ScienceDirect

Applied Thermal Engineering
Volume 112, 5 February 2017, Pages 1289-1296

Research Paper

# Thermodynamic analysis and performance of an adsorption refrigeration system driven by solar collector

M.A. Hadj Ammar [a b], B. Benhaoua [b], F. Bouras [c]

Show more

Share Cite

https://doi.org/10.1016/j.applthermaleng.2016.09.119
Get rights and content

## Abstract

This paper presents the operating and performance of an adsorption refrigeration system driven by a solar collector. The thermodynamic cycle and the working principle of the system are based on the adsorption phenomena at a steady temperature. The system operates with activated carbon (AC)-methanol as a working pair, and Dubinin-Astakhov (D-A) equation was used to describe this phenomena. Comparative study between different types of AC reveals that the one based on stone coal had an optimal performance coefficient (COP) equal to 0.73 whereas a total energy input to the system is 18740.05 kJ and a total daily ice production of 13.65 kg at −3 °C. The studied case indicates that the optimal performance of the system can be obtained for low ambient and condensation temperature with high evaporation temperature. Ice produced can also be improved when the initial water temperature is low.

## Introduction

In the recent years, the use of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) in refrigeration systems have become air pollution. The solar adsorption refrigeration (SAR) system using refrigerants with zero ozone depletion potential (ODP) and zero global warming potential (GWP) is considered as a promising way for the environmental protection and energy conservation [1]. The SAR system have several advantages of being (i) the good alternative to contribute mainly in a considerable number of fields of human life such as in remote areas, where absent electricity network [2], (ii) also to provide needs of people living in such areas by food preservation, vaccine storage, ice making and air conditioning [3], (iii) do not require any synthetic lubricants such as polyolesters [4]. Furthermore, this system compared with traditional vapor-compression systems, is simple, cheap and can be operated without moving parts [5].

The SAR system uses a pair of adsorbent-refrigerant, which is integrated in the solar collector/bed. The regeneration of the refrigerant during day time in the solar collector/bed and the ice production during the

night in the evaporator were ensured [6]. The most widely used working pairs in the SAR system include activated carbon (AC)/methanol [7], [8], [9], activated carbon/ammonia [10], [11], zeolite/water [12] and silica gel/water [13]. The AC-methanol is a suitable working pair to be used in SAR system [14] based on of their large cyclic adsorption capacity, low adsorption heat, high vaporization latent heat of methanol and low desorption temperature [15]. Many experimental studies as well as theoretical and simulation works have been done, as can be described below:

Hassan et al. [16], [17] via a study of a simple solar-driven adsorption cooling system were able to produce cooling power during the whole 24h of the day. Furthermore, a parametric study of the influence on the system performance was discussed. Based on use of MD6070 carbon type compared to 207E4 type, it is found that the system attains a refrigeration *COP* equal to 0.6 and a total daily ice production of 20.16kg at −3 °C. This provides a continuous ice production during the whole day at a rate of 0.84kg per hour. Qasem et al. [18] focused on the study of the thermodynamic processes in the intermittent adsorption cooling system through investigation of the main parameters such as temperature and pressure which affects its performance. On the other hand, they performed a simulation to improve the performance of an ice-maker [19]. The results showed that the optimum performance during whole the year using the type of AC (NORIT RX3-Extra) rather than eight others types of AC, and reaches thermal *COP* of 0.29 and 0.41 in the hot and cold days respectively. In addition, Allouhi et al. [20] investigated the optimal performance for seven pairs of adsorbent-refrigerant such as (AC fiber-methanol, AC-methanol, AC-ethanol, silica gel-water, zeolite-ethanol and zeolite-water) according to the Moroccan country. In this comparative study, a maximum uptake was obtained by AC fiber/methanol; whereas the maximum solar *COP* was about 0.32 for AC fiber/methanol. Theoretical study of a solar adsorption refrigerator was taken by Chekirou et al. [21] in which it showed that the system performance depends strongly on the operating temperatures. Performance and enhancement are still until now the goals of humanity in many life fields [22]. Recently, numerous new technologies were applied for the performance enhancement of the adsorption refrigeration cycle [4], [23], [24], [25], [26], [27].

Worth mentioning from the results given in literature above that lower thermal *COP* of the SAR system are obtained. Such weakness may be caused by: Firstly, the working pairs for operating of the system, and secondly the cycle mode. In fact, the first cause leads to a poor transfer in solar collector/bed, and itself is still needs more investigations.

The aim of this paper is firstly to find, according to operating conditions, the suitable working pair for SAR system from an efficiency point of view. For this a comparative study, concerning four AC as adsorbent and methanol as refrigerant, will be carried out using the cooling production, total energy input, total daily ice production and cycle *COP* as indicators. Secondly this study aims to investigate the operative temperature influence on the system performance.

## Section snippets

### System description and working principle

The suggested SAR system for the cooling power production is schematically shown in Fig. 1. The system consists, beside a storage tank, of three main elements:

- The solar collector/bed containing the AC/methanol as a working pair. It is fixed with an optimum tilt angle to receive the maximum solar energy.…
- The condenser is a unit used to condense, by cooling, a refrigerant from its vapors to its liquid state.…

- The evaporator in which the refrigerant liquid is converted to gas, absorbing heat from the …

…

## Adsorption equilibrium and kinetics

The activated carbon, as a solid surface is subjected to the vapor methanol, this gas molecules strike its surface inside the SAR system. Some of the striking molecules stick to the surface and become adsorbed, while others rebound.

The adsorption rate is large at the beginning of this process due to the important uncovered surface. If the activated carbon surface is being more covered, by the methanol molecules, the adsorption rate decrease. Desorption rate increases due to escaping of the…

## The performance indices

The performance indices which are defined and used in the current study to evaluate the SAR system include the coefficient of performance (*COP*) and the daily total amount of the ice produced ($m_{ice}$). These indices are defined by the following formulas:

- The performance coefficient (*COP*) is defined by the ratio of cooling production ($Q_{ev}$) to the input heat ($Q_{in}$), necessary for heating the solar collector/bed to the regeneration temperature $T_g$, which is calculated from:…

$$COP_{cycle} = \frac{Q_{eV}}{Q_{in}}$$

- The total…

…

## Performance of the system

Based on the previously thermodynamic analysis in Section 3 and the baseline parameters of the simulated cycle which are given in Table 1; the performance of the current system, taking into account a surface area of the solar collector/bed containing the AC35/methanol as a working pair, has been investigated. The values of the constants $w_o$, $D$ and $n$ in the Dubinin-Astakhov (D-A) equation, for the AC35/methanol are given in Table 2, where the properties of methanol have been taken from its state…

## Energy saving and emissions reduction

One of the essential purposes of the SAR system is to reduce the non-solar energy sources, such as electricity or fossil fuels burning resulting also in a reduction of $CO_2$ emissions [3]. According to a study done by Hamouda and Malek in Algeria, there are 650g of $CO_2$ emitted into the atmosphere for each kWh of electricity produced [35]. For this work, the preserved amount of fossil fuel energy and $CO_2$ emissions when we use a SAR system instead of an equivalent conventional vapor-compression…

## Conclusion

In this paper, the operating and performance parameters of an adsorption refrigeration system driven by a solar collector has been studied. The theoretical thermodynamic operating cycle of the system is based on

adsorption at steady temperature which operates with AC as adsorbent and methanol as refrigerant. The operating mode of the system and the ideal thermodynamic cycle were presented and explained in details.

The obtained results showed two sections of system performance. The first section…

## Acknowledgements

This work was supported by VTRS laboratory of El Oued University. We thank Prof. M. Balghouthi from the Center of Energy (CRTEn), Hammam Lif, Tunisia and K. Salhi from CDER, Algeria, for their helpful discussions….

## References (36)

C. Li *et al.*
Experimental study on an adsorption icemaker driven by parabolic trough solar collector
Renewable Energy (2013)

A. El Fadar *et al.*
Study of a new solar adsorption refrigerator powered by a parabolic trough collector
Appl. Therm. Eng. (2009)

M.A. Hadj Ammar *et al.*
Simulation of tubular adsorber for adsorption refrigeration system powered by solar energy in sub-Sahara region of Algeria
Energy Convers. Manage. (2015)

K. Habib *et al.*
Performance evaluation of combined adsorption refrigeration cycles
Int. J. Refrig. (2011)

H.Z. Hassan *et al.*
Dynamic analysis of the CTAR (constant temperature adsorption refrigeration) cycle
Energy (2014)

S. Vasta *et al.*
An adsorptive solar ice-maker dynamic simulation for north Mediterranean climate
Energy Convers. Manage. (2008)

E.E. Anyanwu *et al.*
Transient analysis and performance prediction of a solid adsorption solar refrigerator
Appl. Therm. Eng. (2007)

X. Ji *et al.*
Structure optimization and performance experiments of a solar-powered finned-tube adsorption refrigeration system
Appl. Energy (2014)

A. El Fadar *et al.*
Study of an adsorption refrigeration system powered by parabolic trough collector and coupled with a heat pipe

Renewable Energy (2009)

Wei-Dong Wu *et al.*

Mathematical simulation and experimental study of a modified zeolite 13×-water adsorption refrigeration module

Appl. Therm. Eng. (2009)

View more references

Cited by (31)

Simulation of an improved solar absorption refrigeration system with phase change materials

2022, Energy Reports

Show abstract

Performance of solar adsorption cooling system with internal finned vacuum tube bed

2022, Case Studies in Thermal Engineering

*Citation Excerpt :*

…Wang et al. [4] performed an experimental study on the solar adsorption refrigeration system using activated charcoal-methanol as the working pair, in which the enhancement of mass transfer was considered to increase the COP of the system by 35.9%. with activated charcoal-methanol as the working pair, Hadj et al. [5] explored the adsorption relationship based on the Dubinin-Astakhov equation and conducted a numerical simulation study. They found that the system could perform better at lower condensing temperatures and higher evaporating temperatures.…

Show abstract

Numerical and experimental investigation of multi-halide chemisorption system for exhaust gas heat recycling

2021, Applied Thermal Engineering

Show abstract

A novel cryogenic condensation system based on heat-driven refrigerator without power input for volatile organic compounds recovery

2021, Energy Conversion and Management

Show abstract

Evaluation on performance of solar adsorption cooling of silica gel and SAPO-34 zeolite

2021, Applied Thermal Engineering

*Citation Excerpt :*

…Its strong adsorption ability causes the methanol to vaporize below 0 °C. Hadj Ammar et al. [8] presented the experimental results of the adsorption cooling system that used the activated carbon-methanol. The daily ice production of the system was up to 13.65 kg.…

Show abstract

Toward sustainable refrigeration systems: Life cycle assessment of a bench-scale solar-thermal adsorption refrigerator

2021, International Journal of Refrigeration

Show abstract

View all citing articles on Scopus

## Recommended articles (6)

Research article

Performance evaluation of a zeolite–water adsorption chiller with entropy analysis of thermodynamic insight

Applied Energy, Volume 130, 2014, pp. 702-711

Show abstract

Research article

Experimental investigations on the thermal performance of an ice storage system using twin concentric helical coil

Applied Thermal Engineering, Volume 179, 2020, Article 115737

Show abstract

Research article

Experimental investigation of a solar adsorption refrigeration system working with silicagel/water pair: A case study for Bou-Ismail solar data

Solar Energy, Volume 131, 2016, pp. 165-175

Show abstract

Research article

Performance analysis of static ice refrigeration air conditioning system driven by household distributed photovoltaic energy system

Solar Energy, Volume 158, 2017, pp. 147-160

Show abstract

Research article

Optimal working pairs for solar adsorption cooling applications

Energy, Volume 79, 2015, pp. 235-247

Show abstract

Research article

Thermal analysis and modeling study of an activated carbon solar adsorption icemaker: Dhahran case study

Energy Conversion and Management, Volume 100, 2015, pp. 310-323

Show abstract

View full text