922) [4], using ambient air instead of the inert gas hydrogen in the previous Platen-Munters refrigerating unit. This open cycle has attracted considerable interest worldwide and many research projects have been devoted to the development of such so-called "desiccant cooling" systems.

The concept of desiccant cooling was first introduced by Hausen (1935) [6], which used solid desiccants that were regenerated periodically to dehumidify moist air for air conditioning. The rotary silica gel dehumidifier was invented in 1933 by Miller and Fonda [5]. Desiccant-based equipments have been then widely used for industrial applications since 1930s and commercially since 1980s.

Both the solid and liquid desiccant cooling systems, in their various aspects, have been intensively investigated by many researchers. Parameters that could affect the functioning of the system were studied by Henning et al. [7], who conducted a parametric study of a combined desiccant/chiller solar assisted cooling systems and showed their feasibility and also the primary energy savings of up to 50% with a low increased overall costs. Kadoma et al. [8], investigated the impact of the desiccant wheel speed, air velocity and regeneration temperature on the COP. The authors showed that the desiccant wheel has an optimal speed and established that the COP is inversely proportional to the airflow rate, and that the temperature of regeneration and the cooling capacity had the same evolution tendency. Zhao and al. [9], led an experimental investigation on a desiccant dehumidification unit using fin-tube heat exchanger with silica gel coating and found that the unit can be independently used as a dehumidifier with 100% fresh air under mild conditions.

Different desiccant materials have been used to study the performance of the desiccant cooling system. Shen et al. [10], used the molecular sieve desiccant wheel as adsorbent in a desiccant cooling system and simulated water vapor and carbon dioxide removal from the process air. The authors conducted an optimization study involving the adsorption temperature, the adsorption time, the coefficient of performance and the overall number of transfer units. Techajunta et al. [11], used silica gel as adsorbent and studied its regeneration using incandescent electric bulbs to simulate solar irradiation. The regeneration rate was found to be strongly dependent on the solar radiation intensity while its dependence on the air-flow rate was found to be weak. Mintova and al. [12], investigated on nano-porous materials with enhanced hydrophilicity and high water sorption capacity. They investigated parameters like mechanism of adsorption, ability of modification, enhancement of water adsorption capacity, regeneration ability and stability. Inorganic materials like zeolites, clay and silica were studied. Liang [13], researched on a refrigeration dehumidification system with membrane-based total heat recovery; he showed that the COP can be 2 to 3 times higher than conventional refrigeration dehumidification system.

A wide range of the system simulation studies exist in literature. In 2012, Goldsworthy and White [14], performed simulations using two dimensional numerical model to determine the performance mechanisms of the desiccant wheel dehumidification process. They studied the influence of desiccant equilibrium adsorption isotherm on the overall performance of wheel. Parameters like heat of adsorption, moisture diffusion rate, desiccant specific heat capacity and density were used to provide a further understanding of the restraining mechanisms for low regeneration performance. They concluded that exothermic adsorption process and heat carry-over from the regeneration stream limited the dehumidification process. Ankit [15], accentuated in a review study the principles of desiccant cooling systems through performance studies; its feasibility and advantages of energy and costs saving in different climatic conditions have been proven. Desiccant cooling system could replace other cooling systems such as traditional vapor compression air conditioning system and evaporative cooling system. Minaal et al.