Energy Conversion and Management 94 (2015) 221–232

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Review

A review on development of adsorption cooling—Novel beds and advanced cycles

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ARTICLE INFO

Article history:
Received 1 December 2014
Accepted 24 January 2015

Keywords:
Adsorption bed
Transfer enhancement
Advanced cycle
System optimization

ABSTRACT

The performance of adsorption cooling cycle is highly affected by the heat and mass transfer in the bed, as well as by the cycling mode. Increasing the heat transfer area can effectively reduce the general transfer resistance of the bed. Popular methods to enlarge the transfer area include the plate-finned bed, the spiral plate bed, and the pin-fin bed. Incorporating the heat pipe into the adsorption bed causes the cycling time to decline and the COP to improve. To reduce the contact resistance between the adsorbent particulate and the bed wall, the coating method has been developed in which the slurry adsorption material is daubed onto the solid wall of the tube. Measurements of physical–chemical treatment can be used to improve the thermal conductivity of the adsorption material, but the over-compacted structure of the adsorbent will increase the mass transfer resistance. A few advanced cycling modes have been proposed to improve the performance of the adsorption cooling system. The heat recovery cycle has been studied in depth till today and put into practical application. Analysis of the mass recovery cycle showed that the COP can be increased as much as 100% in comparison to the simple cycle. As a novel cycling mode, the thermal wave cycle has presented the attractive result in the numerical study, while in the experiment it has not yet been verified practically. The surface cascade cycle consists of two stages of basic cycle. As the second cycle is operated at a lower driving temperature, the heat required is supplied by the desorbed vapor from the first stage and then the heat necessary from the outside heat source is decreased. The other advanced adsorption cycles include the multi-bed cycle, the multistage cycle, and the dual mode cycle etc.

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http://dx.doi.org/10.1016/j.enconman.2015.01.076
0196-8904/

1. Introduction

With the rapid development of the global economy and the improvement of peoples' living standard, the consumption of the fossil energy has resulted in more and more serious problem of environmental pollution. Measurements to save the energy and to protect the environment have attracted the international attention in recent years. For the purpose of refrigeration, the system driven by solar energy or industrial waste heat is one of those attracted developments [1,2]. Such kind of system is benign to the environment, and it caters to the demand of sustainable society. In the past decades, the world has witnessed many advances in the field of adsorption cooling, which includes the selection of the working pair [3,4], and the optimization of adsorption bed etc. Choudhury et al. pointed out that the right way to promote the performance of the adsorption cooling cycle should be focused on technologies of the heat recovery, the enhancement of heat and mass transfer, and the efficient cycles [5].

In an adsorption cooling system, the adsorbent bed is the key component, for its work will directly affect the performance of the whole system. The structure of the bed determines if it is able to transfer the heat and the mass efficiently. A high transfer rate of heat and mass is always essential either in the process of the desorption or of the adsorption. The COP of the system is closely connected with the heat and mass transfer rate. Sometimes a special form of adsorption bed is needed as mentioned by Suzuki in the study of the adsorption cycle used in the automobile air-conditioning [6], or a facility of heat storage is needed to promote the work of the bed [7].

The process of the heat and mass transfer in an adsorption bed is controlled mainly by the conduction and the convection insides. For the package kind of adsorption bed, the thermal resistance in the bed refers to [8].

(a) The convective heat transfer between the heating/cooling fluid and the tube wall of the bed. The proportion of this resistance is not big and can be reduced by increasing the velocity of the fluid.
(b) The thermal conduction through the metallic wall of the bed. This resistance is also small, and can be controlled by minimizing the wall thickness under the condition of allowable pressure.
(c) The contact thermal resistance between the metallic wall and the adsorbent particulate.
(d) The thermal conduction inside the adsorbent bed.

The terms of (c) and (d) above are the main form of the thermal resistance that hinders the heat transfer of the bed. Guilleminot et al. pointed out that the thermal contact resistance can result in great temperature gradient near the metallic sealing wall [9,10]. The total heat transfer of the bed can be enhanced either by reducing the thermal contact resistance or by increasing the heat transfer area. On the other hand, the mass transfer refers to the process of the refrigerant transferring in the bed, which is related to the desorption/adsorption speed of the material and the gap size between the adsorbent particulate. To enhance the mass transfer in the bed, it should be considered to reduce the friction between the refrigerant and the absorbent, and need to provide good flow channel for the refrigerant to get through. Nevertheless, the transfer resistance inside and outside the particulate is of different significance. As Solmus et al. pointed out [11], to improve the performance of the adsorption bed the effort should be focused on reducing the inter-particle thermal resistances as well as the interior mass transfer resistances of the particle. Comparatively, the inter-particle mass transfer resistance is less important.

2. Enhancement of heat/mass transfer in adsorption bed

As afore mentioned the poor heat and mass transfer in the adsorption bed has been one of those main factors that hinder the large-scale application of adsorption refrigeration system. In order to improve the heat and mass transfer performance of the bed, scholars around the world have put forth many measures to optimize the bed structure. In this part we will summarize the important advancement with respect to the improvement of the bed performance.

2.1. Increasing the heat transfer area

A large transfer area, together with the transfer coefficient, will reduce the total thermal resistance remarkably. For such consideration scholars put forth some new types of adsorption bed.

2.1.1. Plate-finned bed

The plate-finned bed can take different forms of the structure, such as the finned tube type [12–14], the fin plate type [15], and the flat-pipe type [16], see Fig. 1. These structures improve the heat transfer of the bed due to the fin enlarges the specific transfer area per unit volume and shorten the heat transfer path. In addition to the good heat transfer effect, the plate-finned bed also has the advantage of compact structure and less heat loss. However, the large heat capacity ratio of the metal fin and the tube over the adsorption material will impose a non-ignorable negative effect to the COP and the specific cooling power of the system. Also, the bed body is usually space-consuming. Louajari et al. [17]studied the effect of the finned tube on the adsorber performance that was driven by the solar energy. The results showed that the performance of the machine with fins was higher than the one without fins. The maximal temperature in the adsorber with fins attained 97 °C, while for the one without fins it reached 77 °C only. The COP was increased from 0.075 to 0.111 correspondingly.

2.1.2. Spiral plate bed

As a type of compact adsorption bed, the spiral plate bed is of efficient heat transfer rate and relatively small volume [18]. Its structure is as shown in Fig. 2. The sandwich structure results in the uniform temperature difference between the thermal fluid and the adsorbent material, and then generates high heat flux. With the high efficiency of performance, the bed will not demand very high temperature to drive as the ordinary bed does. This is highly consistent with the tendency of full use of the low level energy such as the industrial waste heat. Meanwhile, the spiral plate bed also has the advantage of simple structure, low manufacture cost, and easy to machine. However, for such bed the working temperature and the pressure cannot be too high. Sealing and repairing the bed body is relatively difficult. More efforts are also needed to fill the adsorbent into the bed.