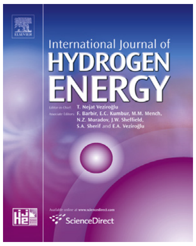
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 7146–7157

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he



Heat recovery process in an adsorption refrigeration machine

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

ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form
9 February 2016
Accepted 9 February 2016
Available online 20 March 2016

Keywords:
Adsorption system
Heat recovery
Thermal performance coefficient
Thermodynamic analysis
Simulation

ABSTRACT

In this paper, a detailed thermodynamic model based on Dubinin–Astakhov equation is given, which presents a complete and precise description of an adsorption cooling machine cycle.

Heat recovery process is one of a lot of useful ways to improve the cooling performance of this kind of machines. This process is also proposed in this paper. In the proposed model, several main factors affecting the performance of cycles are discussed according to the results of computer simulations, such as the working conditions, especially the regenerating temperature, the condensation temperature, evaporation temperature and the two-adsorber temperature difference at the end of heat recovery. The relationship between the performance of the cycle and heat recovery ratio and these factors is initially investigated. The performance of heat recovery cycle is also analyzed and compared with that of the basic adsorption cycle. The obtained results showed that heat recovery can play an important role to improve the performance of an adsorption refrigeration machine.

Introduction

As a consequence of the Kyoto protocol and its predecessor the Montreal Protocol, environmental considerations played an important role in the choice of a refrigeration system, and research efforts are focused on the development of refrigeration technologies which address the environmental concerns of ozone layer depletion and global warming. Adsorption cooling machines constitute very attractive solutions. They are of significance to meet the needs for cooling requirements such as air conditioning, ice-making, and medical or food preservation. Compared with electric driven vapor-compression refrigerator systems, these machines are advantageous because: They are noiseless; They usually employ environmentally friendly substances as refrigerants, which exert no harmful effects on the environment (such as water, methanol and ammonia) [1–3]. They are also advantageous when compared with the absorption systems, mainly because: Their cycle is intermittent, which is well adapted to the renewable energy like solar energy [4]; There is no need for a circulation pump or a rectifier; They can be driven by low temperature heat sources (<100 °C), which can be provided by solar energy with a single solar flat plate collector, which is simple in construction and low cost; No problems related to crystallization occur; The main component of the a machine is fixed, and the other parts are practically not moving almost not movable. Thus, they can be applied in

---

* *Corresponding author*. Tel./fax: +213 31 81 88 72.
E-mail address: chekirouw@yahoo.fr (W. Chekirou).

http://dx.doi.org/10.1016/j.ijhydene.2016.02.070

mobile applications including those where vibration occurs such as automobile applications.

While adsorption cooling systems have all the advantages discussed above, certain drawbacks have become obstacles to its real application and commercialization, such as: The discontinuous operation of the cycle; The large volume and weight relative to traditional refrigeration systems; The low specific cooling capacity; The low coefficient of performance [5]; The long adsorption/desorption time, and thus the long cycle time.

The modeling of the basic cycle of such systems was the subject of many studies so much theoretical that experimental, but the theoretical methods remain the best choice, because they can simulate the influence of different parameters on the system's thermal performance, in order to optimize their working before to carry out experiences. The difference among the main developed models in the literature generally lies in the simplifying assumptions, numerical resolution methods, design and use of modeled system.

Previous theoretical studies [6–13], were focused on the ideal cycle and did not take into account the heat and mass transfer in the adsorbent bed. These models assumed uniform temperature and pressure to optimize the performance of the system.

Some approaches are focused on the choice of an adsorbent/adsorbate pair that makes it possible to obtain a high efficiency coefficient [3,10], [13–16]. Generally, the choice of the adsorbent/adsorbate working pair depends on the application goal. Zeolite/water and silica gel/water pairs are usually used in the refrigeration, air conditioning and chiller fields, whereas activated carbon/methanol and activated carbon/ammonia pairs are used for ice production. Systems with ammonia operate at supra-atmospheric pressure, whereas systems with methanol or water work at under-atmospheric pressure. The activated carbon/methanol pair has proved to be the best pair among those studies so far, because it is reasonably stable chemically, has a high performance coefficient and is less expensive than other pairs [17].

In the basic cycle of adsorption refrigerating machines, the production of cold is intermittent. To attain higher efficiencies with a continuous production of cold, it is necessary to use advanced cycles. Several kinds of advanced cycles have been proposed and tested. Some studies proposed new cycles such as: heat recovery cycle [18–22], mass recovery cycle [23–25], both heat and mass recovery cycle [19,26,27] and thermal wave cycle [28,29].

Heat recovery cycle is one of the best proposed solutions for the purpose of making useful use of the internal thermal energy of the cycle itself, and improving the system's performance. In this point, researchers have put forward some effective methods that promote a useful use of the internal heat of the cycle. Most of results presented in literature are discussed in terms of performance efficiency of the machine.

The experimental results presented by Wang [19], show that the heat recovery operation between two adsorbers increase the COP (thermal performance) by 25% if compared with one adsorber basic cycle system. The COP for a single effect is still low, possibly in the range of 0.4–0.7.

Yong and Sumathy [30] used the two beds thermal system with activated carbon/ammonia. They found that the system achieved a cooling COP of 1.9.

Chua et al. [31] presented a transient model for a two-bed silica gel/water adsorption chiller. The obtained results were validated in terms of temperature. The predicted COP is 0.38 while the experimental one is 0.39.

Qu et al. [27] found that, heat recovery can recover about 30% or so of the total necessary heat input of the basic cycle, for an activated carbon/methanol adsorption airconditioner, using water as the heat transfer fluid. For two tests, in the case of water heat transfer fluid, the COP are (0.37 and 0.34), while in the case of oil is employed as heat transfer fluid, the COP are (0.44 and 0.39).

The results obtained by Waszkiewicz et al. [32] shows that 0.535 is the COP for single bed and 0.925 for a double bed, using the pair zeolite CBV 901/methanol. The advantage of using the new type of zeolite "CBV 901" is its requirement of lower regenerating temperature.

Alam et al. [33] investigated the influence of the operating conditions on the performance of a two-bed silica gel/water adsorption refrigeration system. They showed that the system performance could be improved by optimizing the operating parameters, where the COP did not exceed 0.48.

Maggio et al. [34] showed that the double –bed configuration allows to increase the cooling COP from 0.44 to 0.63. A two dimensional numerical model describing a double bed adsorption machine is proposed, with internal heat recovery, using two heat exchangers coated with a consolidated layer of zeolite 4A and water as adsorbate.

Miles and Shelton [35] report an experimental cooling COP as high as 1.19 with two-adsorber thermal wave cycle using an active carbon/ammonia pair.

The experimental study for silicagel–water adsorption chillers with and without a passive heat recovery scheme is presented by Wang et al. [36]. Results showed that the passive heat recovery scheme improves the COP of a two-bed chiller by 38% without any effect on their cooling capacities. The highest COP achieved with a two beds is about 0.46.

Pons [37] investigated the two adsorbers zeolite/water adsorption system. The best possible theoretical maximum COP obtain is 1.5. However, the experimental results of Douss et al. [1] proved that for the same pair zeolite/water, the COP of the cycle can achieve 0.67.

Meunier [38] found that the COP in the case of single adsorber is 0.425 and in the case of two adsorbers is 0.684, using the pair zeolite/water, and under the following working conditions (evaporation, condensation, adsorption and regenerating temperatures) are (0 °C, 40 °C, 50 °C, 350 °C), respectively.

Recently, a comparative study between three pairs (zeolite 13X/$CaCl_2$, silica gel/$CaCl_2$ and silica-activated carbon/$CaCl_2$) is presented by Alireza et al. [39]. They found that cooling capacity is increased by around 7.7% and 36% when zeilite13X/$CaCl_2$ is used instead of silica gel/$CaCl_2$ and silica-activated carbon/$CaCl_2$, respectively. COP = 0.5 is the cooling performance found using the pair zeolite13X/$CaCl_2$. The obtained results are compared to other studies done by Saha et al. [40] for the pair siicagel/$CaCl_2$ (COP = 0.46) and that done by Tso et al. [41] for the pair activated carbon/$CaCl_2$ (COP = 0.65).

In the case of adsorption cooling systems, the number of adsorbers is not limited to two. Improvements to the process by installing more than two adsorbers into the system can be done.