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Experimental investigation of a solar adsorption refrigeration system working with silicagel/water pair: A case study for Bou-Ismail solar data

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Abstract

The objective of the present work is to build and test a solar adsorption refrigeration device with an adsorbent–adsorbate silicagel–water pair in the weather conditions of Bou-Ismail, Algeria. The refrigeration system proposed in this study consists of three major components: a solar collector (tubular adsorbent bed, reflecting surface, single glazed cover, and 4.5 kg of silicagel material), an air-cooled condenser, an evaporator and supplementary system components. The working operation parameters of the cooling adsorption system were tested successfully. Experimental results indicated that the maximum temperature generated varied from 95 °C to 117 °C, 33 °C of average ambient temperature, the condensing temperature varied from 45 °C to 53 °C, +5 °C of minimum evaporator temperature, and the pressure values recorded in the adsorbent bed during the heating desorption period varied from 80 to 100 mbar. With a total energy received of around 19 MJ/m^2, this solar adsorption refrigeration device can provide a solar COP ranging from 0.083 to 0.09. Such results show the practicability of our solar adsorption refrigeration module and that it has a favorable design for use in medical storage in areas without an electrical network (e.g. the Algeria Sahara region).

Keywords: Adsorption refrigerator; Solar energy; Silicagel–water; COP

1. Introduction

The adsorption cooling technology using solar energy is an attractive field of research and development because the supply of solar energy and the demand for cooling are greatest during the same season. Several adsorption refrigeration systems have been successfully designed, built and tested with different combinations of adsorbents–adsorbate (Boubakri et al., 2000; Buchter et al., 2003; Wang et al., 2005; Luo et al., 2007; Anyanwu and Ezekwe, 2003; Gonzalez and Rodriguez, 2007).

The solar adsorption refrigeration system is an environmentally-friendly technology with zero ozone depletion potential using a natural refrigerant and with zero CFC and HCFC within the system or produced. Moreover, it is an economical system which was developed

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Nomenclature

Cp	specific heat at constant pressure (kJ/kg K)
M_w	water amount (kg)
A	area (m^2)
L	latent heat of evaporation (kJ/kg)
T	temperature (K)
Q	energy (kJ)
P	pressure (mbar)
I	intensity of solar radiation (W/m^2)
Subscripts	
amb	ambient
a	adsorbed
d	desorbed
des	desorption
gc	glazed cover
tw	tubular wall
evap	evaporation
cond	condensing
sil	silica-gel
COP	coefficient of performance
max	maximum
min	minimum
A, B, C, D, E, F	points on Clapeyron diagram

to be used in different applications: food preservation, medical storage, ice production and air conditioning systems.

In the field of solar refrigeration by adsorption, various adsorption refrigeration modules have been developed. The following gives a brief review of recent important literature on this topic.

Lu and Wang designed, and estimated performance of a small solar cooling system. A silicagel–water adsorption chiller was experimentally tested at generation temperatures varying from 60 to 85 °C. The experimental results indicated the cooling capacity varied from 13 to 21 kW and gross COP cold reached 0.15 (Lu and Wang, 2014).

Berdja et al. built a small refrigerator prototype that uses an activated carbon and methanol working pair, in which solar energy can be directly used. The solar COP was found to be equal to 0.081 depending on the refrigerating effect and the solar radiation (Berdja et al., 2014).

Lemmini and Errougani built and tested a solar adsorption refrigeration system using activated carbon AC35 and methanol as the working pair. Tests results in the Rabat site in Morocco illustrated that the solar COP varied from 0.04 to 0.08 (Lemmini and Errougani, 2005).

Hildbrand et al. developed and tested a solar adsorption refrigerator system with 78.8 kg of silicagel–water (Hildbrand et al., 2004). The adsorption refrigerator system operated in the weather condition of Yverdon-les-Bains, Switzerland. The experimental results showed the minimum evaporator temperature reached 0 °C and the solar COP varied from 0.10 to 0.22.

Pan et al. developed and tested a new refrigerator prototype working with calcium chloride-activated carbon and ammonia refrigerant. Experimental results show that the minimum evaporator temperature reached −5 °C, 1.64 kW of cooling capacity, and the optimal coefficient of performance was 0.19 (Pan et al., 2014).

Lu et al. designed a new heat pipe solar adsorption chiller with 65 kg of silicagel. The adsorption refrigerator system operated in the weather conditions of Dezhou-China. Experimental results showed that the cooling capacity and the average solar COP were 17.6 KW and 0.16, respectively (Lu et al., 2013).

Leite et al. built a solar adsorption refrigeration system that used a tubular adsorbent with activated carbon methanol as the working pair, and tested it in the meteorological conditions of Brazil. Experimental results indicated that the maximum solar COP achieved 0.085 (Leite et al., 2007).

Moreover, there are also some studies based on field investigation of solar adsorption refrigeration systems to enhance this technology. This research has concentrated on different aspects: to develop and test a new composite sorbent bed cooling adsorption system (Solmus et al., 2011; Li et al., 2013; Yan et al., 2014; Wang et al., 2014), and to improve the performance of the cooling adsorption machine (Luo et al., 2010; Chang et al., 2009; Wang et al., 2015; Lu et al., 2013).

In addition, to improve the efficiency of solar cooling adsorption devices, some studies have focused on optimizing the solar collector design: Zhao et al. designed and studied of a freeze-proof solar powered adsorption cooling system using a tubular adsorbent bed with an activated carbon–methanol pair. Experimental results showed that for solar radiation values varying from 15.3 to 17.1 MJ, the solar collector design can provide a temperature of 110 °C in the adsorbent bed, and a maximum COP system was about 0.11 (Zhao et al., 2008).

Hamdeh and Al-Muhtaseb studied experimentally a new prototype of a solar cooling adsorption system using activated carbon and methanol as the working pair. Experimental results with a statistical technique demonstrated that increasing the adsorbent mass increased the coefficient of performance (Hamdeh and Al-Muhtaseb, 2010).

El Fadar investigated theoretically the influence of a finned adsorbent collector on the performance of a solar cooling adsorption system. The theoretical model was validated with experimental data. Analysis of the results indicated that the performance of the system depended on the number of fins; it increased when the number of fins increased (El Fadar, 2015).