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Performance improvement of adsorption solar cooling system

Wassila Chekirou*, Nahman Boukheit, Ahcene Karaali

Laboratoire de thermodynamique et traitement de surface de matériaux, Université des frères Mentouri Constantine, Route Ain El Bey, 25000, Constantine, Algeria

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ABSTRACT

This paper presents the study of a tubular adsorber of solar adsorption cooling machine, driven by flat-type solar collector with three different configurations of glazes: (i) single glazed cover, (ii) double glazed cover and (iii) transparent insulation material (TIM) cover. The modelling and the analysis of the adsorber are the key point of such studies, because of the complex coupled heat and mass transfer phenomena that occur during the working cycle. The adsorber is heated by solar energy and contains a porous medium constituted of activated carbon AC-35 reacting by adsorption with methanol.

The simulation technique takes into account the variation of ambient temperature and solar intensity along a simulated day, which corresponds to a total daily insolation of 26,12 MJ/m^2 and an average ambient temperature of 27.7 °C. The obtained solution allows to know the daily thermal behaviour of a tubular adsorber. The model is used to study the influence of the solar collector type and its surface on the system's performances COP_{th} and COP_s (thermal and solar performance coefficient, respectively). It is found that the type of collector configuration and its surface have a big difference on the system's performance.

Introduction

Ecological problems and energy crisis in a globalized world have motivated scientists to develop energy systems more sustainable, having as one of the possible alternative the use of solar energy as source for cooling systems. In the field of the sorption cooling, there are three kinds of system: liquid absorption, solid absorption (chemical reaction) and adsorption. The great advantage of adsorption systems over absorption ones is that they can operate without moving parts, having then lower costs of maintenance. Other advantages in comparison with the compression systems are: simple construction, environmentally benign and noiseless. A lot of applications for adsorption cooling systems have been viewed in both developed and developing countries such as: storage and conservation of vaccine, medical products, food conservation (vegetable, meat, fish, … etc), refrigeration, air conditioning, chillers and ice production.

The adsorber is the most important component in an adsorption cooling systems and the enhancement of heat and mass transfer inside it is the most important factor to improve the performance of such systems. Thus, great efforts have been made to investigate the transfer occurring in the

* *Corresponding author*. Tel./fax: +213 31 81 88 72.
E-mail address: chekirouw@yahoo.fr (W. Chekirou).
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adsorption and desorption process. The previous theoretical studies [1–8] were focused on the ideal cycles and did not take into account the heat and mass in the adsorbent bed, these models assumed uniform temperature and uniform pressure to optimize the performance of the system. Some problems were encountered when trying to adopt the models in situations with non uniform temperature and uniform pressure distribution in the adsorbent bed [9–17]; on the other hand some authors preferred and suggested an elaborate model to describe the inhomogeneity of both pressure and temperature [18–20]. To improve the cooling systems of adsorption, many solutions and different approaches have been suggested in the literature, for instance: Improve the thermal capacity of adsorption by using evacuated tubular collectors [21]; vacuum concentric tubes [22]; simple concentration non-tracking collectors as a compound parabolic concentrator (CPC) [23]; adopting double glass covers [24]; using TIM (Transparent Insulation Material) in order to diminish the heat losses of the adsorber [12,25,26]; cooling the adsorbent bed at night by using the ventilation dumpers [9,27]; develop new adsorbent materials like consolidated composite adsorbents [28], these adsorbents are obtained from the powders of the solid adsorbent mixed with other materials which have a large thermal conductivity [29,30]; compress the adsorbents into blocks or coated on metal tubes [31]; using the thermal wave process [32]; using the internal fins [11,15,33] to improve the contact surface between the external metallic wall of the adsorber and the solid adsorbent.

On the basis of our previous work done by Chekirou et al. [34], a mathematical model, which accounts for heat and mass transfer in a tubular adsorber as well as the effects of non-uniform temperature and uniform pressure distribution, another computer program has been developed in order to determine the influence of the type of the solar collector on the system's performance.

The COP_{th} and COP_s (thermal and solar performance coefficient, respectively) are used as an optimization criteria. The Activated carbon AC35/methanol is chosen as an adsorptive pair. It has proved to be the best pair among those studies so far, because it is reasonably stable chemically, has a high performance coefficient and it is less expensive than others [9]. All the basic parameters used in the model are also cited by Chekirou et al. [34].

The major heat losses from flat plate solar collectors of solar cooling machines are through the top cover, because the sides and the bottom of the collector can be well insulated. Consequently, the use of another type of collector configuration is recommended. One of the objectives of present study is to identify a suitable collector cover from the three available collector configurations: single glazed cover, double glazed cover and transparent insulation material (TIM) cover.

System description

The solar refrigeration system presented in this study consists of the following main elements (Fig. 1): A solar collector coupled to the multi-tubular adsorber filled with the porous medium; a condenser, an evaporator and a receiver which is used to store the fluid refrigerant coming from the condenser.

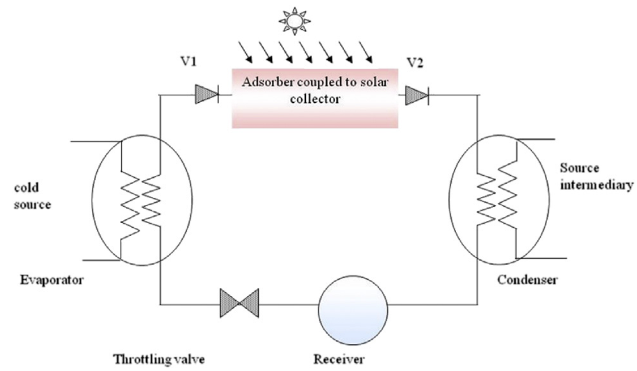

Fig. 1 – Schematic diagram of simple solar adsorption cooling machine.

The adsorptive reactor coupled to the solar collector which has $1 \times 1\,m^2$ surface area (Fig. 2), consists of transparent single glass cover, lateral and rear insulation in order to limit the thermal losses, and 9 connected parallel copper tubes, placed side by side, where the total sum of external diameters tubes is equal to 1 m. These tubes are coated with a selective paint in order to allow good absorption of solar radiation and low emission. Within each tube there is another concentric copper tube, perforated with small holes along its entire length in order to facilitate the flow of methanol into and out of the activated carbon granules and to avoid pressure drops and temperature differences along the tubes. The porous medium consists of a fixed cylindrical bed of activated carbon grains reacting by adsorption with methanol. It is packed in the annular space between two coaxial tubes. The mass of the activated carbon AC-35 is 3.894 kg in each tube and a total of 35.05 kg in all tubes.

Solar intensity and ambient temperature

In order to simulate the system in more realistic manner, the solar intensity and ambient temperature are modelled in this study as variant along the day (hypothetical clear day). These meteorological conditions are taken for Constantine region, which is situated at the north-east of Algeria, at 6°,37′ East (longitude) and 37°,17′ North (latitude), with an average altitude of about 625 m [34].

The solar intensity is assumed to vary sinusoidally from sunrise to sunset according to:

$$G(t) = G_{max} sin\left(\frac{\pi\,\theta}{D_j}\right) \tag{1}$$

Where, G_{max} is the maximum solar intensity occurring at solar noon; D_j is the length of the day and θ is the difference between the time of the day (at a given instant) and the sunrise time in hours.

The total solar intensity G_{tot} per 1 m^2 of collector area is obtained by:

$$G_{tot} = \int_{sunrise}^{sunset} G(t)\,dt \tag{2}$$