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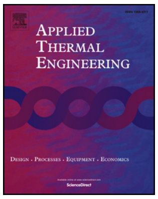

Experimental study of solar powered ice maker using adsorption pair of activated carbon and methanol

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HIGHLIGHTS

- Ice maker investigated experimentally by solar powered using adsorption pair.
- The Dubinin-Raduskevich (D-R) equation was used to compute pair characteristics.
- SAIMS is constructed and tested at real weather conditions of Qena city in Egypt.
- Acrylic sheets is used to enhance heat transfer and adsorbent temperature obtained.
- COP_G is improved in comparison with single, double and TIM.

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ABSTRACT

The present study introduces an experimental work for a solar adsorption ice maker system (SAIMS) using working pair of activated carbon (AquaSorb 2000) and methanol. The isotherm and isobar characteristics of the used pair are investigated by using Dubinin-Raduskevich (D-R) equation then, the SAIMS is constructed and tested at real weather conditions of Qena, Egypt. The findings of the pairs reveal that it suitable for the solar adsorption ice making applications with adsorption capacity found to be 0.6935 kg of methanol per kg of activated carbon (AquaSorb 2000). The constructed SAIMS can produce about 0.4 kg of ice per kg of AquaSorb 2000 by using the acrylic sheets in the adsorption bed instead of glass or other bed covers. Also, the experimental results proved that by using the acrylic sheets with a good design of the adsorption bed and due to the enhancement of heat transfer and high adsorbent temperature, the mass of desorbed methanol and produced ice is increased. Therefore, both gross and net COP are improved in comparison with other previous studies with single, double and Transparent Insulation Material (TIM) in the adsorber.

1. Introduction

Refrigeration and air conditioning systems depend nowadays mainly on vapor compression cycle which run with electricity. These traditional systems consume a very large amount of electricity production all over the world. On the other hand, one of the drawbacks of conventional vapor compression systems is the type of refrigerants used which have a detrimental impact on the environment, by its effect on the depletion of the ozone layer [1,2]. Many conventions such as Montreal (1988) and Kyoto (1998) are held to force the participant countries to replace the type of refrigerants that cause the depletion of ozone layer and to diminishing the greenhouse gas emissions

Nowadays, the adsorption cooling systems powered by solar energy have become one solution to the energy generated by oil and fossil. The intermittent solar adsorption ice making systems has been extensively studied both theoretically and experimentally, mainly due to its simplicity, low operation costs, and its several advantages over the traditional vapor compression refrigeration systems. There are many adsorption pairs but the most common pairs are activated carbon (AC)/methanol [3], silica gel/water [4], zeolite/water [5], activated carbon/R143a [6] and activated carbon/ammonia [7]. The most suitable pair for adsorption and ice making system is activated carbon and methanol

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Abbreviation: AC, activated carbon; CFC, chlorofluorocarbon; COP_G, gross coefficients of performance; COP_{net}, net coefficients of performance; HCFC, hydro-chlorofluorocarbon; HFC, hydro-Fluorocarbon; SAIMS, solar adsorption ice making system; SCP, specific cooling power; TIM, transparent insulation material

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Nomenclature

A_C	collector area [m^2]
$C_{p,r}$	refrigerant specific heat at constant pressure [J/kg K]
D	parameter in D-A equation [K^{-2}]
$h_{fg,i}$	ice latent heat of solidification [J/kg]
$h_{lh,r}$	refrigerant latent heat of vaporization [J/kg]
I	solar radiation or solar intensity [MJ/m^2]
m_i	ice mass [kg]
m_r	mass of condensed refrigerant [kg]
P	pressure [pa]
P_S	saturated pressure [pa]
Q_c	condenser heat amount [kJ]
Q_e	evaporator heat amount [kJ]
Q_{st}	isosteric heat amount [kJ/mol]
R	gas constant [J/mo K]
T_a	adsorbent temperature [°C]
T_{ad}	adsorption temperature [°C]
T_{amb}	ambient temperature [°C]
T_c	condenser temperature [°C]
T_e	evaporator temperature [°C]
T_{max}	maximum adsorbent temperature [°C]
T_w	water temperature [°C]
X	mass of the adsorbate adsorbed in a unit mass of adsorbent [kg/kg]
X_0	maximum mass of adsorbate in a unit mass of adsorbent [kg/kg]
ΔT	temperature change [°C]
ΔX	difference between max. and min. adsorption capacity [kg/kg]

due to its large cyclic adsorption capacity, low desorption temperature and high latent heat of methanol also, it can work as high as 150 °C without decomposition [8]. Also, there are many researches [9–11] studied and compared the different types of activated carbon with methanol to determined the best type for different solar adsorption refrigeration systems.

In the past two decades, a number of numerical and experimental studies have been reported. Most of these studies concerned on improving the performance of the solar adsorption refrigeration systems through modifying the bed design to enhance heat and mass transfer in the system. Pons et al. [12] experimentally investigated a solar adsorption ice maker with 6 m^2 collector areas equipped with dampers to increase the night cooling of the adsorbent bed, these system could produce 30–35 kg ice per day under solar radiation of about 22 MJ/m^2 day. Critoph [13] comprehensively studied the performance limitations of adsorption cycles for solar cooling. Medini et al. [14] studied a solar ice maker with 0.8 m^2 solar collector. The system used one movable heat exchanger that can place in an insulated ice bank to work as an evaporator or placed in a water tank at ambient temperature to work as a condenser, and collector has ventilation port to control the collector heating and cooling. The machine had a daily ice production of 4 kg with a solar COP of .074 when the insolation was 15 MJ/m^2. Headley et al. [15] presented an adsorption refrigerator powered by a compound parabolic concentrating solar collector with the net solar coefficient of performance (COP) being of the order of 0.02. Recently, Boubakri et al. [16] studied the limits of ice production by means of adsorptive collector– condenser technology. Anyanwu and Ezekwe [17] designed, constructed and tested a solar adsorption refrigerator in the tropical climate. In China, some experimental solar adsorption refrigeration devices have also been demonstrated [18]. To improve the performance and the ice productivity of a solar adsorptive system, Qasem and El-Shaarawi [19] design a simulation model with the MATLAB program under Dhahran climate. The results have showed that the daily ice production varied from 5 kg up to 13 kg per m^2 and the solar COP was changed from about 0.42 and 0.12 as the minimum in the hot days to about 0.59 and 0.24 as the maximum in the cold days, respectively. Hassan [20] developed a simulation model for an adsorption ice maker working under Egypt's weather conditions. The results have showed that the system could produce 27.82 kg of ice per day at a temperature of −5 °C with 0.618 COP when the solar insolation was 24.18 MJ/m^2. Also, the cooling capacity and the specific cooling power can be obtained from the system were about 255.6 W and 5.11 W/kg, respectively. Santori et al. [21] developed and tested a solar-powered ice maker for humanitarian aid actions for vaccines storage. The experimental results have been showed that the daily ice production could be up to 5 kg with solar COP was about 0.08 and solar radiation energy of about 28 MJ received by a solar collector of 1.2 m^2 exposed area. All these studies reveal that, in general, the solar adsorption refrigeration system is feasible for areas with abundant solar resources.

From the previous literature it is observed that the SAIMS still needs further improvements to be more competitive with traditional systems. The enhancement of heat and mass transfer in the adsorption bed is the most effective method to increase the system performance. Therefore, the present study focused on the design of the adsorption bed. A solar adsorption ice maker of 0.8 m^2 solar collecting area constructed by using acrylic sheets as a bed cover instead of glass and other traditional covers as it is stronger than glass and have a good thermal and optical properties. The acrylic sheets also, enclosed the adsorber tubes to trap the solar heat and make as greenhouse effect to enhance the heat transfer to the adsorbent. Subsequently, the liberated and condensed refrigerant in the well-designed condenser increased and finally, the system COP increased. After the construction process the system tested under the real weather conditions of Qena, Egypt.

It is essential to determine the needed adsorption characteristics for the used pair before incorporated it in the SAIMS. Thus, the adsorption isotherm and isobar characteristics of the used adsorption pair in the present study (activated carbon (AquaSorb 2000)/methanol) were investigated experimentally and the (D-R) equation were used to verify the numerical results with experimental one. After that, the SCP and COP is calculated numerically and compared with different previous studies to verify it with the practical results obtained from the SAIMS.

2. Experimental set-up

This section divided into two parts the first one discus the experimental set-up used for the adsorption pair investigation and the second part discuss the experimental set-up used for the constructed ice maker.

2.1. Adsorption pair set-up

In order to build a solar adsorption ice maker, the needed characteristics of the adsorption pair must be investigated firstly. Therefore, an experimental set-up is designed and constructed as shown in Fig. 1a, b, and c to evaluate the adsorption properties of the working pair activated carbon (AquaSorb 2000)/methanol. The physical properties of AquaSorb 2000 manufactured by Jacobi Company are listed in Table 1. The main components of the experimental set-up compose of an adsorber made of three parallel copper tube of diameter 15.8 mm and 150 mm long with internal concentric perforated tube to enhance the heat and mass transfer inside the adsorbent tube as shown in Fig. 1c. A glass tube with 12 mm inner diameter and 20 mm long used as evaporator containing methanol. The experimental set-up used some measurements to estimate the adsorption properties of the working pair such as temperature, pressure, and a digital micro balance to weight the mass of the refrigerant adsorbed on the activated carbon.

The GUNT WL110 heat exchanger service unit with PC-Based data