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Thermal behavior and performance assessment of a solar adsorption cooling system with finned adsorber

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ABSTRACT

This paper presents a modeling and optimization investigation of a solar driven adsorption cooling system working with activated carbon–methanol pair. It deals with the effect of internal fins on the thermal behavior of the adsorber and on the system performance. A two-dimensional model describing the coupled heat and mass transfer in the adsorbent bed and energy balance in the main components of the solar collector is presented. Furthermore, a simulation code based on alternating direction implicit method is developed. This model has been validated by experimentation data.

The analysis of the thermal behavior of adsorbent indicates that heat and mass transfer within the adsorbent is enhanced by increasing the number of fins. The simulation results show that, under the climatic, operating and design conditions of the system, the solar coefficient of performance is roughly invariant with changes in number of fins. The results indicate also that the thermal coefficient of performance is improved by increasing the number of fins. However, it is found that there is an optimal range of number of fins varying from 15 to 20 that allows obtaining an optimal performance; the corresponding range of fin spacing is found to be between 4 and 5.2 cm.

1. Introduction

The cooling processes cover a large variety of applications, such as preservation of foods and medical products, air conditioning, agriculture manufacturing, ice making, etc. However, they are frequently achieved by using the conventional vapor compression machines that use valuable electricity energy, which is in turn produced mainly from fossil energy sources that are regarded as depletable. Moreover, these conventional machines are energy-hungry, particularly in hot areas, like Morocco. Indeed, The IIR (International Institute of Refrigeration) has estimated that approximately 15% of all electricity produced worldwide is used for refrigeration and air-conditioning processes of various kinds [1,2]. Furthermore, these machines have a harmful impact on the environment, since they use polluting refrigerants, which are dangerous for both the ozone depletion and greenhouse effect [3].

Adsorption refrigeration is one kind of green technology that can supply refrigeration output for HVAC (heating, ventilation, and air conditioning) [4–6]. The adsorption refrigeration systems, which are commercially available, are more and more the focus of considerable attention over the world because they present several advantages, namely: they use environmentally friendly working fluids, such as water, methanol, ammonia, etc. (zero ozone depletion potential and zero global warming potential), have low maintenance and are not noisy [7] (due to the absence of rotating parts in the main unit), and they do not suffer from corrosion problems, as in absorption systems [8]. They also operate at lower costs in comparison with the absorption systems, as they do not need solution pump [9]. In addition, they can be driven by recovered low-grade heat (industrial waste heat) or renewable energy sources (solar and geothermal energies) for saving energy.

Adsorption cooling is achieved using some working pairs (adsorbent/refrigerant). The choice criteria of the adequate working pair depend on certain desirable characteristics, such as their chemical and physical properties, environment impact, costs and availability, kind of application (freezing, air conditioning …), compatibility and affinity for each other, etc. The common working pairs used in this field include silica gel/water, zeolite/water, activated carbon/methanol, activated carbon/ammonia, etc. The details about the selection criteria of working pairs and their performances are discussed in Ref. [10].

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Nomenclature

Symbols

A_C	surface area of collector (m^2)
C_p	specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
e	thickness (m)
G	global solar irradiance ($W\ m^{-2}$)
L_{ev}	evaporation latent heat of methanol ($J\ kg^{-1}$)
m	mass (kg)
m_a	adsorbed mass of methanol on activated carbon (kg)
N_f	number of fins (–)
P	pressure (Pa)
Q_C	cooling production (J)
T	temperature (K)
t	time (s)
t_{useful}	time at the end of desorption process (s)
U	heat loss coefficient ($W\ m^{-2}\ K^{-1}$)
V	volume (m^3)
W	spacing between fins (m)

Greek symbols

ΔH_{ads}	latent heat of adsorption ($J\ kg^{-1}$)
Δt	time step (s)
Δx	adsorption capacity difference between adsorption and desorption phases ($kg\ kg^{-1}$)
α	absorptivity (–)
ε	emissivity (–)
θ	volume fraction of the adsorbed phase (–)
τ	transmittance (–)
λ	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
μ	adsorbent porosity (–)
ρ	density ($kg\ m^{-3}$)

Subscripts

a	adsorbed, adsorbate
amb	ambient
c	collector
con	condensation
conv	convection
eq	equivalent
ev	evaporation
f	fin
g	gas
gl	glass
ini	initial
l	liquid (methanol)
max	maximum
min	minimum
p	plate (absorber)
rad	radiation
s	solid (adsorbent)
sat	saturation
sky	sky

Abbreviations

AC	activated carbon
COP	coefficient of performance
COP_S	solar coefficient of performance
COP_{th}	thermal coefficient of performance

In spite of their advantages, the adsorption cooling systems present, in comparison with the vapor compression and absorption systems, some drawbacks, such as low specific cooling power and low coefficient of performance, due to weak heat and mass transfer in adsorbent beds, which results in bulky sizes. These disadvantages constitute a hurdle to a widespread application of this green technology.

Solar adsorption cooling systems are particularly interesting and appear to be promising cooling devices, due mainly to the cleanness of the thermal energy that offers solar energy and because of the close coincidence between the abundance of solar radiations and the high peak cooling demands.

During the past few decades, several researches have been achieved on solar adsorption cooling systems to enhance this technology. They have been focused on some aspects among which are: improving the performance of the working pairs [11–13], optimizing the absorbent bed structures and developing composite adsorbents of high adsorption capacity [14–19], using heat pipes [20–23] and various solar collectors [24–26], and developing of advanced continuous cycles [27–30]. It is also verified that heat and mass recovery operation can improve the performance [31,32].

In this view, to improve the COP, some researches focused on optimizing the absorbent bed's structure. For example, in 2006, Al Mers et al. [33] built a model describing the heat and mass transfer in metal pipes with finned-tube. Afterward, in 2010, Louajari et al. [34] investigated the influence of finned cylindrical adsorber on the performance of a solar adsorption refrigeration system. A. Rezk et al. [35] studied theoretically some techniques (coating the first adsorbent layer to the metal surface and packing the rest of adsorbent granules, adding metal particles to the adsorbent) to enhance the heat transfer performance of the adsorbent.

Most recently, in 2014, Xu Ji et al. [36] designed and optimized a large-diameter aluminum-alloy finned-tube absorbent bed collector. The solar-powered solid adsorption refrigeration system with the finned-tube absorbent bed collector was built. The results showed that the large-diameter metal finned-tube absorbent bed structure could enhance the heat and mass transfer greatly, therefore improve the system performance.

The aim of the current paper is to present a modeling and optimizing investigation of a solar adsorption cooling system, using the climatic data of Rabat city–Morocco. The effect of internal fins on the thermal behavior of the adsorber and on the system performance will be discussed.

2. System description and working principle

The scheme of the intermittent solar adsorption refrigeration system is shown in Fig. 1, it is composed of a FPC (flat plate collector) containing the adsorber, which is filled with activated carbon (AC35) and methanol, a pressure transducer, an air condenser, an evaporator, which is placed inside a cold chamber, a liquid nitrogen trap, a vacuum pump and refrigerant valves. Lemmini et al. [37] have experimentally investigated this system.

The flat plate collector consists essentially of a collector box, an absorber plate, which is painted with a selective coating for increasing the absorption of solar radiation, heat insulation and a glass cover for reducing thermal losses from the collector to the surrounding. The collector/adsorber is a parallelepiped with sides of 85 cm and a width of 6 cm, in which 14.5 kg of activated carbon (AC35) are placed between fins. An empty space is left between the adsorbent bed and the bottom of the collector by using a grid for