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Experimental study of the performance of a continues solar adsorption chiller using Nano-activated carbon/methanol as working pair

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ABSTRACT

In this paper, a continuous adsorption chiller is designed and constructed with micro and Nano-activated carbon/methanol as working pair that works with solar energy. The chiller used in this study includes evaporator, condenser, adsorbent bed and compound parabolic collector. The collectors used in this chiller is a compound parabolic type. Unlike traditional systems that perform refrigeration only during the night, in this paper the continuous refrigeration system with two adsorbent beds can produce cold during the day. The main objective of this study is to investigate the effect of Nano-activated carbon on the refrigerator's performance for the first time. For this purpose, at first experiments are performed with only 200 g micro-activated carbon in each bed. In the next steps, Nano-activated carbon is added to the bed in mass fractions of 4.7%, 11.1% and 18.3%, and the experiments are carried out at the two temperatures (30 and 34 °C). The results showed that the addition of Nano-activated carbon with various mass fractions increases the adsorption level. As a result, the adsorption capacity increased and the COP improved. Thus, the addition of Nano-activated carbon with mass fractions of 4.7%, 11.1% and 18.3% to the adsorbent bed at 30 and 34 °C caused 11%, 21%, 33% and 17%, 23%, 25% increase in COP respectively.

1. Introduction

Fossil fuels have problems such as environmental pollution, lack of renewability, etc. therefore, we need new sources of energy. One of these sources is solar energy which can be used as a new alternative energy source. Solar energy has different uses, one of which is to use in adsorption refrigeration systems and adsorption chiller. The most important process of such systems is the adsorption of liquid or gas on the solid surface. In this process, usually the adsorbed particles enter the adsorbed porous and sit on their surface. Thus, when they are adsorbed against the surface of the solids, their atoms, ions, or molecules will adsorb the solid surface. In fact, the adsorption of the adhesion of the atom, ion, or molecules of gas or liquid to the adsorbent surface (Wang et al., 2014). Advantages of solar adsorption refrigeration systems are easy installation and maintenance, without pollution, using a clean and non-polluting energy sources, long life and lack of moving parts. Despite the advantages mentioned, the major disadvantage of these systems is low performance compared to other refrigeration systems.

To improve the performance of the solar adsorption refrigeration system, few studies have been done. The following gives a brief review of important literature on this studies. Islam and Tetsuo (2016) studied thermodynamic performance of a solar adsorption system. They concluded that the adsorption bed, which contained an activated carbon granule and solar collector, could produce 3 kg of ice per day. Bouzeffour et al. (2016) constructed a solar adsorption cooling system that uses silica gel and water as working pair. They concluded that the COP of their cooling system varies from 0.083 to 0.09. Song et al. (2015) designed and constructed an adsorption ice maker system. They used an activated carbon and methanol as working pair. Their results showed that if the desorption temperature is 94 °C, the ice production capacity is 5.1 kg per kg daily and the COP of the system is 0.0322. Hongyu et al. (2014) investigated the effect of adsorbent diameter on the cooling rate of adsorption systems. They concluded that by increasing the pressure drop of the adsorption bed, the efficiency of the mass transfer in the adsorbent bed would be improved. Santori et al. (2014) constructed a solar adsorption refrigerator with working pair of activated carbon and methanol. Their experimental results indicated that the mean efficiency is about 0.08 during one day. Hbib et al. (2013) designed and studied a solar adsorption refrigeration system for different mass of adsorbent (activated carbon/methanol) contains 0.25 to 2.5. The highest COP and cooling power was recorded at 0.27 and 25 kJ/kg respectively. Omisanya et al. (2012) investigated a solar

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Nomenclature

Symbols

COP	coefficient of performance
c_p	specific heat at constant pressure ($J\,kg^{-1}\,K^{-1}$)
I	solar radiation ($W\,m^{-2}$)
m	mass (kg)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
Q	heat transfer (kJ)
SCP	specific cooling power ($W\,kg^{-1}$)
T	temperature (°C)
t	time (s)

Subscripts

ads	adsorbent
chill	chilled
cool	coolector
evap	evaporator
hot	hot
sun	sun
cyc	cycle
w	water

adsorption refrigeration system with silica gel/water as working pair. Their results showed that COP varied from 0.2 to 0.25 in the radiant range of 34 W/m^2 to 345 W/m^2. The evaporating temperature was 11 °C and the highest adsorbent temperature was 110 °C. Hassan et al. (2012) proposed a solar adsorption refrigeration system with activated carbon/methanol that can produce cold overnight. A complete thermodynamic analysis of all components of the system, such as the theoretical cycle, was carried out. They evaluated the effect of many parameters on the COP of the system. Fadar et al. (2009) studied a continuous solar-refrigeration system with parabolic collectors. Their results indicated that under the given working conditions, the specific power and COP were obtained 114 W/kg and 0.42 respectively. Fan et al. (2016) present an extensive study to measure CO2 uptakes on various AC (activated carbons). They found that the COP is influenced mainly by the pore sizes of solid adsorbents, and the adsorptive sites between the adsorbent-adsorbate systems. Demir et al. (2009) studied the mechanism of heat and mass transfer in a ring bed. They showed that the permeability on the mass transfer function and the pressure drop during the flow of the refrigerant from the adsorbent layers was significant. Li et al. (2004) used an activated carbon/methanol and activated carbon/ethanol in a solar ice maker as a working pair. Their results showed that under the same conditions of ambient and radiation, the activated carbon/methanol pair has able to produce ice while the activated carbon/ethanol pair cannot produce ice. Anyanwu and Ezekwe (2003) built and tested a solar adsorption refrigerator with working pair of carbon and methanol. Their experimental results showed that useful COP varied from 0.056 to 0.093 and a total COP varied from 0.056 to 0.07. Hildbrand et al. (2004) investigated an adsorption with working pair of silica gel/water. They designed a condenser that cooled by the natural convection and the evaporator with capacity of 40 litters. The COP was found to be equal to 0.19. Tamainot-Telto and Critoph (2001) studied the thermo physical properties of two samples of monolithic activated carbon in order to design a high-performance adsorption refrigeration system. They obtained that the ammonia concentration with monolithic carbon is up to 30% better than with ordinary granular carbon from the same precursors.

One of the advantages of working pair activated carbon and methanol is that adsorption process required at a low temperature and also desorption process does not require high temperature. As described above, few studies have been carried out on solar adsorption systems. An important and common result of most past studies is that the COP of these systems is low. Therefore, studying on ways to improve the efficiency of adsorption refrigeration systems is still necessary. In this paper, in order to increase the COP a simple method is used compared to the past methods. By adding a few nanoparticles to micro-activated carbon, a new absorbent has been prepared and used. In order to compare the thermal performance of the absorption chiller, experiments with micro-activated carbon are first performed, then the Nano-activated carbon are added to the micro-activated carbon substrate in different mass fractions for enhancement of COP.

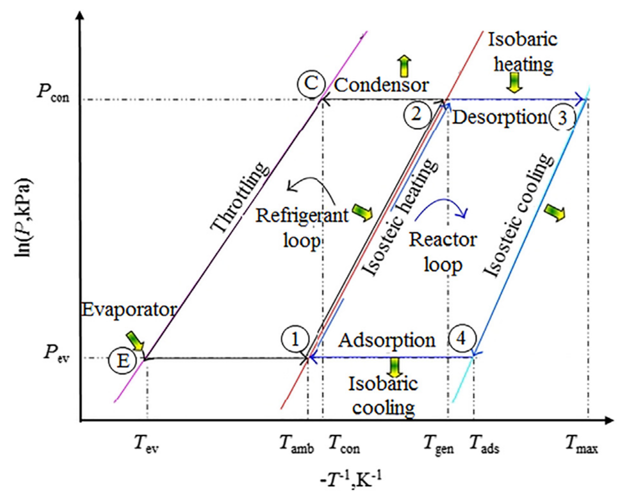

Fig. 1. Clapeyron diagram of adsorption refrigeration cycle (Tamainot-Telto and Critoph, 2001).

2. Description of adsorption cycle and experimental setup

The adsorption thermodynamic cycles include the following four processes, as shown in Fig. 1.

1. The process of increasing pressure and heating at a constant concentration (constant concentration heating process) (1 to 2)
2. Desorption and condensation process at constant condensing pressure (constant pressure heating process 2–3) (2 to 3)
3. Reducing pressure and heat dissipation process at constant concentration (constant concentration cooling process) (3 to 4)
4. Adsorption and evaporation process at constant vapor pressure (constant pressure cooling process) (4 to 1)

In the first step, the initial pressure in the adsorbent is equal to the pressure of the evaporator. Adsorbent heated by the solar energy, which increases the pressure and temperature of the adsorption bed. The process of heating continues as long as the adsorbent pressure reaches a level that repels the adsorbent. In this case, the adsorbent pressure will be equal to the condensing pressure (point 2). In steps 2 and 3, the heat generated by the sun's energy causes the adsorbent to be discharged (steam) from the adsorber. The adsorbing vapor flows to the condenser and condensates. In the disposal process, the adsorbent continues to release the refrigerant from its surface, and the pressure inside the bed will reach the condensing pressure. Processes 1, 2 and 3 are the same process of compression process in compression refrigeration systems. Desorption process will continue continuously until the temperature of the bed increases to keep the condensed pressure constant. In this case one of the following two conditions including (The temperature of the adsorption bed reaches its maximum. In this case it is chemically